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RESEARCH ARTICLE

Analysis of via-fed cylindrical dielectric resonator antennas

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Abstract
In this letter, a study of a feeding technique applicable to cylindrical dielectric resonator antennas is presented. The feeding technique analyzed is based on vias glued at the lateral wall of the cylindrical resonator. A series of parametric studies, in terms of the orientation, position and dimensions of the vias, has been carried out to assess the sensitivity to imperfections of the fabrication process on the antenna parameters. In order to validate the computational results, a prototype has been manufactured and measured with a spherical near-field test facility. The results in terms of S-parameters and radiation pattern are presented and good agreement between simulations and measurements has been obtained.

KEYWORDS
antenna feed, CDRA, cylindrical dielectric resonator antenna, cylindrical resonator, DRA

1 | INTRODUCTION

Due to intrinsic characteristics such as small size, high radiation efficiency, small conductive losses and easy fabrication, dielectric resonator antennas (DRAs) have been studied for satellite communication applications.[1-6] DRAs are typically implemented in cylindrical or rectangular shapes. The cylindrical version is normally composed of a dielectric cylinder with height h, radius a and dielectric constant ε_r glued on a ground plane (GND). The resonance frequency is given in terms of h, a and ε_r.[7]

The size of cylindrical dielectric resonator antennas (CDRAs) can be reduced mainly by two methods. The first technique is based on the use of high values of ε_r, with the expense of degrading the bandwidth (*BW*). The second technique consists to introduce a circular metallic disk on the top surface. If the cylinder height h is electrically small, the presence of the metallic top loading reduces the wavenumber along the axial-direction to zero. Thus, the resonance frequency becomes independent of the h dimension.[8]

One of the ways of feeding CDRAs is by means of a metallic via placed near the lateral wall of the dielectric cylinder. To improve power coupling, metallic strips can be inserted between the vias and the lateral wall.[9] To ensure electric connection, the via must be soldered to the strip. Excitation by means of microstrip line can be also combined with a vertical strip by connecting the end of the line and gluing the vertical strip onto the lateral wall of the cylindrical DRA.[10] The use of a conducting strip to feed DRAs is very versatile and has been used for hemispherical[11] and rectangular DRAs.[12] Besides that, the use of metallic strip between the via and antenna eliminates the unwanted air gap that degrades the excitation of the DRA.[13]

The main drawback of the aforementioned technique is the need of gluing the strip to the lateral wall of the DRA, because this can be done only manually, hence introducing errors in the designed antenna geometry. This is further critical because of the soldering process of the via to the strip, because the heat can melt the glue and the position and orientation of the strip can be accidentally modified. Therefore, this letter presents a parametric study of imperfections that may occur during the fabrication process of the use of strips along with vias to feed top-loaded CDRAs. To the authors' knowledge, such a study has not been published in the open literature yet.

2 | ANTENNA GEOMETRY

For this study, the antenna will be considered to be composed of two laminates of Taconic CER-10 with $\varepsilon_r = 10$ and thickness of 3.18 mm that are glued with the prepeg Fast Rise 27 (FR27) with $\varepsilon_r = 2.75$ and thickness of

0.105 mm.[14,15] For the GND, the laminate Taconic RF-60A ($\varepsilon_r = 6.15$ and 0.79-mm thick[16]) was used. The feeding lines are printed at the bottom face of the RF-60A laminate and the wave-ports (excitation of the ANSYS HFSS model) are located inside the SMA connectors. The coupling between the feeding lines and the resonator is made by metallic vias, as detailed in Figure 1. To improve power coupling, metallic strips have been glued onto the lateral surface of the cylinder with cyanoacrylate glue ($\varepsilon_r = 2.7$[17]). The vias touch the strips in the electromagnetic model. In the prototype, the vias must be soldered to the respective strips.

