DESIGN OF PRINTED MICROSTRIP REFLECTARRAYS REDUCING THE GROUNDPLANE REFLECTION

M. Mussetta[1], P. Pirinoli[2], R. E. Zich[1], M. Orefice[2]

[1]***Politecnico di Milano, Dipartimento di Elettrotecnica***
Piazza Leonardo da Vinci 32, 20133 Milano, Italy
marco.mussetta@polimi.it, riccardo.zich@polimi.it

[2]***Politecnico di Torino, Dipartimento di Elettronica***
Corso Duca degli Abruzzi 24, 10129 Torino, Italy
paola.pirinoli@polito.it, mario.orefice@polito.it

ABSTRACT — An effective technique to design reflectarrays is to use Genetic Algorithms, in order to optimise the structure in terms of its radiation patterns. The total re-radiated field is computed as the sum of all the contributions from each array elements, whose geometrical features are defined through the optimisation procedure. The computed performances of the antenna designed following this approach are in good agreement with those of the measured prototype; however, there are some key issues related to the ground plane reflection, that produces higher side lobes level. In this paper an integrated approach is proposed to reduce this unwanted effect on the far field radiation pattern.

I. INTRODUCTION

Printed reflectarray antennas consist of planar or conformal arrays of printed radiating elements with different sizes, fed quasi-optically by a primary illuminator, for example a horn. The printed elements so re-radiate the illuminating power back into the space.

Printed reflectarrays present appealing feature both from an electromagnetically point of view, since they are high gain antennas, with narrow beam and low side lobe level, and from a mechanical point of view, being lightweight structures with smaller depth in comparison with other types of antennas with comparable electromagnetic features. This is the reason why they have been the object of several publications, as [1, 2, 3, 4, 5, and references therein], just to cite a few among the most recent of them.

The main issue with reflectarrays is that, since the printed elements have different positions on the reflector plane, the field that propagates from the feed to the patches covers different path lengths, and so the incident waves have different phase in each point. The phase differences of the different contribution to the total re-radiated field due to these different path lengths can be compensated by adopting suitably sized or shaped radiating elements, that in this way act similarly to frequency selective surfaces (FSS). The considered shape of the elements may vary, and even if most of the papers deal with rectangular patches, even ring patches or bone shaped patches have been considered [6, 7].

II. REFLECTARRAYS ANALYSIS AND SYNTHESIS

The analysis of a printed reflectarray can be carried out following the standard methods for printed antennas circuits. The use of a rigorous full-wave methods, e.g. the Method of Moments or Floquet theory for infinite large arrays [1], allows to take into account the coupling among the elements of the arrays, and therefore the solution is generally accurate, but they are numerically expensive. On the other hand, the field re-radiated by the reflectarray can be written as the sum of the contributions due to the single elements [2], each of one generated by an excitation currents that depend on the incident field on each patch. The field re-radiated by the single patch can also be evaluated more or less accurately; the simpler and less expensive (from a computational point of view) way to model each array element is through its equivalent circuits, whose parameter can be computed using a transmission line model.

In [3] an efficient and new technique for the design of a printed reflectarray, based on the Genetic Algorithm (GA) [8] optimization of the whole structure, has been presented. In fact, in order to reduce the computational cost of each evaluation of fitness function that has to be optimized by the GA, it is usually convenient to adopt a simplified representation of the single element pattern, as well as of the total re-radiated field.

Thus, the adopted model describes each radiator with the equivalent lumped circuit, while the total re-radiated field is written as the sum of each single contribution. The neglecting of the mutual coupling between the patches is actually not such a brute approximation since, for the reason explained in the following, in the final configurations all the elements of the array have a significantly different size, i.e. they have a different resonance frequency and therefore its mutual coupling can be assumed relatively small.

