SNO and mBBO Optimization Methods for beam-scanning Reflectarray Antennas

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***Abstract*—In these years high gain antennas have become very interesting from an application point of view, in particular the possibility to use a Reflectarray Antenna as a new technology of reflector has been studied by researchers. One of the most alluring features of RA is that modifying the phase of its re-radiating element is possible to obtain the desired pattern in the desired direction. In this work the possibility to obtain a scanning beam RA has been studied applying two evolutionary algorithms: the SNO and the mBBO.**

I. Introduction

Important tools for engineering problems are the Evolutionary algorithms, especially for what concerns the electromagnetics, where the complexity to reach the goals is hard and the strong non-linearity of the equations: their optimization are computationally expensive and, therefore, it is necessary to use an efficient (in terms of convergence and reliability) optimization approach to not increase the cost.

In view of this, in this work two promising evolutionary algorithms are compared: the SNO [1] and the mBBO [2]. These algorithms have been exploited to solve many electromagnetics problems i.e. to design a shaped beam Transmitarray Antenna [3].

During the last years a strong research has been devoted to study high gain antennas, in particular to Reflectarray Antennas for all the good features that they present: in particular one of the most interesting is the possibility to obtain a beam scanning antenna just to "play" with the phase of the reflection coefficient of each re-radiating element. There are different possibilities to design a scanning RA, one of the common solution is to design a RA with active elements, but in this work an alternative solution has been studied: the optimization algorithms try to find the required phase distribution in order to obtain a scanning RA with passive and simple elements.
In this paper the SNO and the mBBO have been applied to the optimization of a 24×24 Reflectarray Antenna, in the Section II the antenna requirements are reported, in the Section III the optimization methods are described and in the Section IV the conclusions are given.

II. Scanning reflectarray

The Reflectarray considered in this work has a squared aperture $D = 12\lambda$, discretized with 24×24 unit cells spaced of 0.5λ at the design frequency of $30GHz$. The feed has a focal distance from the aperture of $0.9D$ in order to mantain a -10 dB of taper at the edges. The re-radiating elements are simple square patches printed on a Diclad 527 substrate with $\epsilon_r = 2.55$ with negligible losses and a thickness of 0.8 mm.

The goal of the optimization problem is to have a scanning RA with direction of maximum radiation of the main beam equal to $\theta = 10^\circ, 20^\circ, 30^\circ$ in the vertical plane. In order to obtain these radiation patterns the feed is moved along a circumference arc for each desired direction. Another specitication are the SLL that are imposed to be equal to -20 dB.

III. Optimization process and results

The antenna optimization has been performed with two different optimization algorithms: the first one is the modified-Biogeography Based Optimization (mBBO) [2] and the second one is the Social Network Optimization [1]. Both these algorithms have demonstrated their capability in solving complex, non linear electromagnetic problems [4], [5].

In order to fairly compare these algorithms, a common stopping criterion has been implemented, *i.e.* the total number of cost function calls, set to 50'000. In fact, this parameter is strictly related with the computational time requested by the optimization process. The populations of the algorithms have been set by means of a parametric analysis conduced on standard benchmarks [6]. The results are that the optimal population for the mBBO is 50 individuals, while for SNO is 25 individuals.

The radiation pattern is evaluated in a numerical way by means of the aperture field method using a discrete grid with 91 samples in θ and 35 in ϕ [7].

In order to meet properly the requirements, a mask is implemented [8]. Having defined the mask $M(\theta, \phi)$, it is possible to define the pattern exceeding the mask as:

$$S(\theta,\phi) = [E(\theta,\phi) - M(\theta,\phi)] \cdot H[E(\theta,\phi) - M(\theta,\phi)] \quad (1)$$

where E is the radiation pattern and H is the Heavyside function.

Three different costs have been used in the optimization to improve the convergence toward the desired result in the minimum number of iterations. The first one is the integral average of the error:

$$I = \frac{1}{n_\theta n_\phi} \iint S(\theta, \phi) d\theta d\phi \tag{2}$$

The second one is the maximum error:

$$S_m = \max_{\theta,\phi}[S(\theta, \phi)] \tag{3}$$

The third one is the pointing error, defined as the absolute difference between the desired scan angle θ_s and the actual one θ_a:

$$\Delta\theta = |\theta_a - \theta_s| \tag{4}$$

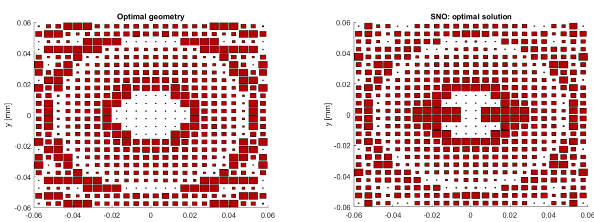
A cost is thus defined for every analysed scan angle:

$$c_i = I + S_m + \left(\Delta\theta \cdot \frac{180}{\pi}\right) \tag{5}$$

Finally the cost function is defined as the sum of the three cost functions of a single scan angle.