An initial estimate for the radius of the CDRA for operation at the dominant mode (TM^z_{11}) can be obtained using[8]

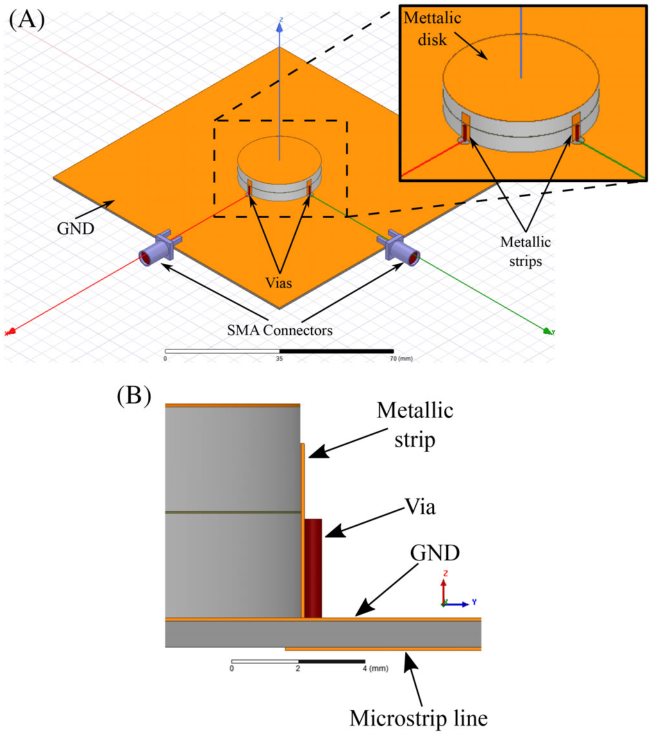

FIGURE 1 Simulation model of the cylindrical dielectric resonator antenna [Color figure can be viewed at wileyonlinelibrary.com]

