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Perforated Dielectric Reflectarray in Ka-band

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***Abstract*—This paper proposes a single-layer perforated dielectric reflectarray antenna that operates in Ka-band. The unit-cell is made up of a dielectric element perforated by a centered square hole, whose size is used to control the phase of the reflection coefficient. This cell has been used to design a 52x52 offset reflectarray working at 30 GHz, whose numerical analysis proves that it has good radiation features. The proposed configuration is particularly convenient since Additive Manufacturing processes can be exploited for its fabrication.**

***Index Terms*—Reflectarray, array antennas, perforated dielectric, 3D printing, Additive Manufacturing.**

I. INTRODUCTION

Reflectarrays (RAs) have emerged in the last years as successful aperture antennas in many applications as satellite communications, radars, point-to-point terrestrial links, remote-sensing systems and deep-space communication links. A reflectarray is composed of an array of re-radiating elements illuminated by a feed source. Each reflecting element, named Unit-Cell (UC), is individually designed to control the phase response and to obtain the required phase-shift for generating a desired radiation pattern. The working principle is similar to that of reflector antenna, with the further advantage that the reflective surface is flat and this contributes to reduce its bulk. Thanks to these characteristics, reflectarrays have the capabilities to provide a high-gain and low profile features with a relatively low-cost fabrication process [1], [2].

Reflectarrays can be essentially classified in two different categories: passive RAs or active RAs. The most widely used way to realize a passive reflectarray consists in printing metallic elements on one or several dielectric substrates with a ground plane on the back. Typically, this configuration is developed adopting microstrip technology since it has low manufacturing cost. For how the metallo-dielectric cells are made, they can be seen as Frequency Selective Surfaces (FSSs). Among the various types of possible metallic elements, the most popular is the square patch, which can be printed in a single [3], double [4] or three-layers configuration [5]. Other possible elements can be square loops [6], cross loops [7], parallel dipoles [8], slots [9] or modified square rings loaded by spiral stubs [10]. Increasing the number of re-radiating elements in the UC or considering more complex shapes improve the number of its degrees of freedom, which can be used to improve the RA features as, for instance, the bandwidth, one of its most critical drawbacks.

Reflectarrays can be designed exploiting several techniques to generate pencil- [4], shaped-beam [11], [12] or contoured beam for space applications [13], to control the polarization [14]–[16], to obtain a single or multi-band behavior [17], to provide asymmetric multibeam [18] and beam-scanning capabilities [19]. Electronically reconfigurable radiation features can be implemented through the introduction of active elements [20] on each cell, such as varactor diodes [21], [22], PIN diodes [23], liquid crystals [24] or MEMS switches [25].

If reflectarrays were originally devised as a planar alternative to reflectors, their good features and the increasing number of their possible applications push the researchers to investigate other, less conventional configurations. Among them, it is worth to mention folded reflectarrays, that combine the planar reflector with a twist grid to obtain a more compact structure, particularly suitable for automotive applications [26], [27]. Another interesting RA structure was introduced in [28], where a convex reflectarray conformed to a cylinder having a given radius of curvature is proposed as a solution easily integrable on curved surfaces as the fuselage of an aircraft.

Alternatively to metallo-dielectric cells, recently other realization techniques have been investigated, as the use of metal-only layer with slots [29], or dielectric-only configurations that use perforations [31], [32] or locally modify the dielectric thickness [33], [34] to control the reflection phase. The advantage of these last solutions is that they can be fabricated adopting an Additive Manufacturing (AM) process, while the configurations that act on the phase of the reflected field through the introduction of circular holes of different size in a single [31] or multi-layer [32] substrate are generally manufactured drilling the dielectric material.

In this paper, an innovative single-layer UC configuration is used to design a perforated dielectric reflectarray in Ka-band. The unit-cell, that presents a single, square hole, is firstly introduced and described, then the results of the reflection coefficient analysis are presented. After this, the simulated radiation features of a 52×52 offset Reflectarray are discussed.

II. RA DIELECTRIC UNIT-CELL

The proposed unit-cell is a single dielectric layer having a square hole located in the center, as shown in Fig. 1. The concept of square, eventually not uniform, perforations in a dielectric UC, was first introduced in [35], [36], where it was used to design a transmitarray. Here, the idea is extended to the case of a RA, whose UC is obtained adding a metallic back plane and properly adjust its size and the thickness of the dielectric layer [37] (see Fig.1). The reflection coefficient (phase and magnitude) can be controlled by varying the hole size d, or, in other words, to change the effective permittivity of the unit-cell.

