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***Abstract*—A 3D printed folded reflectarray that uses fully dielectric resonator elements and a spherical polarizer realized with a metalized plastic structure is presented in this paper. To reduce the thickness of the reflecting surface, a 3D printable dielectric material with a high-value of the dielectric constant is used, while the spherical polarizer is exploited to enhance the reflectarray bandwidth compared to a flat configuration. Preliminary results show very good performance of the antenna, with a gain of about 28 dBi and an efficiency greater than 50% in the whole 1-dB bandwidth of 13.4%.**

***Index Terms*—reflectarray, folded reflectarrays, 3D-printing, additive manufacturing.**

I. Introduction

Many upcoming applications require antenna systems that offer broadband and beam scanning radiating performance, while also being low in complexity, manufacturing costs, and volume. This makes them easier to integrate into the infrastructure where they need to be mounted. In this framework, reflectarrays (RAs) [1], [2] have emerged as a potential alternative to conventional reflectors or phased arrays due to their ability to meet these requirements. While significant efforts have been made in the past to improve the radiating capabilities of RAs and overcome some of their limitations, such as reduced bandwidth, less attention has been paid to designing more compact configurations. Using a folded reflectarray (FRA) [3] can solve this problem since it consists of a feed antenna, a planar polarizing grid, and a planar reflectarray that acts as a polarization-twist reflector and introduces the desired phase delay. A folded reflectarray can offer at least half the thickness of a conventional RA with the same focal ratio but at the cost of a narrower bandwidth.

In this paper, we propose a folded reflectarray that uses fully dielectric reradiating elements [4], [5] and a spherical plastic metalized polarizer [6], allowing for low-cost manufacturing using 3D printers in case of a moderate number of samples. The RA unit cell consists of a dielectric resonator made from a material with a high dielectric constant to minimize thickness. Its shape provides the desired phase shift between the incident and reflected field and twists the field polarization by 90°. Dielectric reradiating elements have shown low sensitivity to the frequency, which guarantees bandwidth enhancement. The spherical polarizer also contributes to enlarging the antenna frequency band by allowing a smaller variation of the path length from the feed to the different elements of the reflectarray. The proposed RA design takes into account manufacturing constraints, especially when using materials with high dielectric constants.

The dielectric element is first introduced and described in Sect. II, including the design and additive manufacturing aspects related to its realization. In Sect. III, the project of a circular folded reflectarray operating in Ku-band is presented, and its radiation performance is investigated through its numerical analysis. Finally, in Sect. IV some closing remarks are summarized.

II. Dielectric Unit Cell

The proposed RA unit cell is a fully dielectric element (except for the ground plane) composed of a rectangular dielectric resonator built at the top of a thin substrate, as shown in Fig. 1. The unit cell must ensure sufficient phase coverage for achieving the desired phase shift between the incident and the reflected field and also to twist the field polarization of 90 degrees. For this reason, two geometrical parameters must be independently varied, as the sizes L_x and L_y of the parallelepiped (see Fig. 1). The behavior of the unit cell is sketched in Fig. 2 and summarized in the following. The field E_i is reflected by the polarizer and impinges on the unit cell tilted of 45° with respect to the two sides of the parallelepiped; the vector field is therefore decomposed into the two components E_0 parallel to the parallelepiped sides. Each of them is affected separately by L_x or L_y in such a way that the reflected field components present the desired phase delay and the same phase delay plus an additional