$$a = \frac{\chi'_{11}}{\omega\sqrt{\mu_0\varepsilon_0\varepsilon_r}} \tag{1}$$

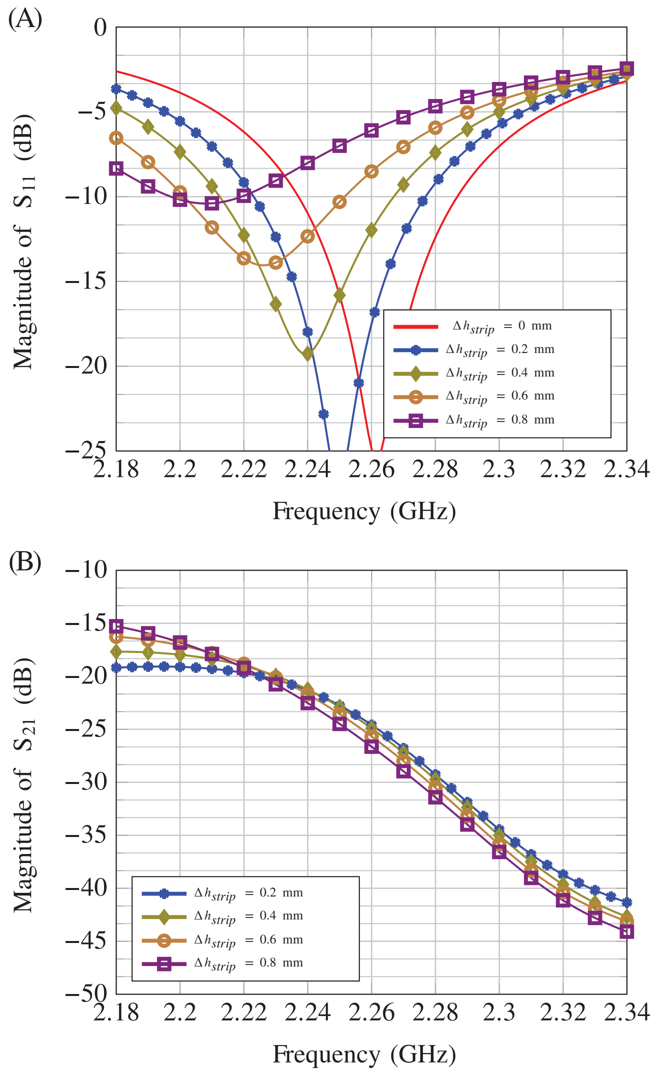

FIGURE 3 Influence of the strip height increment on the S-parameters for $h_{strip} = 5.50$, $w_{strip} = 2.00$, $h_{via} = 3.00$, $\Delta z = \Delta x = 0$ (all dimensions in millimeters) [Color figure can be viewed at wileyonlinelibrary.com]

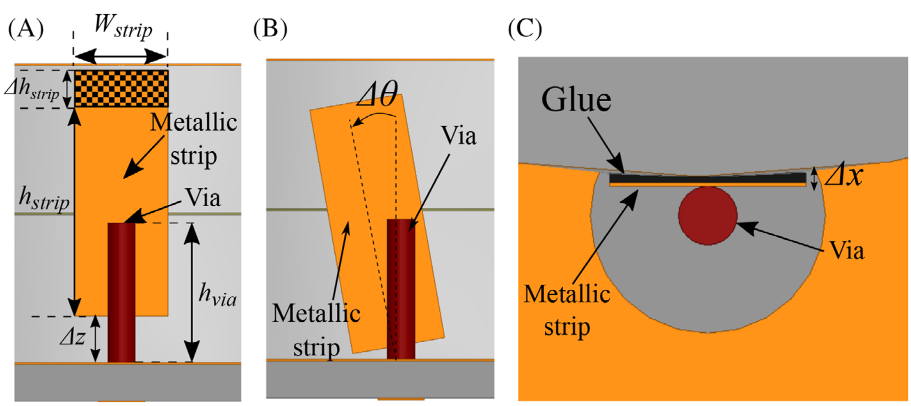

FIGURE 2 Variables for the parametric studies of the cylindrical dielectric resonator antenna [Color figure can be viewed at wileyonlinelibrary.com]