The problem design variables are a quarter of the geometrical lengths of the patches (two symmetries are considered) and a Beam Deviation Factor for each scan angle; thus, in total there are 147 design variables.

The optimal solutions of the two optimizers are shown in Figure 1, while the radiation patterns of the three considered scanning angles using the SNO method are depicted in Figure 2 and Figure 3.



(a) BBO optimal geometry. (b) SNO optimal geometry.

Fig. 1. Optimal solution obtained.

IV. Conclusions

In this work, the two evolutionary algorithms (SNO and mBBO) have been applied to optimize a beam scanning Reflectarray problem. Both methods were able to produce a distribution of the RA elements using a cost function based on the calculation of the radiation patterns in all the considered scanning angles.

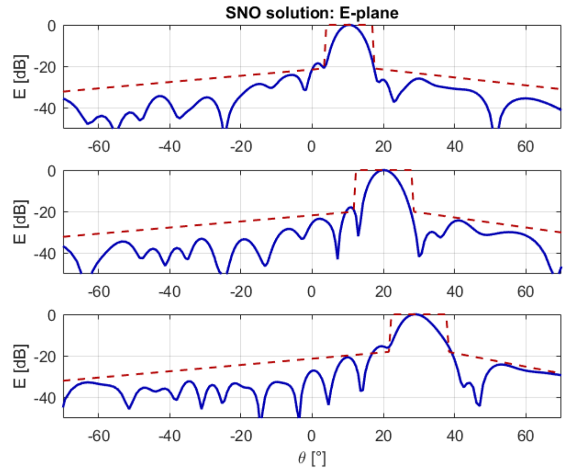


Fig. 2. E-plane optimized radiation patterns for each scanning angle using the SNO algorithm.

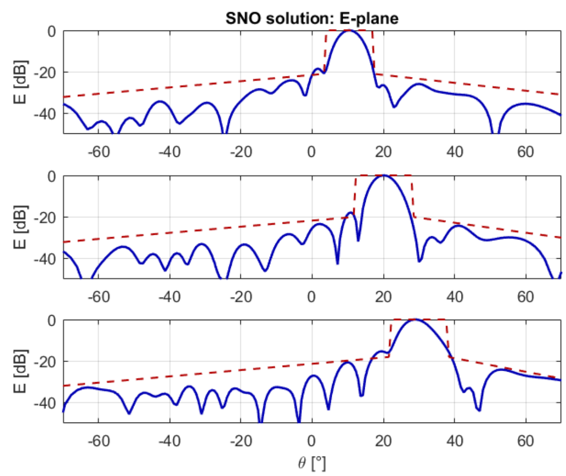


Fig. 3. H-plane optimized radiation patterns for each scanning angle using the SNO algorithm.

References

[1] F. Grimaccia, G. Gruosso, M. Mussetta, A. Niccolai, and R. E. Zich, "Design of tubular permanent magnet generators for vehicle energy harvesting by means of social network optimization," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 2, pp. 1884–1892, 2018.

[2] M. Mussetta, P. Pirinoli, and R. E. Zich, "Application of modified bbo to microstrip filter optimization," in *Antennas and Propagation Society International Symposium (APSURSI), 2013 IEEE*. IEEE, 2013, pp. 410–411.

[3] B. M. et al, "Application of social network optimization to shaped beam transmitarray antennas."

[4] A. Niccolai, F. Grimaccia, M. Mussetta, and R. E. Zich, "Reflectarray optimization by means of sno and pso," in *Antennas and Propagation (APSURSI), 2016 IEEE International Symposium on*. IEEE, 2016, pp. 781–782.

[5] M. Mussetta and P. Pirinoli, "M m c n-bbo schemes for electromagnetic problem optimization," in *Antennas and Propagation (EuCAP), 2013 7th European Conference on*. IEEE, 2013, pp. 1058–1059.

[6] X. Li, K. Tang, M. N. Omidvar, Z. Yang, K. Qin, and H. China, "Benchmark functions for the cec 2013 special session and competition on large-scale global optimization," *gene*, vol. 7, no. 33, p. 8, 2013.

[7] J. Huang and J. A. Encinar, *Reflectarray antennas*. John Wiley & Sons, 2007, vol. 30.

[8] F. Grimaccia, M. Mussetta, A. Niccolai, and R. E. Zich, "Comparison of binary evolutionary algorithms for optimization of thinned array antennas," in *2018 IEEE Congress on Evolutionary Computation (CEC)*. IEEE, 2018, pp. 1–8.