The completely dielectric structure of the UC makes it favorable to be printed by using AM techniques, as made in [38], [39]. In view of this, the material employed here for the RA design is the 3D-printable resin VeroWhitePlus$^{\mathrm{TM}}$ ($\varepsilon_r = 2.77$, tan$\delta = 0.021$) provided by Stratasys$^{®}$. The UC has been designed in Ka-band at the operating frequency $f_0 = 30$ GHz. The geometrical parameters as the height T, the periodicity W and the variation range of the hole size d have been fixed taking into account the AM limitations, as widely discussed in [38]. The final configuration has a periodicity $W = 0.3\lambda_0 = 3$ mm, a thickness $T = 1.4\lambda_0 = 14$ mm while d varies between 0.5 mm and 2.65 mm.

The Floquet analysis in CST MW Studio$^{®}$ has been used to compute the reflection coefficient. Its amplitude ($|S_{11}|$) and phase ($\angle S_{11}$), as a function of d and computed at 30 GHz, are plotted in Fig. 2a and Fig. 2b, respectively. For larger holes, $|S_{11}|$ is higher than -2 dB, while for smaller values of d it decreases until -4 dB. This effect is due to the not-negligible losses introduced by the 3D-printable dielectric material. The curve of $\angle S_{11}$ provides a phase range greater than 360°.

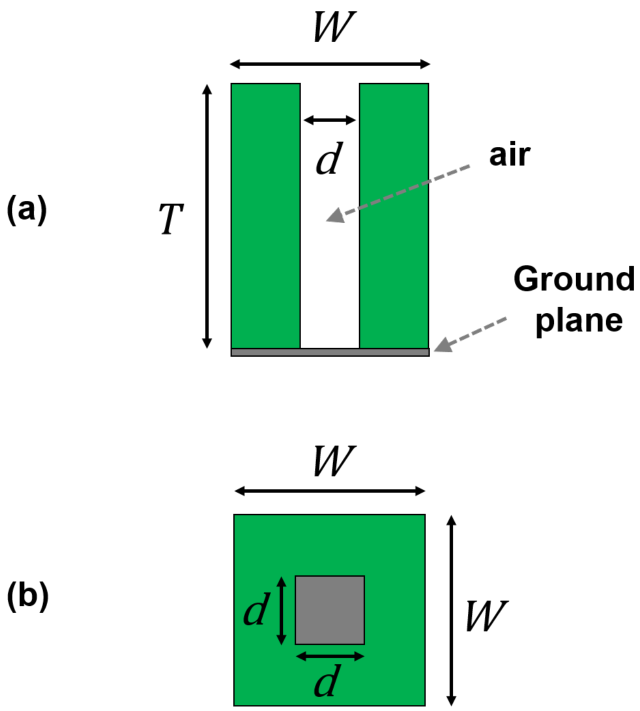
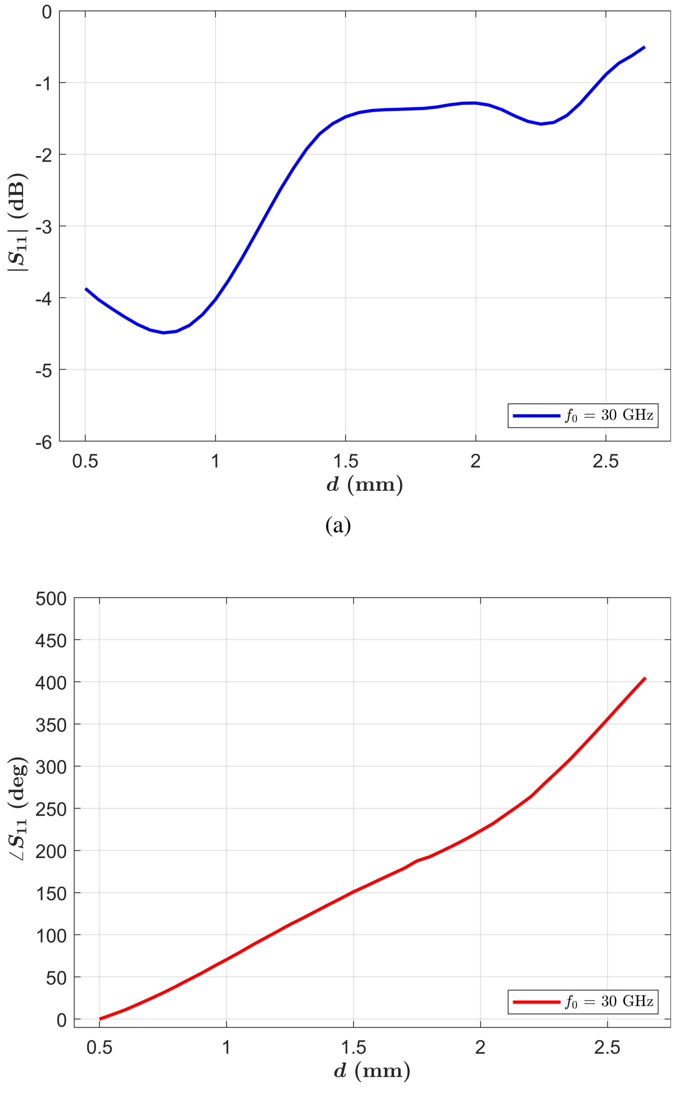