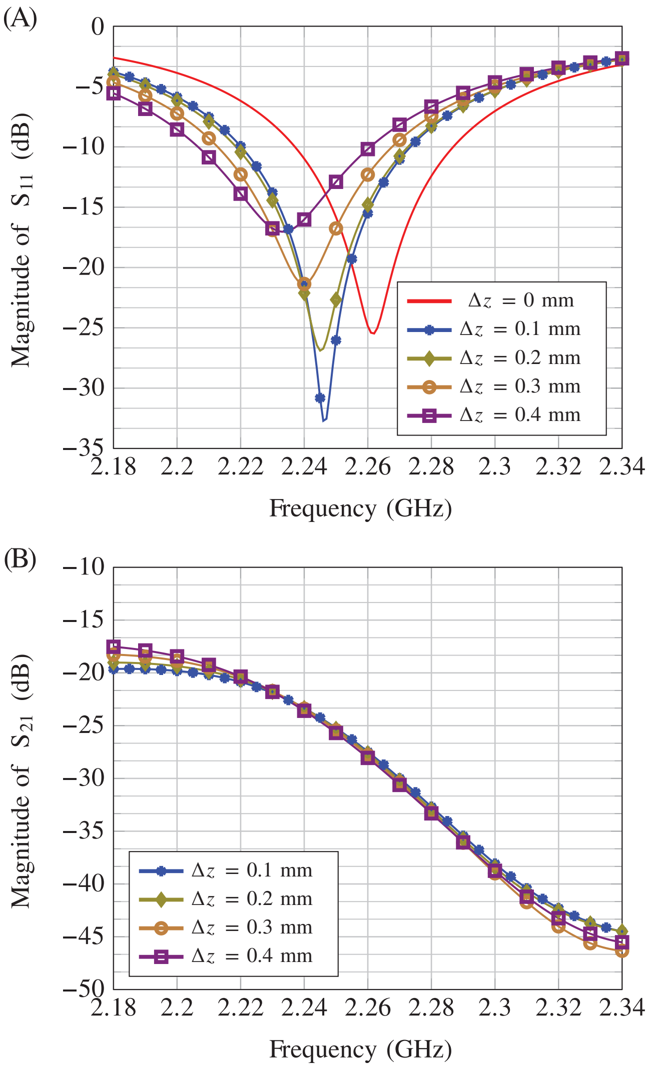

FIGURE 4 Influence of the metallic strip position on the S-parameters for $h_{\text{strip}} = 5.50$, $w_{\text{strip}} = 2.00$, $h_{\text{via}} = 3.00$, $\Delta h_{\text{strip}} = \Delta\theta = \Delta x = 0$ (all dimensions in millimeters) [Color figure can be viewed at wileyonlinelibrary.com]

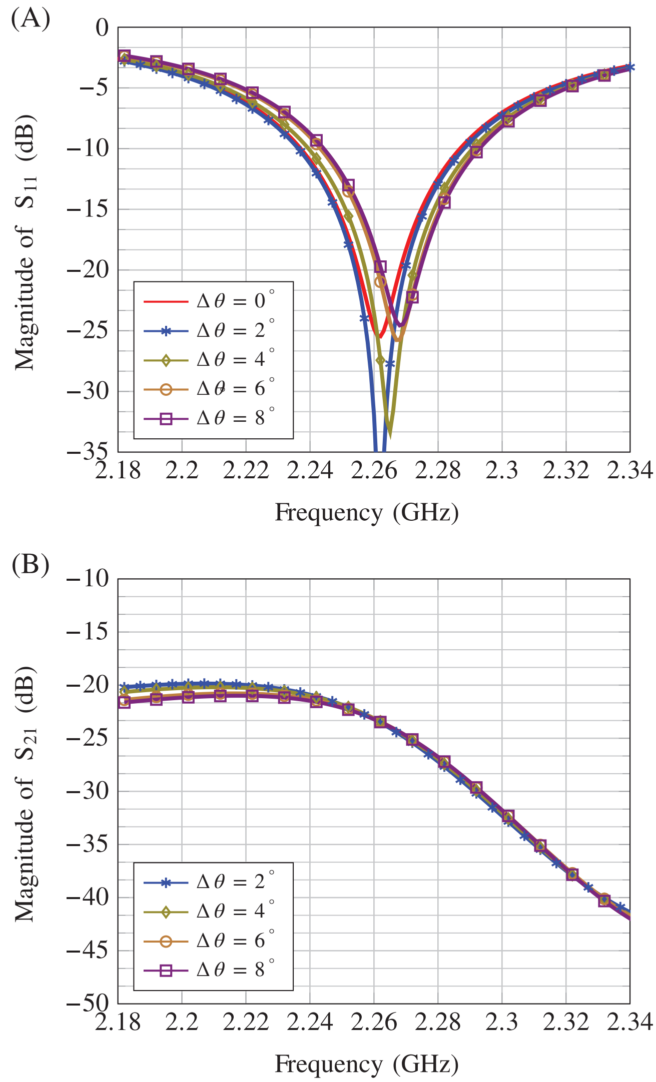

FIGURE 5 Influence of the metallic strip orientation on the S-parameters for $h_{\text{strip}} = 5.50$, $w_{\text{strip}} = 2.00$, $h_{\text{via}} = 3.00$, $\Delta z = \Delta h_{\text{strip}} = \Delta x = 0$ (all dimensions in millimeters) [Color figure can be viewed at wileyonlinelibrary.com]

where χ'_{11} represents the first zero of the derivative of the Bessel function of the first kind and $\omega = 2\pi f$. The strip height h_{strip} can be used to fine tune the antenna resonance frequency and for impedance matching. For operation at 2.26 GHz (useful for satellite communications), the optimum dimensions are $a = 13.00$ mm, $h = 6.36$ mm, $h_{\text{strip}} = 5.50$ mm, $w_{\text{strip}} = 2.00$ mm and $h_{\text{via}} = 3.00$ mm. The size of the GND is $90 \times 90\ \text{mm}^2$.

