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Circularly Polarized Huygens Source Antenna Based on Two Stacked Dielectric Resonators

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Abstract—In this paper, a cross-shaped dielectric resonator antenna arranged in a stacked configuration is proposed to realize a Huygens source in circular polarization at 2.45 GHz ISM band. The antenna principle relies on the combination of two pairs of orthogonal electric and magnetic dipoles. The antenna is designed and optimized with numerical analysis using far-field simulations in Ansys HFSS. It finally has a radiation pattern oriented in one half-space without the use of a ground plane.

Index Terms—Dielectric resonator antenna, Huygens source, circular polarization, half-space radiation.

I. INTRODUCTION

The interest in small-size autonomous platforms is growing rapidly. UAVs are, for instance, more and more used in the fields of media, agriculture, and industry. Another example concerns the space industry where nanosatellites could yield a significant reduction in the launching and operation costs. These two applications share the common constraint of embedding complex systems without a large metallic plate for antenna support.

This integration constraint is important for antenna design in terms of size, polarization and radiation pattern. Such pattern requires improved radiation properties in the forward direction and low backward radiation despite the lack of a ground plane. These requirements can be satisfied by designing a Huygens source, *i.e.*, an antenna with a half-space radiation pattern.

Based on works related to magneto-electrical sources to obtain circular polarization (CP) [1], and a Huygens source radiation pattern [2], some antennas with cardioid radiation pattern and CP properties have been proposed [3][4][5].

In a previous paper [6], the authors have presented a single-fed linearly polarized Huygens source antenna based on stacked dielectric resonators (DRs). As a new contribution, we present an original solution to design a Huygens source in CP. It consists of a cross-shaped antenna made of two stacked rectangular DRs with different electrical and physical properties.

II. ANTENNA PRINCIPLE AND DESIGN

A. Antenna principle

The antenna principle to design a Huygens source in CP relies on the orthogonal combination of two linearly polarized Huygens sources. According to the coordinate system shown in Fig. 1, the first Huygens source which is linearly polarized

along the xz -plane, is due to the TE_{111}^x and quasi- TM_{111}^y modes in the DR, which radiate a magnetic and electric radiation pattern-like, respectively [7]. The quasi- TM_{111}^y is denoted here in reference to the corresponding cylindrical resonator mode. On the other hand, the second Huygens source which is linearly polarized along the yz -plane, is generated by the TE_{111}^y and quasi- TM_{111}^x modes in the DR.

B. Dielectric resonator antenna design

The dielectric resonator antenna (DRA) at $f_0 = 2.45$ GHz ISM band is designed to realize a Huygens source pattern, both theoretically using the dielectric waveguide model (DWM) [7] and numerically using eigen mode analysis in Ansys HFSS. The cross-shaped antenna is made up of two stacked DRs, as shown in Fig. 1. The stacked cross-shaped DR is fed using two coaxial probes 90° out of phase to excite the TE_{111}^x and TE_{111}^y modes with the required phase difference in order to achieve CP. In addition to that, the quasi- TM_{111}^x and quasi- TM_{111}^y modes are excited using the electric field distribution of the x -directed and y -directed magnetic dipoles, respectively. Here, a proper frequency shift between TE and quasi-TM modes allows to satisfy the requirements to obtain CP. This frequency shift is accomplished by setting the electrical and physical properties of the stacked DR.

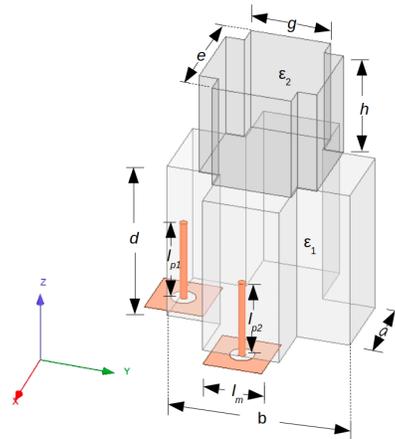


Fig. 1: Stacked cross-shaped DRA.

A parametric analysis of the antenna dimensions is performed in order to adjust the frequency shift between TE and

quasi-TM modes. The electrical and physical properties of the DRs are $a = 13$ mm, $b = d = 31$ mm, $e = h = 20$ mm, $g = 13.5$ mm, $\epsilon_{r1} = 11.5$, and $\epsilon_{r2} = 18$. Finally, the total electrical antenna dimensions are $d + h = 0.41\lambda_0$, and $b = 0.25\lambda_0$. The probes have a diameter of $d_f = 1.23$ mm, and lengths of $l_{p1} = 15.5$ mm and $l_{p2} = 15$ mm. The probes are supported by small metallic plates with square dimensions of $l_m = 0.08\lambda_0$ to ensure the impedance matching. Table I shows the eigen modes for the stacked cross-shaped DRA. As a result, we observe that the desired modes radiate around f_0 .

