High-efficiency Reflectarray Using Dielectric Resonator Elements

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***Abstract*—In this paper, a dielectric resonator-based unit-cell is used to design a reflectarray antenna with improved efficiency. The unit-cell is a dielectric structure composed of a cylindrical element placed on a squared base having a ground plane at the bottom. The diameter of the cylinder is the parameter chosen for controlling the phase of the reflection coefficient. To verify its effectiveness, the proposed cell is employed to design a Ka-band offset reflectarray consisting in 52×52 elements. Simulated results show that the antenna is able to achieve a maximum gain of 32.3 dBi at 30 GHz, corresponding to an aperture efficiency of 55%.**

I. Introduction

Most of the modern microwave and millimeter-waves communication systems require high-gain antennas. Examples where they are used are radar systems, satellite communication, remote sensing systems, point-to-point terrestrial links or deep-space communication links. Combining the best characteristics of arrays and reflector antennas, Reflectarrays (RAs) have emerged in the last years as a successful solution for realizing high-gain antennas. A reflectarray is a structure consisting in a (quasi-)periodic array of reflecting elements, illuminated by one or several feed source(s). Each element of the array, usually called Unit-Cell (UC), is designed to produce a phase shift that compensates for the differences among the path lengths between the feed and each re-radiating element itself [1]. The phase that each RA unit-cell must provide is obtained through an appropriate choice of its geometrical parameters.

Reflectarray unit-cells are tipycally realized with microstrip technology: metallic elements are printed on one [2], [3] or more [4] dielectric substrates. Recently other realization techniques have been investigated as an alternative to the conventional microstrip RAs. An attractive solution is the possibility to develop, except for the ground plane, a completely dielectric unit-cell, where the reflection coefficient can be controlled using circular [5] or square [6] holes, variable-height elements [7] or exploiting dielectric resonator elements [8]–[10]. The main advantage of these solutions is that they can be fabricated adopting Additive Manufacturing (AM) processes.

This paper proposes the design of a Ka-band reflectarray using a dielectric unit-cell with a cylindrical dielectric resonator mounted on a thin dielectric substrate. The unit-cell is firstly introduced and described, then some results on the possibility to control the reflection coefficient varying the cylinder diameter are presented. Finally, the simulated radiation features of a $15.6\lambda \times 15.6\lambda$ offset reflectarray designed using the proposed UC are discussed.

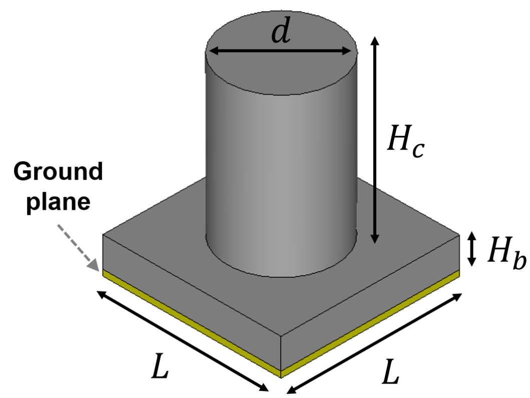

Fig. 1: RA dielectric unit-cell with cylindrical elements.

II. Dielectric Unit-cell

The proposed RA unit-cell is shown in Fig. 1: over the metallic ground plane a thin dielectric layer is laid and over it a cylindrical element is placed. Being completely dielectric (apart from the ground plane), this cell could be manufactured using AM techniques, as the Fused Deposition Modeling (FDM). Among the various material available for FDM printers, there are ABS material filaments, that could even have a quite high relative dielectric constant ($\varepsilon_r \leq 10$), and this is particularly suitable for the proposed UC, since it allows to reduce the size of the resonator. Examples of such filament materials employed for the realization of reflectarrays or lenses can be found in [10] and [11]. In view of these considerations, the material chosen for the present purpose is the PREPERM® ABS1000, characterized by a nominal permittivity of $\varepsilon_r = 10$ and tan$\delta = 0.004$.