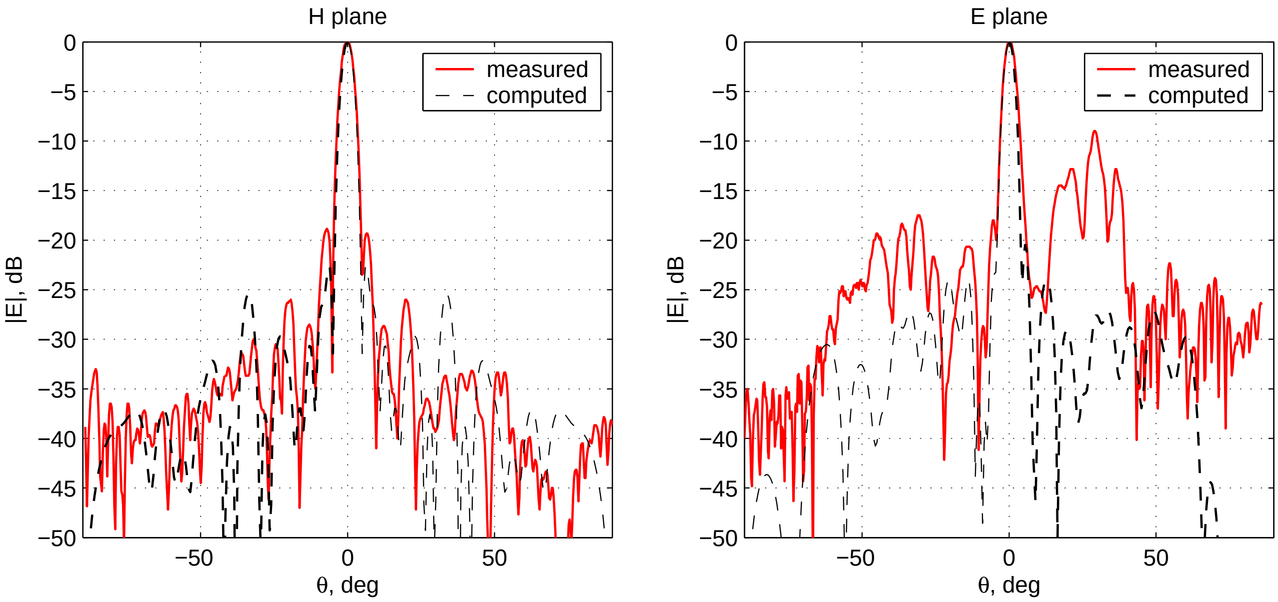


Figure 1: Measured and computed radiation pattern of the elliptic contour reflectarray presented in [3] in the H plane (left) and E plane (right).

III. THE PROTOTYPE 18 GHz REFLECTARRAY

The results reported in Fig. 1 refer to a prototype reflectarray with printed patches working at 18 GHz, that has been manufactured in order to validate the design procedure described in [3]. The radiating elements are printed on a substrate with height $h = 1.66$ mm and dielectric constant $\epsilon_r = 2.16$; the distance between elements is 15 mm, i.e. the maximum allowed to avoid the presence of grating lobes, and so the total height of the panel is about 31 cm.

The feed is a pyramidal horn of size 6.1×4.6 cm, placed in offset position 40 cm away from the reflecting surface; the projection of the feed on the reflectarray plane is 10 cm from its bottom side. Its measured radiation pattern, in the range of the angular width of the reflectarray from the feed, $(34°)$, is well approximated with a cosine-on-pedestal function, that has been used as incident field term in the design procedure. Since the main lobe of the horn defines a cone, whose intersection with the reflectarray plane is an ellipse, only the patches inside an elliptical contour defined in this way have been considered (see Fig. 2, left).

The radiation pattern of the described antenna prototype has been measured: in Fig. 1 the results in the horizontal and vertical plane are shown, together with the computed one. The measured gain is around 30 dB.

