



UNIVERSITY
OF TRENTO

DIPARTIMENTO DI INGEGNERIA E SCIENZA DELL'INFORMAZIONE

38123 Povo – Trento (Italy), Via Sommarive 14
<http://www.disi.unitn.it>

MONOPULSE COMPROMISE ARRAYS - A REVIEW

L. Manica, P. Rocca, and A. Massa

January 2011

Technical Report # DISI-11-157

Monopulse Compromise Arrays – A Review

Luca Manica, Paolo Rocca, and Andrea Massa
ELEDIA Research Group @ DISI - University of Trento
E-mail: andrea.massa@ing.unitn.it

A monopulse RADAR is a device aimed to detect the position of a target by using the information collected from an antenna that generates two different kinds of beams on the same aperture, namely sum and difference pattern [1]. These beams can be obtained by means of reflector antenna with two or three feeds, or by using linear (2D tracking) or planar (3D tracking) arrays. The latter solution is usually preferred since antenna arrays are easier to build and the beam patterns can be steered electronically. Moreover, such a structure can be installed on mobile vehicles.

In order to provide an accurate detection of the target the generated patterns have to satisfy some constraints as narrow beamwidth, low sidelobe level (SLL), high directivity. More in details, the sum pattern requires a high gain, whereas the difference pattern should have maximum slope on boresight direction since it is related to the sensitivity of the RADAR. For such reasons, analytical techniques have been developed in order to compute the excitations of the radiating elements. In the synthesis of sum patterns using linear arrays, the techniques reported in [2][3] provide the optimal (i.e., narrowest first null beamwidth for a specified SLL) excitations, whereas a method to obtain the optimal excitations for difference patterns (i.e., narrowest first null beamwidth and largest normalized difference slope on the boresight for a specified SLL) has been described in [4]. In the synthesis of planar arrays, sum and difference patterns are synthesized computing the excitations as in [5] and in [6], respectively.

However, using the analytically computed excitations to synthesize the sum and the difference pattern of a monopulse antenna leads to two independent feed networks. Such a solution is usually unacceptable because the costs, the non-negligible complexity and the arising electromagnetic interferences. In order to reduce the feed network complexity the sub-arraying strategy has been proposed in [7]. Accordingly, the sum pattern is generated by a set of independent excitations whereas the difference excitations are obtained from the sum coefficients by properly grouping the array elements and by weighting each sub-array in order to satisfy the user-defined constraints. In such a framework, several approaches for defining how the elements could be grouped and the subarrays weights computed have been proposed: analytically technique as in [7], optimization approaches as [8-11] or hybrid approaches [12]. Even if the aforementioned approaches allow significant advancements in the sum-difference compromise synthesis, they cannot easily manage large arrays because the exponential growing of the solution space. In order to overcome such a drawback, an innovative strategy allowing the proper choice of the grouping of the elements and the computation of the sub-array weights has been proposed in [13]. More in detail, such an approach obtains the compromise difference pattern properly matching the optimal difference excitations. As a matter of fact, the clustering procedure can be guided considering similarity properties among the array elements, significantly reducing the number of trial solutions. Consequently, the space of the solution has been modeled as a non-complete binary tree in which every complete path represents a “contiguous partition” assuring the presence [14] of the optimal solution (i.e., the grouping for which the distance between optimal and compromise excitations is minimal) in the tree. The problem is then recast as the searching of the minimal-cost path from the root to the leafs of the solution tree. Once the best path has been found the sub-array weight are automatically computed guarantying the minimal distance between the target and compromise excitations. Moreover, in order to explore efficiently such a structure, an innovative local-search algorithm has been developed exploiting the closeness (to a sub-array) property of some elements, namely *border elements*, of the array. As a result, such an algorithm has the capability to match properly the optimal target pattern with excellent computational performances in terms of both occupied memory and computational time. The resulting compromise pattern shows better features (narrower beam-width of the main lobes and lower maximal side lobe level - SLL) in comparison with other state-of-art techniques.

A hybrid real/integer differential evolution method (hybrid-DE) has been used in [15] to maximize the directivity of the sub-arrayed beam. In such a framework, choosing as target a set of excitations providing a difference pattern with maximal directivity [16] or with maximal slope in the null of the boresight direction [17] the proposed excitation-matching strategy has shown its versatility to optimize different compromise pattern features.

Furthermore, from a careful analysis of the solution tree has been shown that some parts of the tree are repeated and then there is not need to store them in memory. As a consequence, the whole solution space has been modeled by means of a Direct Acyclic Graph, (DAG) allowing the representation of all the contiguous partitions in a non-redundant and compact way in comparison with the binary tree. Moreover, the DAG allows the implementation and