Fig. 1: Perforated dielectric RA unit-cell: (a) Side view; (b) Top view.



(a)

(b)

Fig. 2: Variation of the reflection coefficient S_{11} at 30 GHz with d: a) Amplitude; b) Phase.

III. REFLECTARRAY DESIGN

Adopting the unit-cell introduced in the previous section, an offset reflectarray composed of 52×52 UCs and having size $D = 15.6\lambda_0 = 156$ mm has been designed. The feed is a 3D-printed conical horn, optimized to work in in Ka-band [40], located at 156 mm ($F/D = 1$) from the RA surface and at

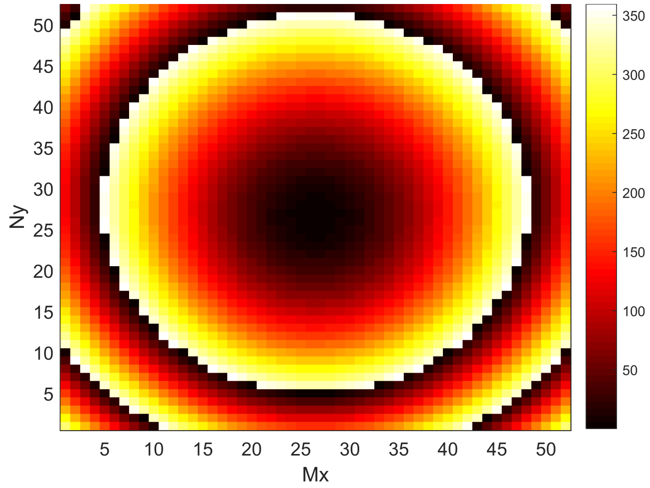


Fig. 3: Required phase distribution the of 52×52 dielectric perforated RA.

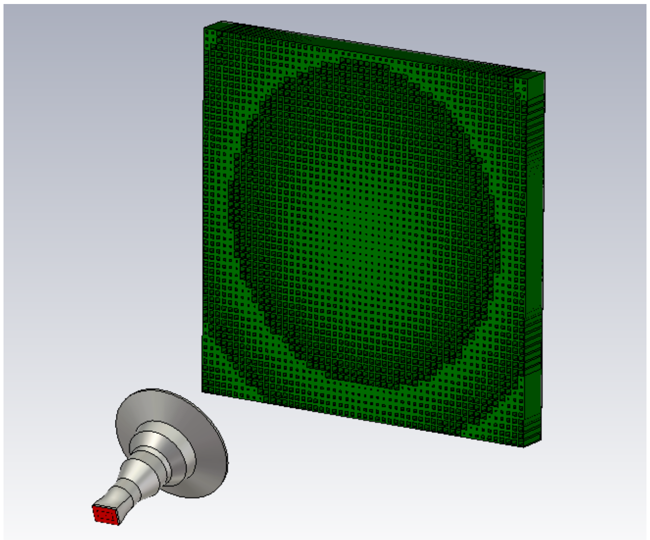


Fig. 4: 3D model of the 52×52 dielectric perforated RA.

a distance from the RA lower border such that its radiated field impinges on the RA center with an angle equal to 20°, to minimize the blockage effect. It has a gain of 17 dBi at 30 GHz and half-power beamwidths (HPBW) in E-plane and H-plane of 32.3° and 33.2°, respectively. Fig. 3 shows the phase distribution over the RA aperture required to focus the beam in the direction specular to that of arrival of the incident field. It has been used to determine the size d of the hole in each unit cell: the resulting configuration has been simulated with CST MW Studio® and its 3D-model is shown in Fig. 4.

