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To cite this version:

J. de Araujo, Christophe Morales, C. Morlaas, A. Chabory, R. Pascaud, et al.. A Dual-Band Hollow Dielectric Resonator Antenna for GPS Applications. 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Dec 2021, Singapour, Singapore. pp.1177-1178, 10.1109/APS/URSI47566.2021.9704754 . hal-03665747

A Dual-Band Hollow Dielectric Resonator Antenna for GPS Applications

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***Abstract*—This work presents a dual-band hollow rectangular dielectric resonator antenna (DRA) fed by a single coaxial probe, which is designed to operate at the L5 and L1 bands for Global Positioning System (GPS) applications. The dimensions of the dielectric resonator are designed so that each one of its fundamental modes TE$^x_{\delta 11}$ and TE$^y_{1\delta 1}$ resonates at the L5 and L1 bands, respectively. However, the higher-mode TE$^x_{\delta 21}$ may appear at the upper band and, thus, disturbing the radiation characteristics of the TE$^x_{\delta 11}$ mode. To overcome this situation, an air gap is introduced into the DRA to shift this mode away from the L1 band. Also, the reflection coefficient and radiation patterns are simulated and the results show the efficiency of the proposed model.**

I. INTRODUCTION

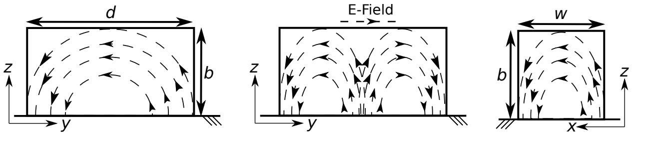
Over the last years, dielectric resonator antennas (DRAs) have been gaining popularity due to their small size, low-conducting losses, high radiation efficiency, potential broadband response, and low cost [1]. Also, DRAs can be excited by different feeding techniques and their high design flexibility allow them to be employed in a variety of applications such as the Global Positioning System (GPS).

Different low-profile antennas have been considered to operate at GPS frequency bands [2], [3]. However some of them present complex structures and feeding techniques, which can be a problem, when the platform presents limited spaces for antennas. In this scenario, DRAs have been extensively investigated and employed due to their aforementioned advantages.

In this letter, we present a single-fed rectangular DRA (RDRA) operating at the L5 (1176.45 MHz ± 10.23 MHz) and L1 (1575.42 MHz ± 10.23 MHz) bands of GPS, where the fundamental TE$^x_{\delta 11}$ and TE$^y_{1\delta 1}$ modes are considered, due to their broadside radiation pattern. However, some undesirable higher-modes can be excited as well, distorting and creating nulls in the aimed radiation pattern. To overcome this issue, a gap is introduced into the DRA and its effect is analyzed and discussed. Besides, Ansys HFSS was used to investigate the reflection coefficients, radiation patterns, and antenna gain.

II. ANTENNA DESIGN AND ANALYSIS

The RDRA is considered to operate at L5 and L1 bands due to its higher degree of freedom than the circular and spherical ones. As the antenna must present similar radiation characteristics at both lower and upper bands, the modes of interest are the fundamental TE$^x_{\delta 11}$ and TE$^y_{1\delta 1}$, since they present broadside radiation patterns, as required for GPS applications.



(a) TE$^x_{\delta 11}$ (b) TE$^x_{\delta 21}$ (c) TE$^y_{1\delta 1}$

Fig. 1. Electric field distribution of the (a) TE$^x_{\delta 11}$, (b) TE$^x_{\delta 21}$, and (c) TE$^y_{1\delta 1}$ modes in an ordinary rectangular DRA.

At first, the dimensions of the DRA are calculated using the Dielectric Waveguide Model (DWM) [4] and the Eigenmode solution of Ansys HFSS. Considering an RDRA over a ground plane, with a dielectric constant ε_r equal to 23, depth $d =$ 53 mm, width $w =$ 23 mm, and height $b =$ 25.5 mm, the TE$^x_{\delta 11}$ and TE$^y_{1\delta 1}$ modes resonate at 1.17 GHz and 1.57 GHz, respectively.

When the fundamental modes are excited by a single probe, some unwanted higher modes may be excited as well. For the aforementioned values, the TE$^x_{\delta 21}$ resonates at 1.58 GHz. As this mode and the TE$^y_{1\delta 1}$ occur around the same frequency, the radiation pattern at the L1 band can be distorted. Therefore, it is necessary to employ some technique to shift the TE$^x_{\delta 21}$ mode away from the L1 band, which can be done by varying the dielectric constant in a given part of the DRA where the electric field is weak for the fundamental modes and strong for the TE$^x_{\delta 21}$ mode. To understand where to vary ε_r, the electric field distribution of each mode must be carefully analyzed and they can be seen in Fig. 1. One can note that the center of the DRA is the best place to decrease ε_r in order to increase the resonance frequency of the TE$^x_{\delta 21}$ mode without affecting that much the fundamental ones.