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180° phase shift, respectively. Such a unit cell can be conveniently manufactured through Additive Manufacturing (AM) techniques, such as the Fused Deposition Modeling (FDM). To minimize the unit-cell dimensions, the choice of filaments with high relative dielectric constant and low losses is particularly convenient. As an example, results obtained in the case in which the chosen material is PREPERM® ABS1000 ($\varepsilon = 10$, $\tan\delta = 0.004$) are summarized in the following. The unit cell has been designed to operate in Ku-band, and precisely at 17 GHz. After an optimization process, the unit cell results in a periodicity $P_x = P_y$ =8.57 mm, heights of the substrate (H_s) and of the rectangular block (H_b) equal to to $H_s = 1.0$ mm and $H_b = 2.4$ mm, respectively, corresponding in a total thickness $H_{tot} = 3.4$ mm $= 0.19\lambda_0$, being λ_0 the wavelength in free-space at 17 GHz. Both the L_x and L_y of the resonator (Fig. 1) are varied between $L_{min} = 2.5$ mm to $L_{max} = 8.5$ mm. The dielectric cell has been numerically simulated using the Floquet analysis in CST MW Studio and considering a normal incidence at 17 GHz. To design the proper element distribution on the reflectarray surface, the reflection coefficient has been calculated varying independently L_x and L_y for both the principal field components. Fig. 3 shows the amplitude and phase of the reflection coefficient as a function of the side L_y for $L_x = 2.5$ mm and for different frequencies, evaluated for y-polarized electric field. The magnitude remains no lower than -0.8 dB for most of the L_y range except for a strong decrease around 7.8 mm. For what concerns the phase, the curves for 15 and 16 GHz exhibit a phase coverage of less than 200°, whereas the remaining curves show a variation of 500°.

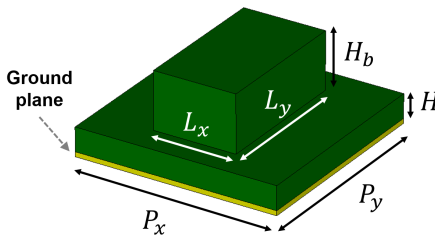

Fig. 1. Dielectric unit-cell with rectangular dielectric resonator for Folded reflectarrays.

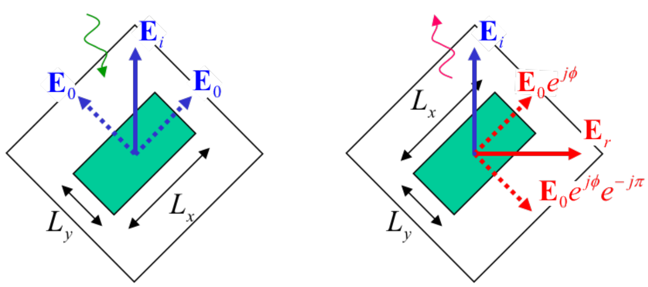

Fig. 2. Sketch of the unit cell behavior.

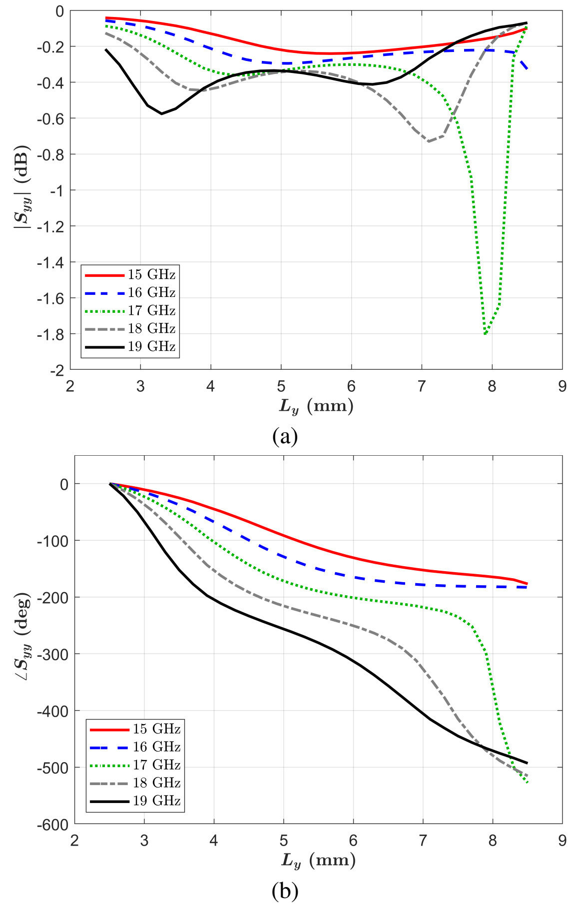

Fig. 3. (a) Magnitude $|S_{yy}|$ and (b) phase $\angle S_{yy}$ of the reflection coefficient versus the size L_y of the rectangular dielectric element for different frequencies, computed for $L_x = 2.5$ mm when a plane wave with an y-polarized electric field orthogonally impinges on the element embedded in a periodic lattice with period $P_x = P_y$ =8.57 mm.

