AN ADVANCED TECHNIQUE FOR REFLECTARRAY POWER PATTERN SYNTHESIS AND ITS EXPERIMENTAL VALIDATION

O.M. Bucci, A. Capozzoli, G. D'Elia, S. Russo
Dipartimento di Ingegneria Elettronica e delle Telecomunicazioni
Università di Napoli Federico II
via Claudio 21, 80125 Napoli Italia
phone +39-081-7683115; fax +39-081-5934448
email: g.delia@unina.it

Abstract – A new power pattern synthesis of shaped beam reflectarrays is presented. The approach is based on an accurate electromagnetic model of the structure and exploits a flexible, effective and efficient synthesis scheme. The algorithm represents a significant evolution with respect to existing approaches. The paper enlighten the differences with respect to the past and numerically and experimentally validate the method.

1. Introduction

Microstrip reflectarrays represent a promising solution to the tight requirements enforced on antenna systems by the modern spatial, military and telecommunications applications. In particular, if properly designed, they can allow high performance antennas, with low costs and weight and with compact dimensions. However, to design high performance reflectarrays, radiating an electronically reconfigurable shaped beam, accurate, effective and efficient synthesis techniques are mandatory. In particular, from the design specifications on the far-field pattern, the synthesis algorithm must calculate the resonant lengths of the patches. Several methods have been proposed till now in the literature [1-4], essentially based on simplified electromagnetic models of the system as well as on synthesis strategies which do not exploit at best the degrees of freedom of the radiating structure.

The aim of this communication is to describe the main features of a new approach to the power pattern synthesis of shaped beam reflectarrays, recently introduced in [5, 6], and to enlighten the differences with respect to existing techniques. To show the effectiveness of the approach numerical as well as experimental results are presented.

2. Comparison between synthesis techniques

The first synthesis technique of shaped beam reflectarrays has been presented in [1]. The proposed method does not fully exploit the degrees of freedom of the radiating structure, since the synthesis approach essentially leads back the problem to a shaped reflector antenna synthesis. Many efforts have been made [2-4] to develop accurate methods and overcome the limits in [1]. However, to simplify and speed up the synthesis algorithms, approximate electromagnetic models have been exploited as well as synthesis techniques unable to exploit at best the potentiality of the radiating system. These limitations become more evident when high performances and complex beam are required, with compact structures.

In particular, concerning the aspects related to the electromagnetic model, in [2] the dependence of the reflectarray radiated pattern on the peculiar feed characteristics is disregarded and the same reflecting features are considered for all the array patches. In [3, 4] a phase only synthesis (POS) is considered. In other words, it is assumed that the patch resonant dimensions influences only the phase of the aperture, while the variations of the reflected amplitude have been neglected. Moreover, the incident field on the

ISBN: 89-86522-78-0 94460©KEES

reflecting surface has been approximated by retaining only the components parallel to the reflectarray elements.

It is worth noting that, even if some of the above approximations can be tolerated when the design of non compact reflectarrays are considered, they do not allow a straightforward control of the spillover and aperture efficiency when multifeed systems are considered.

Concerning the aspects related to the synthesis scheme, let us observe that these methods employ the iterative projection approach in [7] and enforce the design specifications on the field amplitude. This choice lead to a synthesis algorithm not flexible and very sensitive to the traps problem, as discussed in [8].

The synthesis method proposed here, AS later on, is based on an accurate expression of the reflectarray far field power pattern as a function of the feed field and of the design parameters of the reflecting system [5, 6, 9]. In particular, the reflecting features of the elements are described by the generalized scattering matrix $\underline{\underline{S}}_i$. The true dependence of both the amplitude and the phase of each elements of $\underline{\underline{S}}_i$ on the patch resonant lengths has been explicitly taken into account by exploiting a fullwave MoM method. Furthermore, the different working environment of each patch has been accounted for and an accurate feed pattern has been considered. Finally, the generalized projection method [10] has been used and the design specifications have been enforced on the field square amplitudes of both the copolar and crosspolar components, ensuring an algorithm flexible and robust with respect to the traps problem [8].