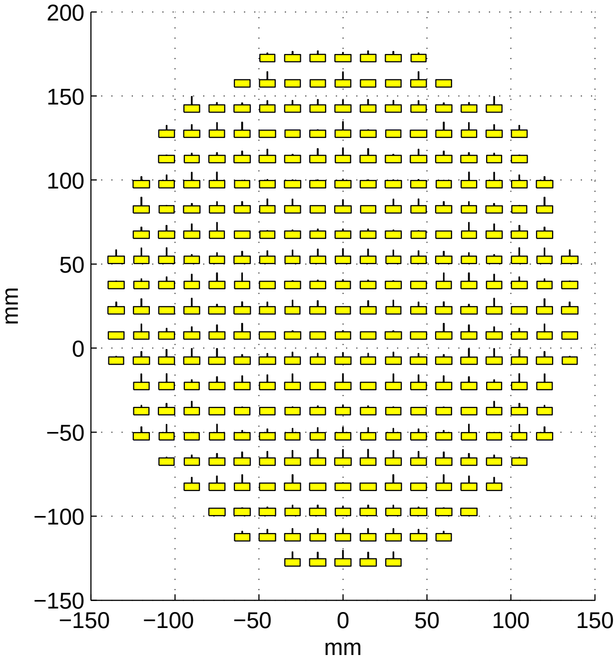
The main differences between the two patterns are a higher level (almost +5 db) and a broadening of the first side lobe of the measured pattern and a higher level of the side lobes in the angular region in correspondence of the specular reflection from the feed.

The discrepancies appear to be mainly due to the reflection from the ground plane, that are not taken into account in the theoretical model; in fact, a remarkable portion of the ground plane is not covered by the radiating elements.

IV. TECHNIQUES FOR REDUCING THE GROUND PLANE REFLECTION

As the comparison with experimental results shows, the computed radiation patterns of the antenna designed following the proposed approach are in good agreement with those of the measured prototype for what concerns the H plane, while, especially in the E plane, the discrepancies can be ascribed mainly to the reflection from the ground plane, that in the simplified model are usually not taken into account. The role of the ground plane is in fact that of reflecting incident field completely and thus reducing the back-radiation.

In order to reduce this unwanted contribution two ways can be considered: the first consists in taking into account the ground plane radiation in the simplified model, in such a way that the GA should redistribute the phase compensation above the antenna surface in order to minimize the side lobe levels. In order to mantain the simulation of the reflectarray as faster as possible, the mere geometrical optics can be adopted to compute the contribution to the total field due to the reflection from the ground plane; this is not a precise technique, but is a good approximation to locate where the biggest issues are for the level of the side lobes. In fact, the optimization of the whole reflectarray, as suggested in the proposed design procedure, can be carried out using a suitable version of the GA, whose target is the maximization of the re-radiated



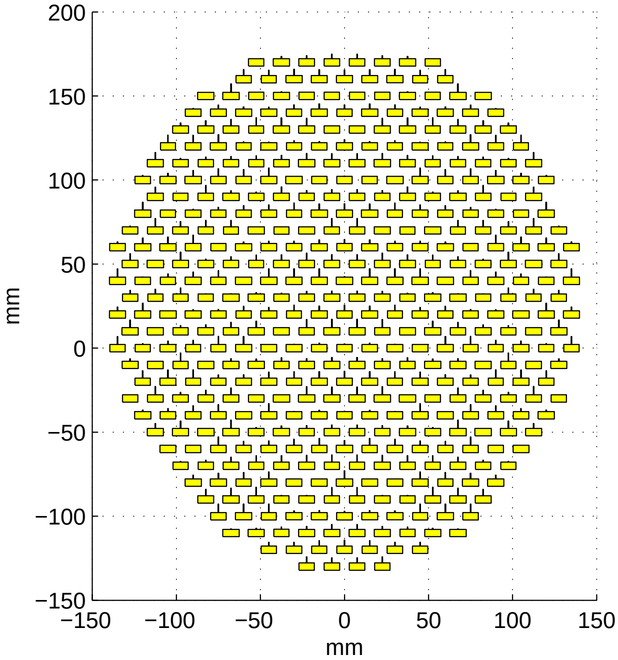


Figure 2: Patch distribution over the reflecting surface for the regular grid (left) and the enhanced grid (right)

field in the desired direction, and the simultaneous minimization of the level of side lobes.

