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Huygens Source Antenna using Stacked Dielectric Resonators

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***Abstract*—In this paper, an antenna made of two dielectric resonators is proposed to realize a Huygens source in linear polarization. The goal is to design an antenna with a radiation pattern oriented in one half-space without the use of ground plane. The principle relies on the combination of two collocated electric and magnetic dipoles at the center frequency of 2.42 GHz. The optimization of the antenna dimensions is performed with numerical analysis using far-field simulations in ANSYS HFSS. As a result, the antenna achieves a front-to-back ratio of 41 dB.**

***Index Terms*—Dielectric Resonator Antenna, Huygens source, front-to-back ratio, half-space radiation.**

I. INTRODUCTION

For satellite-based positioning systems (GNSS) and unmanned aerial vehicle (UAV) aplications, an antenna with a half-space radiation pattern is required. Such pattern has improved radiation properties in the forward direction and low backward radiation. It can be achieved by incorporating reflectors and/or ground planes [1]. However, the antenna size is naturally increased.

Another technique to achieve half-space radiation is to design a Huygens source, i.e. an antenna with cardioid shape pattern. It has been shown in [2] that two complementary antennas made of an electric dipole and the open end of a coaxial line carrying the TE_{11} mode, can provide equal radiation patterns in the E- and H- planes, and in certain conditions of amplitude and phase between both antennas, a Huygens source can be obtained. Recently, some Huygens sources have been proposed using a helical-ring antenna [3] or a dielectric resonator antenna (DRA) [4].

In this paper, we propose an original Huygens source antenna that consists of two stacked dielectric resonators (DRs) with different electric and physical properties. This paper is organized as follows. Section II explains the theory to obtain a Huygens source pattern. Section III shows the methodology used to design the proposed antenna and discusses the antenna performances obtained in simulations.

II. ANTENNA PRINCIPLE

Classical designs on Huygens source combine two elementary antennas radiating same field in their E- and H- planes. To achieve this requirement, two orthogonal electric and magnetic dipoles can be used. It is well-known that the radiation pattern of an electric dipole is a figure-8 and a circle in the E- and H-planes, respectively [2].

Equivalent x-directed magnetic and y-directed electric dipoles can be generated in a rectangular DRA by exciting TE^x_{111} and TM^y_{111} modes, respectively. Both must be collocated at the center frequency f_o to maximize the field in the $+z$-direction and cancel it in the $-z$-direction.

To evaluate the amplitude and phase difference of each mode independently, we analyze the far field radiation of the TE^x_{111} mode in the H-plane at $\phi = 90°$ and the TM^y_{111} mode in the E-plane at $\phi = 0°$.

III. DESIGN AND RESULTS

A. Dielectric Resonator Antenna Design

A Huygens source antenna at $f_o = 2.42$ GHz is designed. It is made of two DRs with different physical values and fed by a single feed probe, as illustrated in Fig. 1.

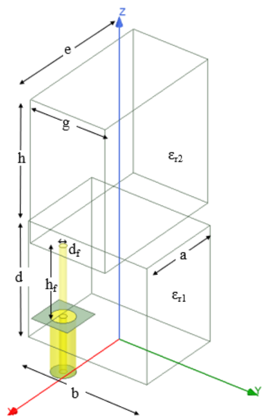

Fig. 1: Proposed antenna.

Two DRs with different permittivities are used to produce both TE^x_{111} and TM^y_{111} modes at f_o. The dimensions of the DR located at the bottom of the structure, namely DR_1, are computed theoretically based on the Dielectric Waveguide Model (DWM) [5]. As first step, we fix $\varepsilon_{r1} = 18$ related to DR_1. As a result, we find $a = 16$ mm, $b = 23$ mm, and $d = 27$ mm. Again, we apply the DWM for DR_2 by fixing $\varepsilon_{r2} = 25$. Finally, we obtain $e = 30$ mm, $g = 14.5$ mm, and $h = 30$ mm.

In order to excite the TE^x_{111} mode, the DR_1 is fed using a coaxial probe. The probe diameter $d_f = 1.23$ mm and height $h_f = 12.8$ mm. The probe is supported by a small patch with square dimensions of $0.06\ \lambda_0$, allowing to achieve the impedance matching. Afterwards, we want to feed the DR_2

using the electric field distribution of the x-directed magnetic dipole. The goal is to excite the TM^{y}_{111} mode to generate an equivalent electric dipole along y-direction with the desired phase difference. The phase difference can be controlled by optimizing the dimensions d related to DR_1 and $e = h$ of DR_2, taking into account that both equivalent dipoles are not collocated due to the relative position of each DR. In addition, the coupling between both DRs produces a frequency shift that can be corrected by optimizing the antenna dimensions.