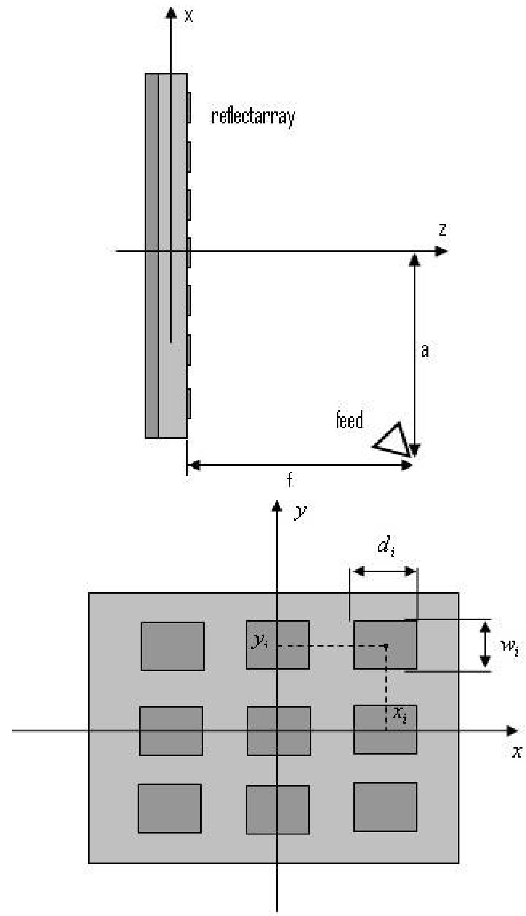

Fig. 1: *Geometry of the reflectarray*

3. Numerical and experimental tests

The proposed approach has been exploited to design a shaped beam microstrip reflectarray working at 14.15 GHz. In particular, we have considered a reflectarray made by 15x15 rectangular patches printed on a dielectric substrate Rogers Duroid with relative dielectric permittivity 2.2 and thickness 1.574mm. The elements have been arranged on a rectangular grid with a spacing equal to 0.56λ in the E-plane and to 0.68λ in the H-plane. The patch width w_i has been set equal to 0.84cm. To reduce the blocking effects, an offset feeding configuration has been considered. In particular, the feeding pyramidal horn, oriented toward the reflectarray center, has been located at f=65cm and a=10cm (see Fig. 1). A shaped top-flat beam with a triangular profile has been required. The design specifications have been assigned in a flexible way by means of two couples of mask functions bounding the square amplitude of the copolar and the crosspolar components, respectively. For the copolar component, we have enforced a 0 dB level, with a tolerance of ±5 dB, inside the region to be covered and, outside, only an upper bound level equal to –25dB. The crosspolar masks involve only an upper bound, equal to –45 dB. It is worth noting that such upper level does not represent the specified isolation between the two components and has been chosen to make the crosspolar component as low as possible.

To analyse the role of the electromagnetic model on the accuracy of the reflectarray design, three different cases have been considered. Case A refers to the POS with a starting point corresponding to a reflectarray made of patches with uniform length. Case B refers to the AS with a starting point corresponding again to a uniform reflectarray. Case C refers to the AS with a starting point corresponding to final result of case A. The POS has been realized by considering a matrix $\underline{\underline{S}}_i$ equal to the one calculated at the resonance multiplied by a complex scalar factor with unitary modulus depending on the patch length.

In Figs. 2-4 the zoomed co-polar power patterns of the field radiated by the synthesized reflectarray in the three considered cases are depicted. On the other side, the power pattern at the starting point of case C, i.e., the pattern radiated by the reflectarray synthesized by exploiting the POS and evaluated by exploiting the more accurate model involved in the AS approach, is presented in Fig. 5.

When considering the results of POS, it must be noted that, since the POS exploits an approximate model of the scattering behaviour of the array elements, the pattern in Fig.2 does not represent the real radiated far field by the synthesized structure. A more accurate estimation of the real pattern radiated by the reflectarray synthesized by the POS is represented in Fig.4.

