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A Printed Reflectarray with Annular Patches

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Abstract – **In this paper an example of Printed Reflectarray, designed to validate the concept of the use of annular patches, will be analyzed and discussed. The analysis of the structure and the computation of the phase curves for the field reflected from the patches, needed for the design of the elements, have been carried out with full wave methods taking into account the interaction among the elements.**

The reflectarray sample is a 5x5 elements structure, and the results have shown good pattern behavior and symmetry.

1 INTRODUCTION

Research activity in Printed Reflectarrays (PRAs) is still a theme of significant interest, as it is confirmed by the continuing research and recent scientific literature on this subject [1], and the attention dedicated to it by the Networks of Excellence on Antennas [2]. The reason is well known: they have attracting characteristics in space and terrestrial telecommunication applications, because the reflectarray technology can lead to high directivity antennas with deployable lightweight flat structure, to reduce the losses with respect to an equivalent array and its feed system, combining in this way the advantages of reflectors and arrays; however research is going on also to overcome their intrinsic limitations (see e.g. [3]).

The most common PRAs have square (or rectangular) patches, and the phasing characteristics are obtained with well know techniques (size variation, stubs, orientation, etc). Less investigation (although with some interesting results, as e.g. in [4]) has been carried out on PRAs consisting of non-square/rectangular shapes, as circular, annular, etc. In particular, the use of annular patches may be interesting because in the fundamental mode TM11 the resonant size is significantly lower than for the circular or rectangular patch, and also because of the additional degree of freedom of the aspect ratio (outer/inner radius). It is therefore possible to control the phase of the reflection coefficient by varying the size of the patch and in particular only the inner ring radius.

In a previous paper [5] the analysis of the structure, and in particular the computation of the phase curves needed for the design of the patches, has been carried out with several full wave techniques (among which those previously used in [6]), taking into account the interaction among the elements. Here some of those results are used to design (and successively build and test) a Reflectarray structure as a proof-of-concept. In the following section the radiating properties of the annular element will be briefly reviewed. A section on the design of the RA follows, together with the results and their analysis.

2 THE RADIATING ELEMENT

The annular patch has been used both as single radiator and in arrays by several authors (see e.g. [6-8]), and also for some phase corrections of Fresnel reflectors [9]. As many patch radiators, it may have different modes of radiation in correspondence of the resonances of the equivalent resonator. The most common way to derive the resonant dimensions of the annular patch, around which there is the maximum phase variation, is to use the equivalent coaxial cavity model with magnetic walls, and then compute the electromagnetic field; this technique is more accurate if the effective dielectric constant $\varepsilon_{\mathrm{eff}}$ is used, as well as the effective inner/outer radii a_e and b_e, whose equations can be found in the literature (see e.g. [10-12]), and whose details will be omitted here for sake of brevity.

The most useful modes, because of the form of the radiation pattern, are the TM11, characterized by a very compact size of the element, and the TM12, with larger size of the radiator (typically, three times or more) but also with larger bandwidth. Despite this positive feature, the size of the annular patch in the TM12 mode is too large, and this makes impractical its use for arrays and reflectarrays, because of the possibility of grating lobes, especially when the main beam is off the normal, as it happens often in reflectarrays. Moreover, it this way one of the advantages coming from the use of annular patches, instead of other more conventional radiating elements, i.e. the possibility of maintaining constant the distance between adjacent elements varying only the inner radius, would be lost.

The TM11 mode will therefore be used: its radiation pattern is symmetric and broad (see fig.1), so that it can be easily used also for wide scan angles.

The other feature of annular patches that makes them particularly appealing for the use in reflectarrays, is that they posses more degrees of freedom (inner and outer radii) with respect to conventional shapes (e.g. square or circular), and they can be used all together to improve the performances of the PRA, e.g. its bandwidth [13]. This is a very important aspect, because it allows obtaining PRAs that at the same time have enhanced radiating properties, but that are

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relatively easy from the point of view of the design and of the manufacturing.

However, the goal of having a denser and more regular grid (that could reduce the specular reflection) generally leads to limit the attention to the case in which only one geometrical parameter of the ring is varied to obtain the desired phase of the reflection coefficient.