To effectively increase as much as possible the resonance frequency of the TE$^x_{\delta 21}$ mode, an air gap is introduced into the center of the DRA, as it can be seen in Fig. 2. Also, to understand the behavior of the resonance frequencies of the TE$^x_{\delta 11}$, TE$^y_{1\delta 1}$ and TE$^x_{\delta 21}$, Fig. 3 shows their variation for different values of b_1, considering $\epsilon_r = 23$, $d = 53$ mm, $w = 23$ mm, $b = 25.5$, $d_1 = 15$ mm, $w_1 = 15$ mm, and $D = 200$ mm. We observe that the TE$^x_{\delta 21}$ mode is much more sensible than the fundamental modes when b_1 varies and, thus, the gap can be employed to avoid this higher-mode in a given

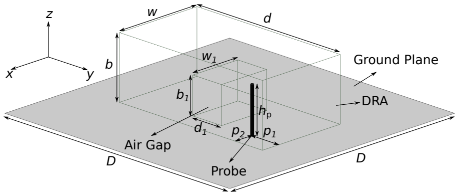


Fig. 2. Perspective view of the hollow RDRA.

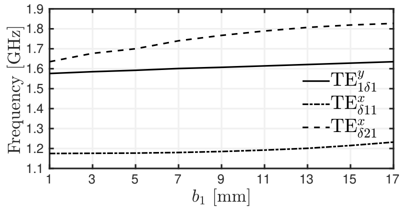


Fig. 3. Curves of resonance frequencies of the $\mathrm{TE}^{x}_{\delta 11}$, $\mathrm{TE}^{y}_{1\delta 1}$, and $\mathrm{TE}^{x}_{\delta 21}$ modes for different values of b_1.

frequency band by decreasing ε_r at the center of the DRA.

Finally, the optimized dimensions of the DRA are, in mm, $d = 54$, $w = 25$, $b = 25.5$, $d_1 = 9$, $w_1 = 20$, $b_1 = 15$, $p_1 = 3$, $p_2 = 2$, $h_{pin} = 17$ and $D = 200$ and ϵ_r is 23. Taking these values into account, the resonance frequencies of the $\mathrm{TE}^{x}_{\delta 11}$, $\mathrm{TE}^{y}_{1\delta 1}$ and $\mathrm{TE}^{x}_{\delta 21}$ modes are 1.17 GHz, 1.57 GHz and 1.79 GHz, respectively. Also, as a matter of comparison, an RDRA without gap was designed as well, where its parameters, in mm, are $d = 53.2$, $w = 22.3$, $b = 25.5$, $p_1 = 3$, $p_2 = 0$, $h_{pin} = 18$, and $D = 200$, and ϵ_r is equal to 23. Fig. 4 shows the reflection coefficient of the DRA with and without the gap, where it is possible to note the resonance at L5 and L1 bands, as expected.

The ϕ- and θ-components of the gain, in dB, at 1.17 GHz and 1.57 GHz at $\phi = 0°$ and $\phi = 90°$ for the DRA with and without the air gap are shown in Fig. 5. The radiation patterns are similar at both lower and upper bands for the hollow DRA with orthogonal polarization as expected, which does not happen for the regular DRA, due to the presence of the $\mathrm{TE}^{x}_{\delta 21}$ at the upper band. To be more specific, at $\phi = 0°$ and 1.57 GHz, the ϕ-component of the gain for the DRA without the gap presents a null for $\theta = 285° \pm 15°$, which creates a blindspot, which is not acceptable for GPS applications, and the direction of the main lobe is shifted to around 30° as well. Thus, the difference between the radiation pattern of the DRAs with and without the gap shows the efficiency of the proposed model.

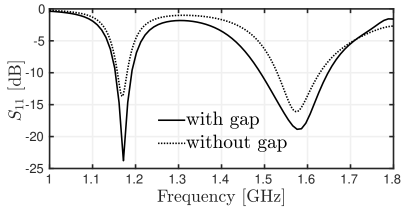
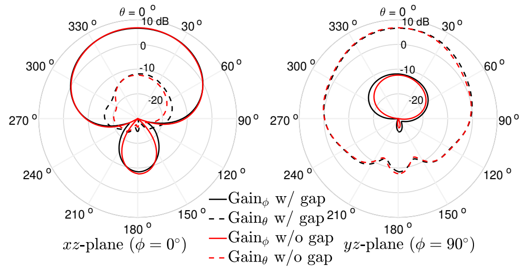
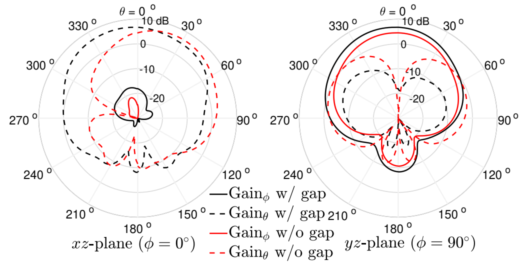


Fig. 4. Simulated reflection coefficient of the proposed DRA on HFSS.



(a) 1.17 GHz



(b) 1.57 GHz

Fig. 5. Simulated radiation patterns at (a) 1.17 GHz and (b) 1.57 GHz of the RDRA with and without the air gap.

III. CONCLUSION

A hollow RDRA with dual-band operating at the L5 and L1 bands of GPS is proposed. The antenna presents an air gap at its center to avoid the presence of the $\mathrm{TE}^{x}_{\delta 21}$ mode, which distorts the expected broadside radiation pattern. Also, the effect of this gap is studied and results such as the reflection coefficient and radiation patterns are compared with the DRA without the gap, showing the efficiency of the proposed method. Future work will consist of dealing with circular polarization and manufacturing the proposed antenna using additive manufacturing, which provides new degrees of freedom and flexibility to design DRAs.

IV. ACKNOWLEDGMENT

This work was supported by the Defense Innovation Agency (AID) of the French Ministry of Defense (Research project CONCORDE N° 2019 65 0090004707501).

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