B. Parametric Study

A parametric analysis of the antenna dimensions is performed in order to compensate the frequency shift due to the coupling between both DRs. The phase difference is calculated from the simulated far-field radiation patterns and corrected using Eigen mode analysis by considering the physical separation of the equivalent dipoles.

A parametric analysis of the dimension d related to DR_1 is performed to maximize the front-to-back (F/B) ratio. It has been observed that an adjustment of the dimension d can improve the F/B ratio. Thus, the final dimension is $d = 21$ mm. Afterwards, the DR_2 is also optimized. Fig. 2 shows the parametric analysis developed for the square dimensions $e = h$. As observed, a maximum F/B ratio at $f_o = 2.42$ GHz can be achieved for $e = h = 26$ mm. Finally, the electrical antenna dimensions are $a = 0.13\ \lambda_0$, $b = 0.19\ \lambda_0$, $d = 0.171\ \lambda_0$, $e = h =\ 0.21\ \lambda_0$, and $g = 0.12\ \lambda_0$.

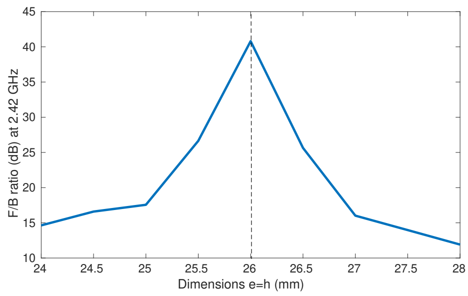

Fig. 2: Variation of the dimensions $d = f$ vs. F/B ratio at 2.42 GHz.

C. Antenna Performances

Fig 3 shows the simulated S11 parameter and F/B ratio of the proposed antenna. The antenna has an impedance bandwidth of 9.5 % from 2.27 GHz to 2.5 GHz, for a reflection coefficient of $\mid S_{11} \mid \geq 10$ dB. Furthermore, the antenna has a F/B ratio bandwidth of 3.3 %, considering a $F/B \geq 15$ dB.

Fig. 4 illustrates the radiation pattern of the proposed antenna. Left figure shows the 3D antenna directivity at 2.42 GHz. Observe that the back radiation is significantly reduced. Right figure depicts the 2D antenna directivity at $\phi = 0°$ and $\phi = 90°$. The antenna has a maximum directivity ($\theta = 0°$) of 6 dBi at 2.42 GHz and a $F/B = 41$ dB.

However, both E- and H-planes of the radiation pattern are not perfectly symmetric. The reason for this behavior is that both equivalent dipoles are not collocated. Moreover, the

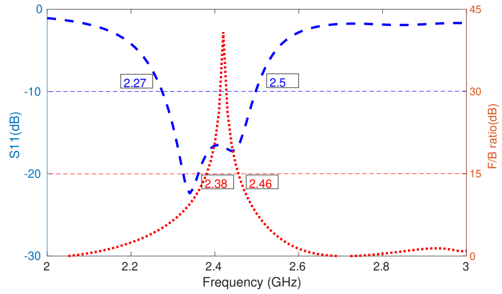

Fig. 3: S11 and F/B ratio of the proposed antenna.

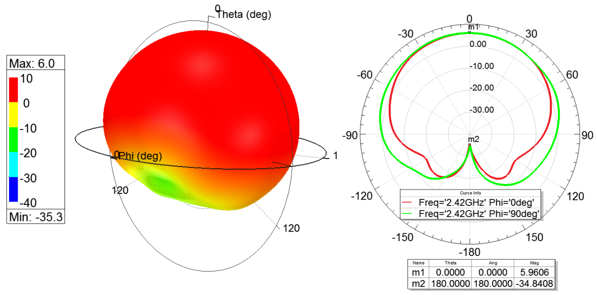

Fig. 4: 3D and 2D total antenna directivity (dBi) at 2.42 GHz.

amplitudes of both TE^{x}_{111} and TM^{y}_{111} modes are not the same because they do not radiate with perfect symmetric E- and H-patterns like elementary dipoles do. Therefore, higher order modes can also radiate.

IV. CONCLUSION

A stacked DRA has been designed to achieve a half-space radiation pattern with no backward radiation, i.e. a Huygens source. The methodology relies on the combination of two electric and magnetic dipoles generated by two rectangular dielectric resonators with different physical and electric properties.

The combination of TE^{x}_{111} and TM^{y}_{111} modes contributes to achieve a half-space radiation without ground plane. The proposed antenna has a F/B ratio of 41 dB at 2.42 GHz with a F/B bandwidth of 3.3 %. In addition, the impedance bandwidth of the stacked DRA is 9.5 %.

Future work will consist in building this antenna using additive manufacturing. This technology can provide new degrees of freedom and flexibility to facilitate the manufacture of both dielectric resonators with different dielectric constants.

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