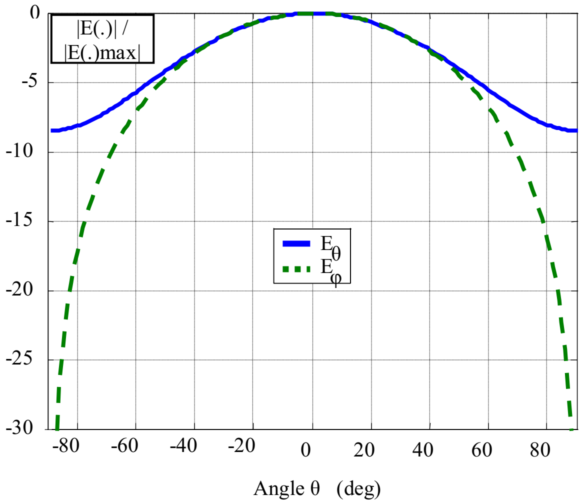

Fig.1: Normalized radiated field (TM 11) in the planes φ=0 and 90°

3 CONTROL OF THE REFLECTION PHASE

The relationship between the phase of the reflection coefficient and the annular patch geometrical parameters has been computed following the usual procedure (see e.g. [14] for square patches) of considering the patch embedded in an infinite array of equal elements, and analyzing the scattering of an incident plane wave from this structure with a full wave approach.

Several configurations have been examined, and a number of design curves have been determined, by varying several parameters of the structure (substrate height, dielectric constant, range of aspect ratio, incidence angle), that allow to compute the reflected phase vs. aspect ratio and therefore the appropriate dimensions of the patch. The results of this parametric analysis have been partially reported in [5]: from there it is possible to conclude that:

- a “thin” annular patch produce a large (near 360°) phase variation with an aspect ratio variation of about ±20%, and therefore it is more sensitive to fabrication tolerance;
- increasing the substrate height the phase variation become slower;
- the phase variation is almost independent from the incidence angle;
- the value of the substrate dielectric constant does not affect significantly the phase variation.

An example of the phase behaviour with the relative variation of the patch inner radius (*da/a*) is shown in Fig. 2. In this case the substrate parameters were assumed as ε_r=2.2, h=0.0236λ_0, with a reference element (da=0) relatively thick, with aspect ratio R=4 (resonant dimensions b=0.177λ_0 and a=0.0442λ_0). The incidence is normal and the element spacing of the array is d=0.44λ_0.

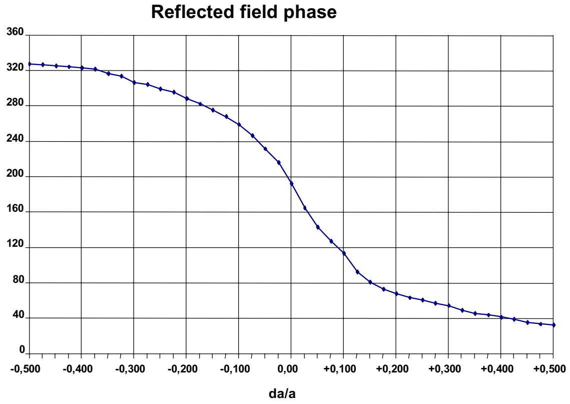

Fig.2: Reflected field phase variation versus the geometrical parameters of the annular patch

4 DESIGN OF THE REFLECTARRAY

The reflectarray design described in the following was done to verify experimentally the feasibility of such structure, as a proof of concept. Therefore no special constraints were imposed on the efficiency and on side lobes. A relatively small reflectarray was designed (5x5 elements), with cell size smaller than the limit for the grating lobes, in order to reduce the distance between adjacent elements. The frequency chosen was 4 GHz (λ=75 mm), with cell size 30 mm. The ring diameter was chosen in order to be near resonance at the design frequency on a substrate of height 1.6 mm (1/16”).

To avoid the blockage effects the feed was placed in offset position, and to reduce the importance of the spurious specular reflection from the ground plane, the phasing of the elements was chosen such to have them radiating in phase in the specular direction (see fig.3): in this way, the field re-radiated from the patches is much higher than the spurious reflection.

The quasi-planar wave re-radiated from the patches is inclined with respect to the plane of the reflectarray: this allow to reduce the offset, as shown in the figure, and to keep always a relatively low angle of incidence.

Another useful feature for the proof of concept is to have a smooth phase variation; consequently adjacent elements have about the same dimensions and therefore the structure is nearer to the ideal model of infinite array of equal elements used for deriving the phase curve. To obtain this, the feed position was chosen at a distance about twice of the reflectarray size. The feed pattern was relatively broad, in order to have a quasi-uniform illumination on the reflectarray: obviously, this leads to a poor efficiency because of the high spillover.