3 | PARAMETRIC ANALYSIS

As mentioned in Section 1, due to the fabrication process, the metallic strips may not be precisely positioned as in the simulation model. Therefore, in order to assess the influence of the position, orientation and dimensions of the metallic strips on the antenna parameters, a parametric study has been carried out. In Figure 2, the considered variables are indicated, namely the strip position (Δh), the strip length increment (Δh_{strip}), the inclination ($\Delta\theta$) and the thickness of the glue layer (Δx). Such analysis is important for antenna design and should be known in advance to estimate the influence of fabrication tolerances onto the antenna performance.

The first analysis takes into account the variation of the strip height increment Δh_{strip}. The curves are shown in Figure 3, where one can see that longer strips will lead the resonance to lower frequencies. This parameter can be used during the design process to fine tune the antenna resonance frequency. However, larger frequency displacements cannot be achieved with this parameter alone, since the impedance matching degrades and the resonance frequency is strongly governed by the DRA radius a and by the used dielectric constant ε_r. The coupling between the two ports is not strongly affected by Δh_{strip}.

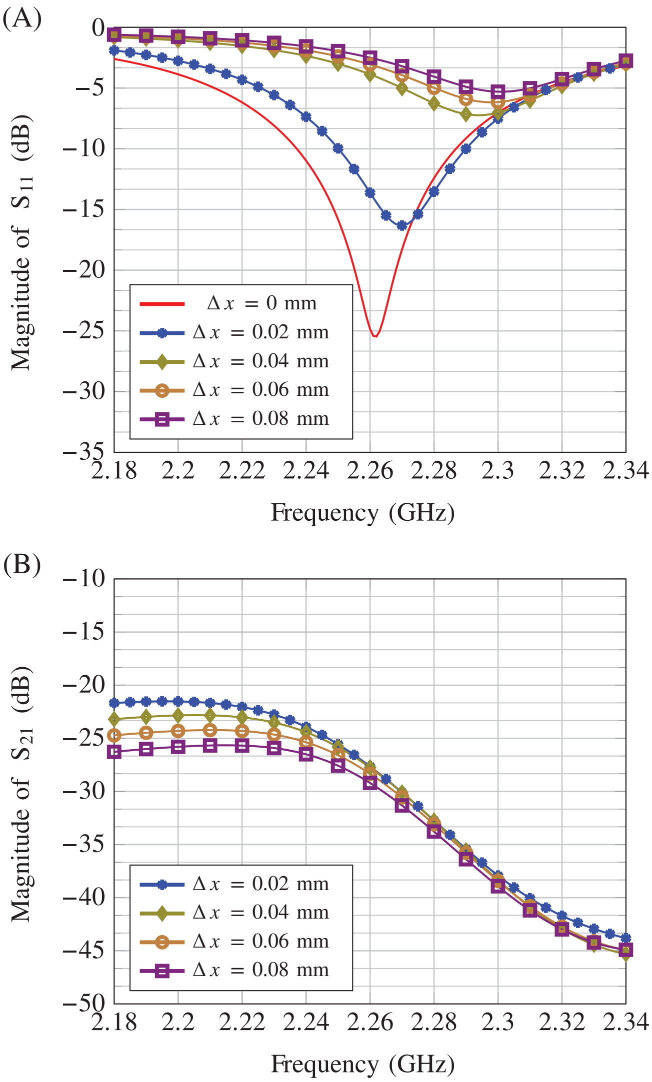

FIGURE 6 Influence of the glue thickness on the S-parameters for $h_{strip} = 5.50$, $w_{strip} = 2.00$, $h_{via} = 3.00$, $\Delta z = \Delta h_{strip} = \Delta\theta = 0$ (all dimensions in millimeters) [Color figure can be viewed at wileyonlinelibrary.com]