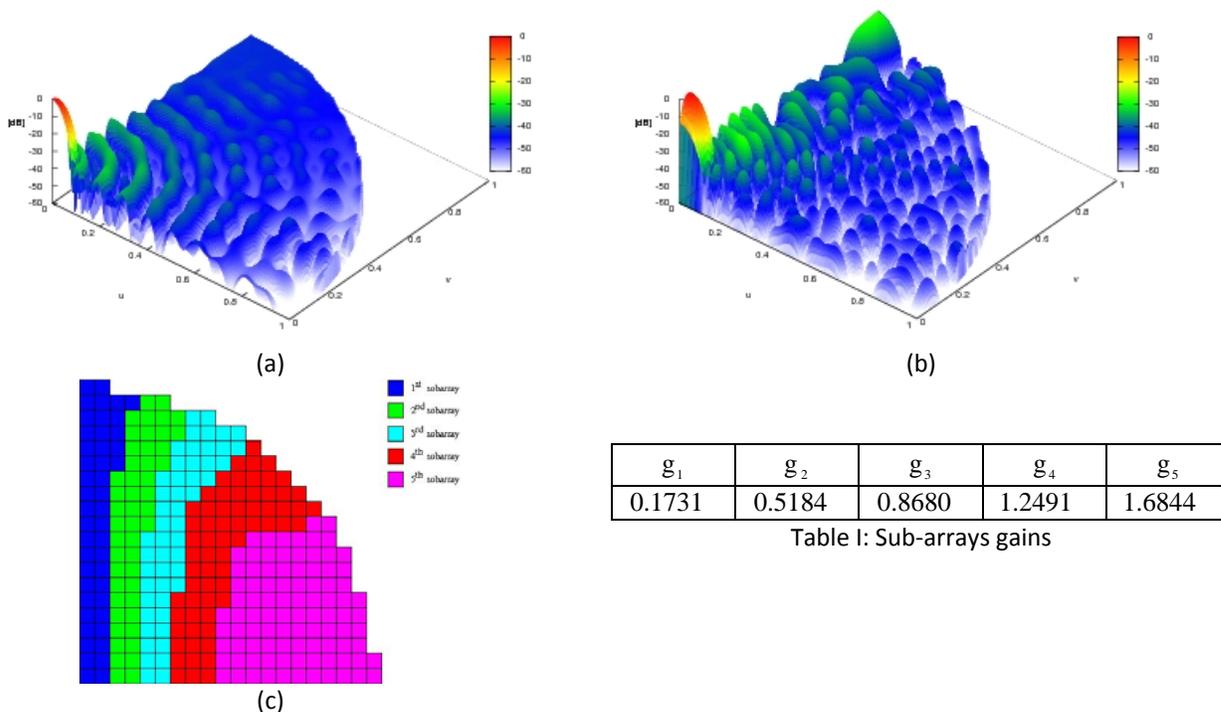


Figure 1: Taylor sum pattern 35 [dB] $\bar{n} = 6$ (a), optimized compromise difference pattern (b), and corresponding sub-arrays configuration obtained by means of ACO (c) (Reference Bayliss [6] pattern with 30 [dB] $\bar{n} = 7$, $Q = 5$)

the effective use of a fast graph-searching algorithm to look for the optimal compromise pattern. Then, the effectiveness of the proposed excitation matching technique in sampling the solution space has been assessed through experiments concerned with high-dimension synthesis problems showing appreciable results both in the pattern matching and in the reduction of the computational burdens.

Moreover, additionally improvements of the features of the compromise difference pattern have been obtained properly modifying the procedure described in [12]. By considering the problem in hand, such a strategy is aimed at finding the subarray configuration and the coefficients of the subarray 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. It is based on the exploitation of the convexity of the functional with respect to a sub-array gains and it is carried out by means of a *convex programming* (CP) method. Accordingly, in the approach described in [19] once the clustering has been determined as in [13], the sub-array gains are computed as in [12]. As a result, the proposed hybrid approach outperforms state-of-art global optimization strategies, and it shows also the feasibility to synthesize compromise pattern with arbitrary shapes or sidelobe masks.

However, using a local-search strategy could be trapped into local minima since the function to be optimized is not convex with respect to the sub-array membership. To avoid such a drawback, a suitable state-of-art evolutionary strategy, namely Ant Colony Optimizer (ACO), has been used to properly explore the space of the solutions because its intrinsic structure is very appropriate to fully exploit the graph-model of the space of the contiguous partitions [20]. Thanks to the effectiveness of the ACO in sampling the space of the solutions it outperforms the previously developed strategy by achieving a better compromise solution.

In order to show the effectiveness of the proposed approach to deal with the compromise synthesis of difference pattern in monopulse arrays the following assessment is presented. As far as the optimal setup is concerned, the sum and difference optimal excitations has been chosen to generate a Taylor pattern $35[dB]$ $\bar{n} = 6$ [5] [Figure 1(a)] and a Bayliss pattern characterized by $30[dB]$ and $\bar{n} = 7$ [6], respectively. The radiating elements are placed on a 40×40 regular rectangular grid with inter-element spacing $d_x = d_y = 0.5 \lambda$ lying on the xy -plane. The radius of the circular aperture of the antenna is $R = 20 \lambda$. Consequently, the total number of radiating elements is equal to 1208. Concerning the compromise solution, $Q = 5$ sub-arrays have been considered. The resulting compromise pattern obtained by means of ACO is shown in Figure 1(b) whereas in Figure 1(c) is reported the final subarrays configuration. Finally, in Table I reports the optimized sub-array weights. Although the sub-arrayed feed network is very simple in comparison with the one able to generate the reference pattern (5 sub-arrays gains against 302 element excitations), the features of the compromise pattern are very close to the target features. More in detail, the compromise pattern has the same beam-width of the target pattern and the maximal value of the SLL is $-27.91[dB]$ close to target value of $-30[dB]$.