From Fig. 5 it is evident that the POS does not ensure a good fulfilment of the design specifications. On the other side, Fig. 4 enlighten two key aspects of the synthesis. Firstly, the result of POS can be successfully refined by the AS. Secondly, the subsequent use of POS and AS provides better results than those obtained in Case B. In conclusion, the numerical analysis proves that an accurate model is necessary to adequately fulfil the design specifications.

From the case C synthesis, a printed shaped beam reflectarray prototype has been realized and characterized to experimentally validate the approach. The realization has been performed in the Antenna Lab of our EmLab. The characterization has been performed in the Anechoic Chamber of our EmLab, by exploiting the NFFF cylindrical antenna characterization facility. In Fig.6 the measured power pattern is presented. Beside the inaccuracy due to the realization process, the measured pattern shows a good agreement with the synthesized one. As a final remark, we stress that the synthesized and measured crosspolar levels are under -30 dB, ensuring a good isolation.

Acknowledgments **-**The authors would like to thank Mr. L. Monzo for his contribution to the realization and characterization of the prototype.

4. References

[1] D. M. Pozar, S. D. Targonski and R. Pokuls, "A shaped-beam microstrip patch reflectarray", *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1167-1173, July 1999.

[2] S. Costanzo, F. Venneri, G. Di Massa and G. Angiulli, "Synthesis of microstrip reflectarrays as planar scatterers for SAR interferometry", *Electron. Lett.*, vol.39, no.3, pp. 266-267, Feb '03.

[3] J. A. Encinar, J. A. Zornoza, "Efficient phase-only synthesis of countered-beam patterns for very large reflectarrays", *International Journal of RF and Microwave Computer-Aided Engineering,* Vol.14, Issue 5, pp.415-423, Sept.'04.

[4] J. A. Encinar, J. A. Zornoza, "Three-layer printed reflectarrays for countered beam space application", *IEEE Trans. Antennas Propagat.*, vol. 52, pp. 1138-1148, May '04.

[5] O. M. Bucci, A. Capozzoli, G. D'Elia, S. Musto, "A new approach to the power pattern synthesis of reflectarrays", *URSI International Symposium on Electromagnetic theory*, Pisa, Italy, May 23-27 '04.

[6] O. M. Bucci, A. Capozzoli, G. D'Elia, S. Russo, "Power pattern synthesis of reflectarrays comparison between two approaches", XV RiNEm, Cagliari, Italy, Sept.'04.

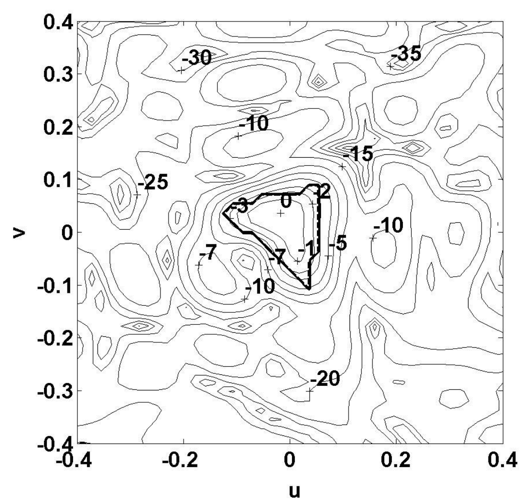

Fig. 2: *The synthesized copolar amplitude (case A)*

[7] O. M. Bucci, G. Franceschetti, G. Mazzarella, G. Panariello, “Intersection approach to array pattern synthesis”, Proc. IEEE, 82, 3, 1994.

[8] O. M. Bucci, G. D’Elia, G. Romito, “Power synthesis of conformal arrays by a generalised projection method”, *IEE Proc.-Microw. Antennas Propag.,* vol. 142, no. 6, pp.467-471, Dec. 1995.