In this way, once the total size of the array and the spacing between the patches are fixed, the geometrical features are encoded in order to represent the starting population for the genetic algorithm. From that point the algorithm proceeds in varying the width of the patches and the lengths of the stubs, that corresponds to vary the shunt resistance and the reactive load representing the stub, up to the satisfaction of the required fitness constrains, such as the minimization of the side lobes level. If the presence of the ground plane reflection is taken into account as described before, higher lobes are located in the region where specular reflection is, and these negatively affects the fitness value, causing the GA to search a different solution with a lower level of those lobes.

A validation of the proposed method is reported in Fig. 3 (left), where the measured radiation pattern shown in Fig. 1 is compared with the computed one, after the addition of the ground plane contribution obtained by means of specular reflection. The simulated radiation pattern is quite close to the measured one, confirming that a good approximation of the ground plane effect can be obtained by the proposed procedure.

Nevertheless, since with this solution only a small reduction of the ground plane effect can be obtained, a second possible solution is the reduction of the inter-element spacing, that in the first design has been chosen as for a standard array, with a regular squared grid: in this case the idea is that of covering more of the ground plane for reducing its effect.

The inter-elements spacing cannot however be reduced too much otherwise the hypothesis of neglecting mutual coupling becomes no longer applicable. The reduction of the inter-element spacing, in fact, must clearly be done with a new design of the reflectarray, not using the usual criteria for minimizing the number of elements. On the other hand, the minimization is required in arrays to have simpler BFN, and this is not the case for the reflectarrays.

The proposed patch distribution has been chosen in order to reduce the inter elements spacing maintaining the distances between the borders of the patches to a constant value (such that mutual coupling can still be neglected). This makes the squared grid unsuitable due to the presence of stubs, since sufficient room must be left for them. The adopted solution is then the use of a triangular grid (Fig. 2, right), that satisfies these constrains.

Simulations have been done with the proposed techniques in order to verify if the adopted solutions could give an improvement in the design of reflectarrays, taking into account the groundplane reflection. The results are reported in Fig. 3 (right).

V. CONCLUSION

In this paper an integrated approach has been proposed to reduce the effects of the groundplane reflection on the radiation pattern of a printed reflectarray, by taking into account its specular reflection in the design procedure and changing the distribution of patches over the reflecting surface.