The RA unit-cell is designed to work in Ka-band, at the central frequency $f_0 = 30$ GHz. The geometrical parameters have been optimized to obtain a sufficient phase coverage and to reduce the presence of the strong resonances. The final configuration has a periodicity $L = 0.3\lambda_0 = 3$ mm, while the heights of the base and of the cylinder are $H_b = 0.5$ mm and $H_c = 2.6$ mm, respectively. The diameter d of the cylinder can vary in the range from 0.4 mm to 2.8 mm to control the phase of the reflection coefficient. The UC analysis has been

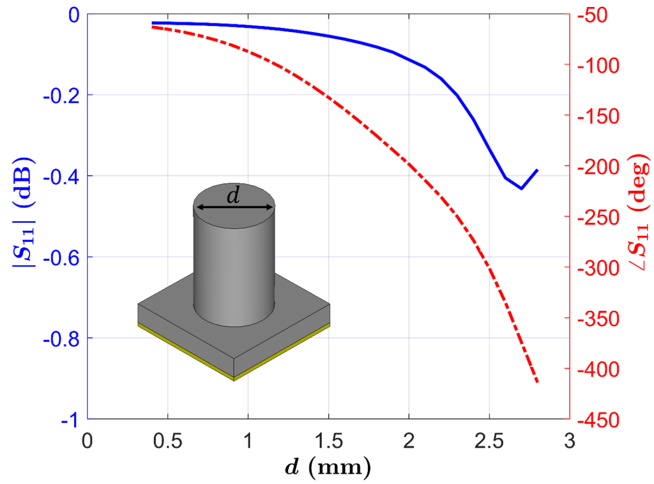

Fig. 2: Amplitude and phase of the simulated reflection coefficient S_{11} (at 30 GHz) as a function of d.

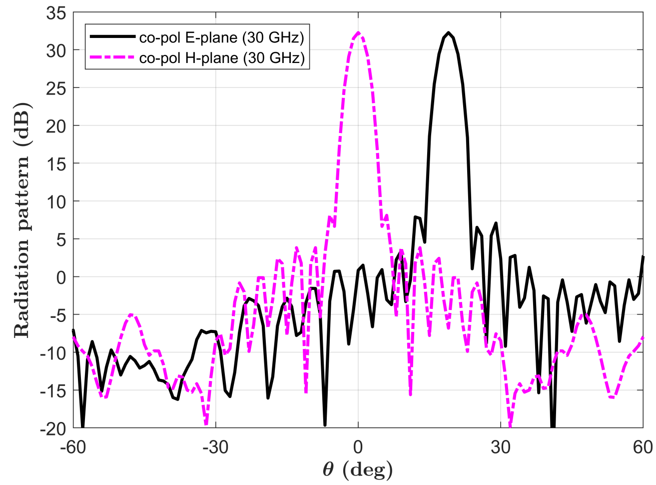

Fig. 3: Numerically evaluated radiation patterns in E-plane and H-plane at 30 GHz.

carried out using CST MW Studio®. The reflection coefficient resulting amplitude ($|S_{11}|$) and phase ($\angle S_{11}$), computed at 30 GHz, are shown in Fig. 2 as a function of the diameter d. The value of $|S_{11}|$ remains higher then -0.5 dB for the whole interval, while the curve of $\angle S_{11}$ provides a phase coverage of 351°.

III. Reflectarray design

The unit-cell presented in the previous section has been adopted to design an offset reflectarray working at 30 GHz in Ka-band. The RA is a square array of 52×52 and it has a size of $D = 15.6\lambda_0 = 156$ mm. The array is illuminated by a 3D-printed conical horn optimized to work in in Ka-band [12] that presents a gain of 14.4 dB at 30 GHz and half-power beamwidths (HPBW) in E-plane and H-plane of 25.4° and 25.1°, respectively. The horn is placed at a focal distance of F =186 mm ($F/D \simeq 1.2$) from the RA surface and with an offset angle of -20° respect to the normal direction to reduce the blockage. The required phase compensation of each cell has been chosen to obtain a pointing direction defined by $\theta_{max}20°$ and $\varphi_{max} = 0°$.

The radiation performance of the dielectric reflectarray has been numerically analyzed using CST MW Studio®. The RA provides a gain of 32.3 dBi at 30 GHz that corresponds to an aperture efficiency of 55%. The obtained 1-dB Gain bandwidth is 14.6%. The simulated radiation patterns in E-plane and H-plane are shown in Fig. 3. The HPBW in E-plane is 4.1°, while in H-plane is about 3.9°. The Side-Lobe-Level (SLL) is -24.3 dB and -24.1 dB, for E-plane and H-plane, respectively.

IV. Conclusion

In this work, the design of a medium-sized dielectric reflectarray whose unit-cells consists in a cylinder with variable diameter mounted on a thin square dielectric layer, is proposed. Some preliminary results on the unit-cell analysis and the RA radiation performance are presented. In particular, the antenna provides a gain of 32.3 dBi at 30 GHz, and a 1-dB gain bandwidth of 14.6%. The major improvement of the proposed RA is the aperture efficiency, achieving 55%. The future activity will focus on the aspects involving the manufacturing of a prototype using AM techniques and its experimental characterization.

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