Notice that, during the design process, some of the constraints introduced by the manufacturing technique have been taken into account. In particular, the size of the nozzle, which cannot be smaller than 4 mm because of the viscosity of the material, does not allow to vary continuously the side of the unit cell, and this increases the error on the phase delay and the relative shift it can provide. Moreover, the presence of (small) air bubbles formed during manufacturing, which cannot be avoided, could strongly modify the dielectric properties of the fused material, with consequent malfunctioning of the RA. To reduce this effect, an accurate a priori characterization of the material is necessary.

III. Folded Dielectric Reflectarray Design

Adopting the unit cell introduced in the previous section, a folded dielectric reflectarray has been designed. The structure has a circular shape, with diameter $D = 188.5$ mm $= 10.7\lambda_0$ and it is composed of 408 dielectric unit cells. The antenna is fed with a circular waveguide that is characterized by a radius of 5.9 mm. The calculation of the required phase distribution and the design of the spherical polarizer has been carried out

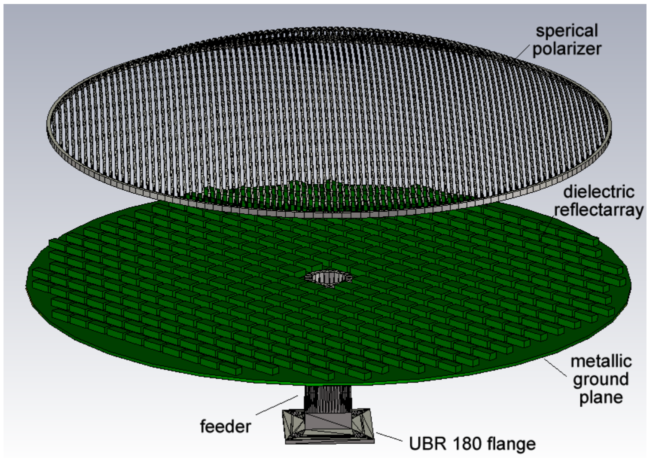

Fig. 4. 3D model of the designed Folded dielectric reflectarray with a spherical polarizing grid and a circular waveguide as a feed.

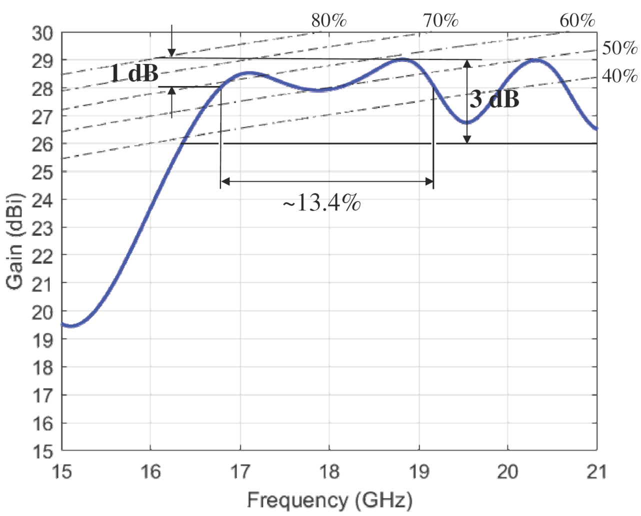

Fig. 5. Gain and aperture efficiency versus frequency.

following the method and design procedure described in [6]. The spherical polarizer has a curvature radius of 197.5 mm and its vertex is located at 77.5 mm from the RA surface, which corresponds to an equivalent $F/D \sim 0.82$.

The 3D model of the entire FRA is shown in Fig. 4 and it has been simulated with the time domain solver of CST MW Studio® on an Intel(R) Xeon(R) CPU E5-2637 v4 @ 3.50GHz 4 core (116661552 mesh cells, 138GB peak memory, 9h54m21s CPU time).