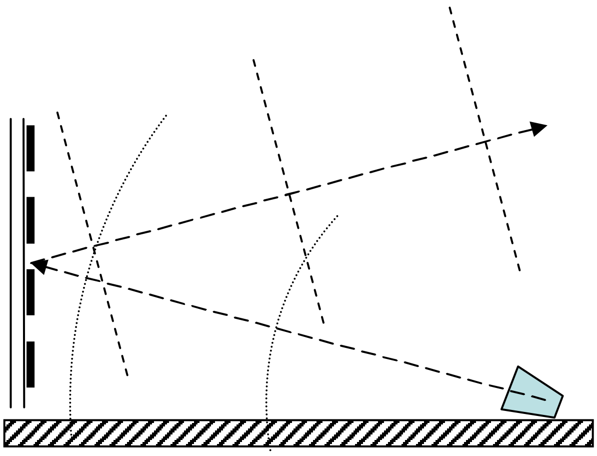

Fig. 3: Scheme of the design of the Reflectarray

The path difference can be easily calculated: in this case the range of the phase compensation required is relatively low, about 75°. Figure 4 shows a colour map of the phase adjustment required for the elements. The inner dimensions of the patches have been computed using the design curves described in the previous paragraph. The radiation pattern in both E (vertical) and H (horizontal) is shown in fig.5.

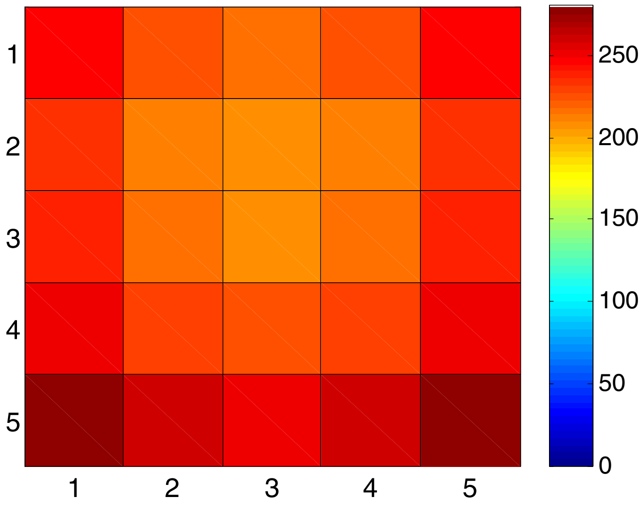

Fig. 4: Colour map of the phase adjustment required for all elements.

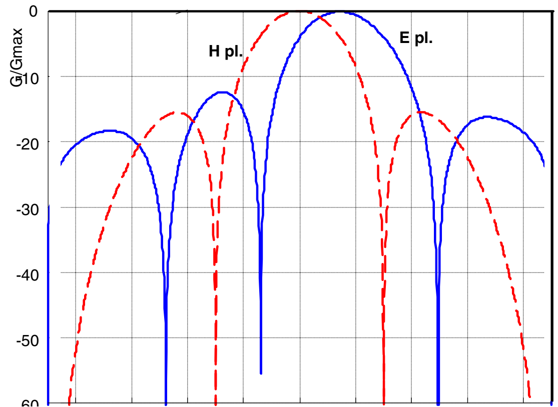

Fig. 5: Radiation patterns of the reflectarray on the symmetry (vertical) plane (E plane, solid curve) and in the H plane (dashed curve).

CONCLUSIONS

In this paper an example of Printed Reflectarray, designed to validate the concept of the use of annular patches, has been presented. The analysis of the structure and the computation of the phase curves for the field reflected from the patches, needed for the design of the elements, have been carried out with full wave methods taking into account the interaction among the elements.

The reflectarray presented is a 5x5 elements structure, and the results have shown good pattern behavior and symmetry.

The results show that the use of annular patches in reflectarrays is an interesting alternative to more conventional solutions, because it opens possibilities and options that are absent in rectangular patch shapes, as the phase control with inner radius only and fixed outer radius (i.e. maximum size) of the element, a wide range of variation of the reflection coefficient phase, a smaller size of the elements for the fundamental TM11 mode, a constant outer size, allowing a more regular and dense lattice, and, finally, a behavior independent on incident polarization.

Acknowledgments

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