[9] D. M. Pozar, S. D. Targonski, H. D. Syrigos, “Design of Millimeter Wave Microstrip Reflectarrays”, *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 287-296, Feb. 1997.

[10] O. M. Bucci, G. D’Elia, G. Mazzarella, G. Panariello, “Antenna Pattern Synthesis: A New General Approach”, Proc. IEEE, 82, 3, 1994

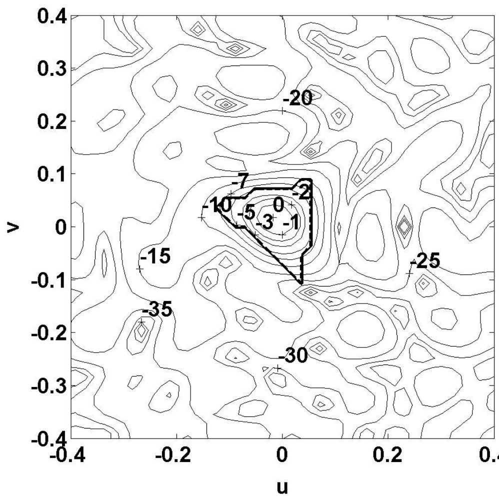

Fig. 3:*The synthesized copolar amplitude (case B)*

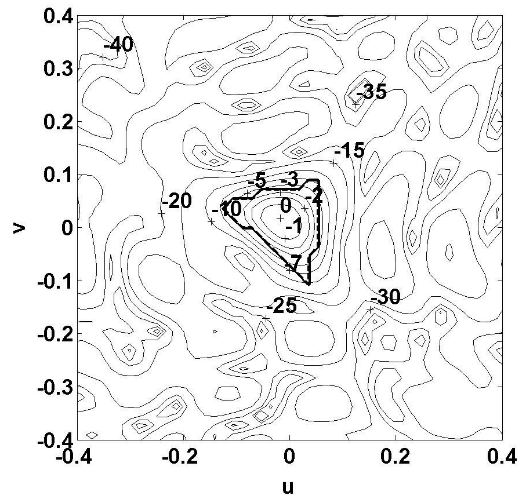

Fig. 4:*The synthesized copolar amplitude (case C)*

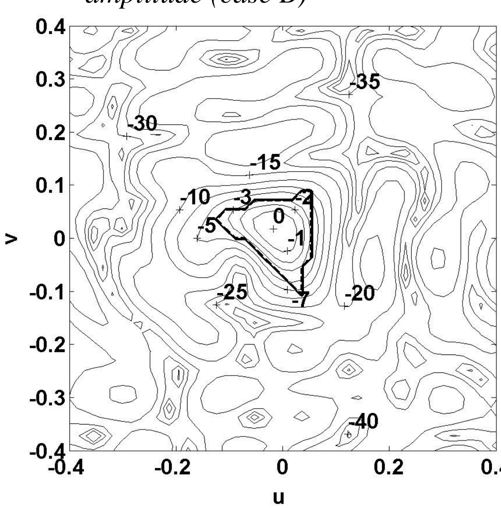

Fig. 5: *The synthesized copolar amplitude at the starting point (case C)*

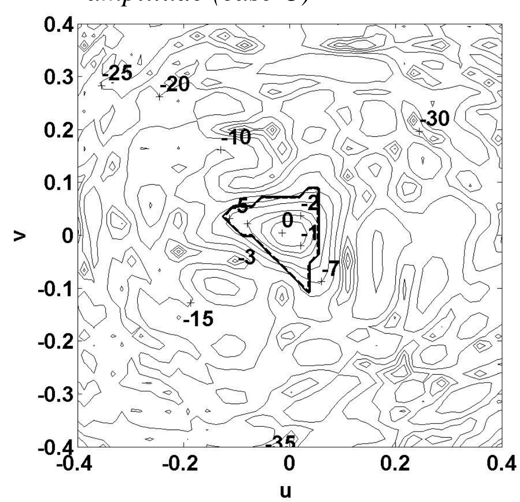

Fig. 6: *The measured copolar amplitude (zoomed)*