The simulated co-polar and cross-polar components of the radiation pattern in E- and H-plane are shown in Fig. 5 and 6, respectively. The beam in E-plane is characterized by a HPBW of 4.1°, while in H-plane is about 3.9°. In both the principal planes the Side-Lobe-Level (SLL) is good, achieving -17.6 dB in E-plane and -19 dB in H-plane. The maximum cross-polarization level is -30.2 dB and -33.5 dB in E-plane and H-plane, respectively.

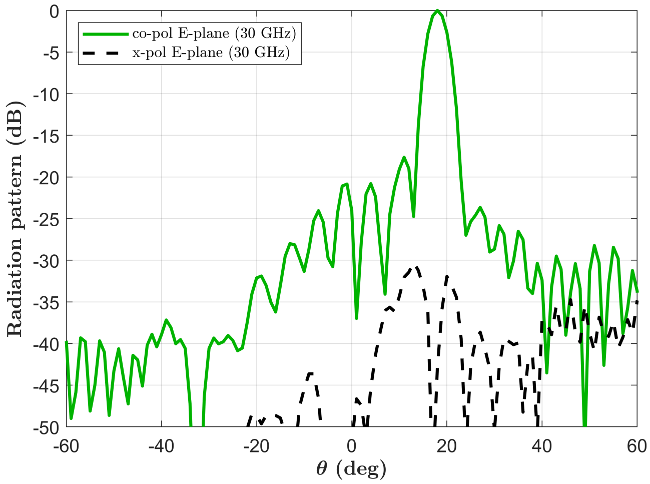


Fig. 5: Computed co-polar and cross-polar components of the radiation pattern in the E-plane, at 30 GHz.

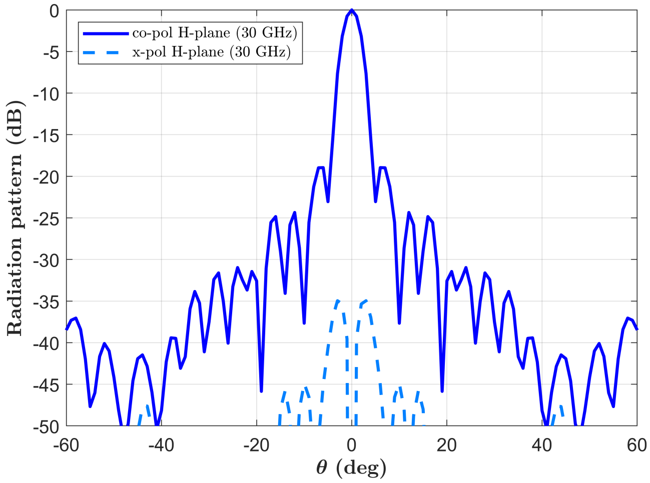


Fig. 6: Computed co-polar and cross-polar components of the radiation pattern in the H-plane, at 30 GHz.

The computed gain is equal to 29.3 dBi at the design frequency, that corresponds to an aperture efficiency of 27.5%. This reduced value is mainly due to the manufacturing limitations, i.e. the use of a material with relatively high losses and the tolerances of the AM process. The antenna efficiency could be improved reducing the range of variation for d, i.e. avoiding its smallest values in correspondence of which $|S_{11}|$ is lower, or more effectively changing dielectric material, i.e. using another one, characterized by an higher value of ε_r and lower losses. It is however worth to notice that the designed antenna has a wide 1-dB bandwidth, equal to the 11.7%.

IV. CONCLUSION

In this work, the design of a medium-sized dielectric reflectarray based on square hole perforations has been proposed. The results of the unit-cell analysis and the RA radiation performance have been presented. The antenna showed a gain of 29.3 dBi at 30 GHz, an aperture efficiency of 27.5% and a 1-dB gain bandwidth of 11.7%. Further details and the experimental validation of a 3D-printed prototype will be shown at the Conference.

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