References

- [1] M. I. Skolnik, *RADAR Handbook, Third Edition*. Mc-Graw Hill, New York. 2008.
- [2] C. L. Dolph, "A current distribution optimizes for broadside arrays which optimizes the relationship between beam width and sidelobe level," *Proc. IRE*, vol. 34, pp. 335-348, 1946.
- [3] A. T. Villeneuve, "Taylor patterns for discrete arrays," *IEEE Trans. Antennas Propag.*, vol. 32, no. 10, pp. 1089-1093, Oct. 1984.
- [4] D. A. McNamara, "Direct synthesis of optimum difference patterns for discrete arrays using Zolotarev distribution," *IEE Proc. H Microwaves Antenna Propag.*, vol. 140, no. 6, pp. 445-450, 1993.
- [5] T. T. Taylor, "Design of a circular apertures for narrow beamwidth and low sidelobe," *Trans. IRE Antennas Propag.*, vol. 8, pp. 17-22, 1960.
- [6] E. T. Bayliss, "Design of monopulse antenna difference patterns with low sidelobe," *Bell System Tech. Journal*, vol. 47, pp. 623-640, 1968.
- [7] D. A. McNamara, "Synthesis of sub-arrayed monopulse linear arrays through matching of independently optimum sum and difference excitations," *IEE Proc. H Microwave Antennas Propag.*, vol. 135, no.5, pp. 293-296. 1988.
- [8] F. Ares *et al.*, "Optimal compromise among sum and difference patterns," *J. Electromag. Waves Appl.*, vol. 10, pp. 1543-1555, 1996.
- [9] P. Lopez *et al.*, "Subarray weighting for difference patterns of monopulse antennas: joint optimization of subarray configurations and weights," *IEEE Trans. Antennas Propag.*, vol. 49, no. 11, pp. 1606-1608, Nov. 2001.
- [10] S. Caorsi, A. Massa, M. Pastorino, and A. Randazzo, "Optimization of the difference patterns for monopulse antennas by a hybrid real/integer-coded differential evolution method," *IEEE Trans. Antennas Propag.*, vol. 53, no. 1, pp. 372-376, Jan. 2005.
- [11] Y. Chen, S. Yang, and Z. Nie, "The application of a modified differential evolution strategy to some array pattern synthesis problems," *IEEE Trans. Antennas Propag.*, vol. 56, no. 7, pp. 1919-1927, Jul. 2008.
- [12] M. D'Urso, T. Isernia and E. F. Meliaddò, "An effective hybrid approach for the optimal synthesis of monopulse antennas," *IEEE Trans. Antennas Propag.*, vol. 55, no. 4, pp. 750-759, Apr. 2007.
- [13] L. Manica, P. Rocca, A. Martini, and A. Massa, "An innovative approach based on Tree-Searching Algorithm for the Optimal Matching of Independently Optimum Sum and Difference Excitations," *IEEE Trans. Antennas Propag.*, vol. 56, no. 1, pp. 58-66, Jan. 2008.
- [14] W. D. Fisher, "On grouping with maximal homogeneity," *Amer. Statistical J.I.*, pp. 789-798, 1958.
- [15] A. Massa, M. Pastorino, and A. Randazzo, "Optimization of the directivity of a monopulse antenna with subarray weighting by a hybrid differential evolution method," *IEEE Antennas Wireless Propag. Lett.*, vol. 5, no. 1, pp. 155-158, Dec. 2006.
- [16] L. Manica, P. Rocca, and A. Massa, "An excitation matching procedure for sub-arrayed monopulse arrays with maximum directivity," *IET Radar, Sonar & Navigation*, vol. 3, no. 1, pp. 42-48, Feb. 2009.
- [17] L. Manica, P. Rocca, M. Pastorino, and A. Massa, "Boresight slope optimization of sub-arrayed linear arrays through the contiguous partition method," *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 253-257, 2008.
- [18] P. Rocca, L. Manica, R. Azaro, and A. Massa, "Hybrid approach to the synthesis of subarrayed monopulse linear arrays," *IEEE Trans. Antennas Propag.*, vol. 57, no. 1, pp. 280-283, Jan. 2009.

- [19] L. Manica, P. Rocca, M. Benedetti, and A. Massa, "A fast graph-searching algorithm enabling the efficient synthesis of sub-arrayed planar monopulse antennas," *IEEE Trans. Antennas Propag.*, vol. 57, no. 3, pp. 652-663, Mar. 2009.
- [20] P. Rocca, L. Manica, and A. Massa, "An improved excitation matching method based on an ant colony optimization for suboptimal-free clustering in sum-difference compromise synthesis," *IEEE Trans. Antennas Propag.*, vol. 57, no. 8, pp. 2297-2306, Aug. 2009.