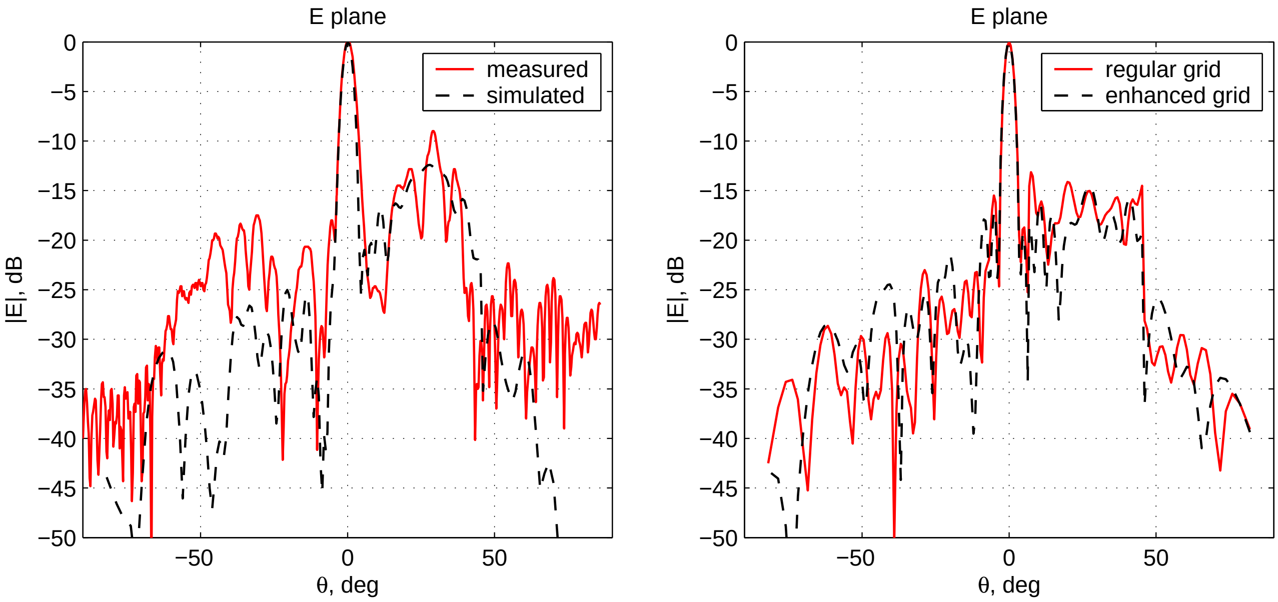


Figure 3: On the left, a comparison of the experimental result (Fig. 1, right) with the computed one, after addition of the specular reflection contribution. On the right, E plane radiation pattern of the elliptic contour reflectarray, after it has been re-designed taking into account the ground plane effect.

As Fig. 3 shows, the level of the side lobes of the re-radiated field can be reduced by GA if specular reflection is taken into account in the design procedure. The effectiveness of the triangular grid is demonstrated by a slight improvement in the side lobes level, but the contribution to the total re-radiated field due to the presence of the ground plane is still quite high, suggesting that further enhancements must be studied.

REFERENCES

[1] D.M. Pozar, "Bandwidth of reflectarrays" *Electronics Letters*, Vol. 39, Oct. 2003, pp. 1490-1491

[2] J. Huang, "The development of inflatable array antennas", *IEEE Antennas and Prop. Magazine*, Vol. 43 , Aug. 2001, pp. 44-50

[3] M. Mussetta, G. Dassano, P. Pirinoli, R. E. Zich, M. Orefice, "Design, Optimization and Experimental Measurements of a 18 GHz Microstrip Reflectarray", *Proceedings of the 13th International Symposium on Antennas JINA 2004*, Nov. 8-10, 2004, Nice, France, pp. 240-241.

[4] T.N. Chang, Y.C. Wei, "Proximity-Coupled Microstrip Reflectarray", *IEEE Trans. Antennas Propagat.*, Vol. 52, March 2004, pp. 631-635

[5] J.A. Encinar, J.A. Zornoza, "Three-Layer Printed Reflectarrays for Contoured Beam Space Applications ", *IEEE Trans. Antennas Propagat.*, Vol. 52, May 2004, pp. 1138-1148

[6] M. Orefice, P. Pirinoli, C. Zuin, "A Printed Reflectarray with Annular Patches", *Digest of the 2004 IEEE AP-S Int. Symposium*, Monterey, CA, 2004, vol. 5.

[7] M. Bozzi, S. Germani, L. Perregrini, "Performance Comparison of Different Element Shapes Used in Printed Reflectarrays", *Proceedings of the 2003 IEEE AP-S*, Columbus, Ohio, pp. 294-297.

[8] Y. Rahmat-Samii, E. Michielssen, Eds., *Electromagnetic Optimization by Genetic Algorithms*, Danvers, MA, USA, John Wiley and Sons, 1999.

[9] D.G. Berry, R.G. Malech, W.A.. Kennedy, "The Reflectarray Antenna", *IEEE Trans. Antennas Propagat.*, Vol. AP-11, pp. 645-651, 1963.

[10] R.D. Javor, X.D. Wu, K. Chang, "Design and performance of a microstrip reflectarray antenna", *IEEE Trans. Antennas Propagat.*, Vol. AP-43, pp. 932-939, 1995.

[11] A.G. Derneryd, "A theoretical investigation of the rectangular microstrip antenna element", *IEEE Trans. Antennas Propagat.*, Vol. AP-26, pp. 532-535, 1978.