Fig. 5 shows the gain of the entire antenna versus frequency. In the same plot, several dash lines are drawn, corresponding to the indicated (percent) values for the aperture efficiency. The computed gain at 17 GHz is equal to 28.5 dBi, which corresponds to a very high aperture efficiency of 61.2%. As expected, the use of the spherical polarizer and of the dielectric reflectarray enhances the bandwidth: in fact, from the simulation, it emerges that the 1-dB and 3-dB gain bandwidths are equal to the 13.4% and 29.3%, respectively.

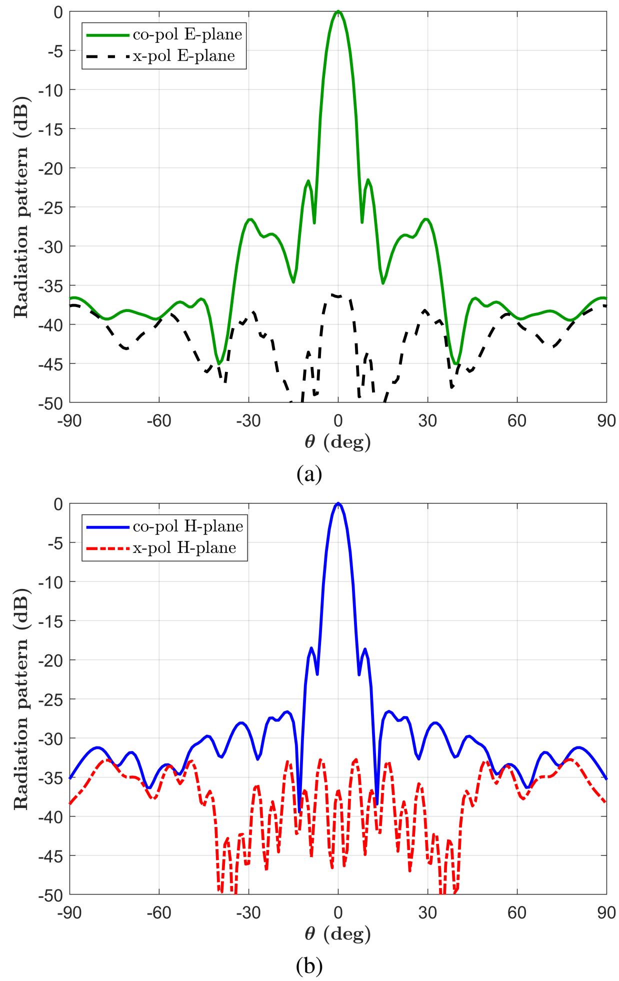

Fig. 6. Computed co-polar and cross-polar components of the radiation pattern in the E-plane (a) and H-plane(b), at 17 GHz.

The simulated co-polar and cross-polar components of the radiation pattern in E- and H-plane are shown in Fig. 6a and 6b, respectively. The beam in the E-plane is characterized by an HPBW of 6.1°, while in the H-plane is about 5.6°. In both the principal planes, the Side-Lobe-Level (SLL) is good, achieving -18.6 dB in E-plane and -21.6 dB in H-plane. The maximum cross-polarization level is -36.2 dB and -32.7 dB in the E-plane and H-plane, respectively.

IV. Conclusion

In this work, a dielectric RA unit cell based on a rectangular dielectric resonator is used in conjunction with a spherical polarizer to design a circular and center-fed folded reflectarray working in Ku-band. Some preliminary results of the unit cell analysis and the RA radiation performance are presented. They demonstrate the effectiveness of the proposed configuration that combines the improvements gained from the use of a spherical polarizer and the dielectric unit cell. The major relevant features of the proposed folded RA are the aperture efficiency, reaching 61.2%, and the 1-dB (13.4%) and 3-dB (29.3%) gain bandwidths. The future activity will focus on the aspects involving the manufacturing of a prototype using FDM techniques and its experimental characterization. In particular, we expect that the fused material has a dielectric constant of about 10% lower than the nominal value. At the congress time, the results of several measures for different materials and printing settings will be presented.

Acknowledgment

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