TABLE I: Resonance frequency (GHz) of the eigen modes in the optimized cross-shaped DR.

| Modes | TE_{111}^x | TM_{111}^x |
|---------------------|--------------|--------------|
| Resonance frequency | 2.35 | 2.72 |

III. ANTENNA PERFORMANCES

Fig 2 shows the simulated S_{11} and S_{21} . The antenna has an impedance bandwidth of 21.2% from 2.26 GHz to 2.78 GHz, for a reflection coefficient of $|S_{11}| \leq 10$ dB. Furthermore, a low coupling between the two coaxial probes ensures a good orthogonality between the desired TE and quasi-TM modes.

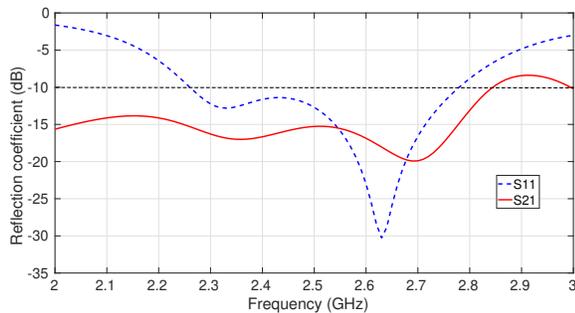


Fig. 2: Simulated reflection coefficient.

The total simulated front-to-back (F/B) and axial ratio (AR) of the antenna are shown in Fig. 3. The Huygens source antenna achieves the largest F/B ratio of 31.8 dB at 2.43 GHz. Besides, the DRA has a F/B ratio bandwidth ($F/B \geq 15$ dB) of 5.3% from 2.38 GHz to 2.51 GHz, and an AR bandwidth ($AR \leq 3$ dB) equal to 22.9% from 2.22 GHz to 2.78 GHz.

Fig. 4 illustrates the simulated radiation patterns of the proposed antenna. It corresponds to a Huygens source. Furthermore, the DRA operates in left-hand CP at 2.45 GHz with a maximum simulated gain at boresight of 5.93 dBi.

IV. CONCLUSION

A stacked cross-shaped DRA has been designed in circular polarization in the 2.45 GHz ISM band to achieve a Huygens source radiation pattern. The methodology relies on the combination of two orthogonal pairs of TE and quasi-TM modes.

The proposed DRA has an impedance bandwidth of 21.2%, and a 3-dB axial ratio bandwidth of 22.9%. Furthermore, it operates in left-hand circular polarization with a maximum simulated gain of 5.93 dBi at 2.45 GHz.

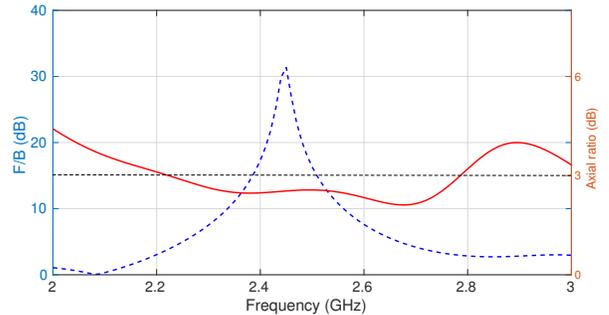


Fig. 3: Simulated front-to-back and axial ratios.

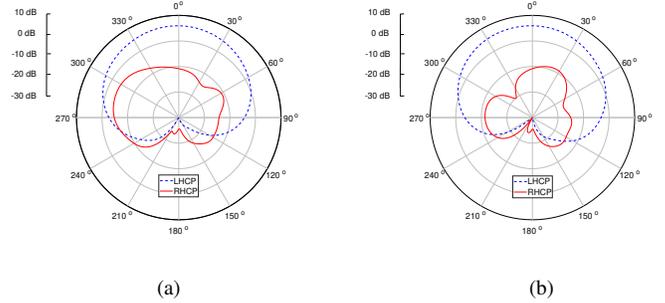


Fig. 4: Simulated total antenna gain (dBi) at 2.45 GHz, considering $\phi = 0^\circ$ and $\phi = 90^\circ$.

Due to the need of a heterogeneous dielectric, additive manufacturing can be used to build the proposed antenna. Moreover, in order to manage the permittivity difference between the upper and lower DRs, a periodized structure of several unit cells using 3-D printing of ceramics can be envisaged, as previously done in [8].

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