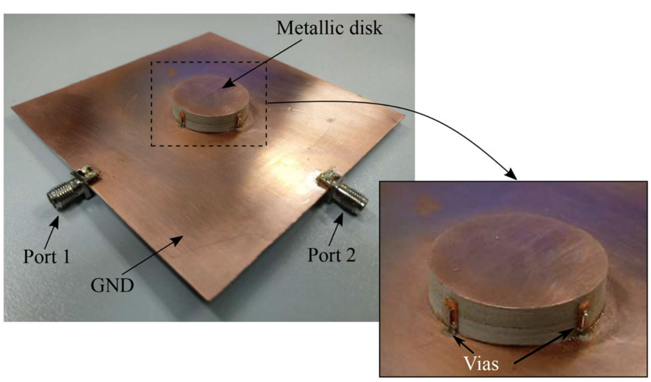

FIGURE 7 Prototype of the dual-fed cylindrical dielectric resonator antenna [Color figure can be viewed at wileyonlinelibrary.com]

The second analysis is done by varying the strip position (Δz) related to the GND. The simulation results are shown in Figure 4, where it is demonstrated that the resonance frequency is shifted toward lower frequencies by increasing the separation between the metallic strip and the GND. This has a similar effect as the parameter Δh_{strip}, since the effective length of the strip is increased as Δz is made larger.

By varying the orientation of the strip ($\Delta\theta$) related to the via, the results are shown in Figure 5. It is verified that changes in the orientation shift the resonance only slightly toward higher frequencies. For exciting the dominant mode TM^z_{11}, the parameter $\Delta\theta$ should be kept as close as possible to zero.

The fourth variable is the thickness of the glue Δx used to attach the strip to the dielectric cylinder. By inspecting Figure 6, this parameter seems to be very critical for both resonance frequency and impedance matching, since only very small variations may produce strong deviations in the S-parameters. From the results, it can be verified that the antenna cannot be accurately modeled without including the glue layer in the simulation model, although its thickness cannot be controlled precisely during manufacturing.

4 | RADIATION OF CIRCULAR POLARIZATION

A prototype of the CDRA has been designed and fabricated for operation at 2.26 GHz and a photo of the prototype is shown in Figure 7. The comparison between measured and simulated S-parameters as a function of the frequency is shown in Figure 8. Based on the parametric analyses presented in the previous section, the simulated curves for $\Delta x = 0.02$ mm, $\Delta z = 0.2$ mm, $\Delta h_{strip} = 0$ and $\Delta\theta = 0$ fit well the experimental curves.

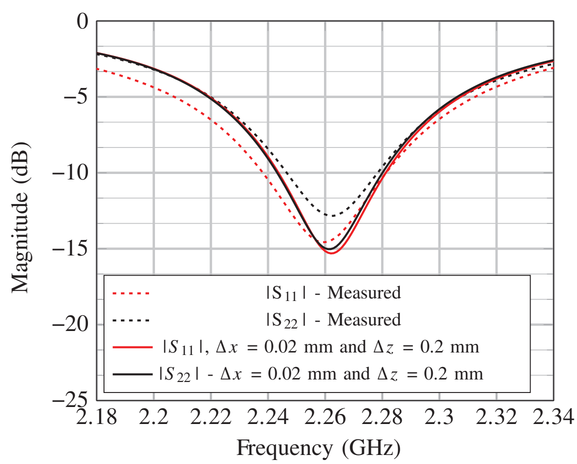

FIGURE 8 Comparison between simulated and measured S-parameters for the dual-fed CDRA. CDRA, cylindrical dielectric resonator antenna [Color figure can be viewed at wileyonlinelibrary.com]

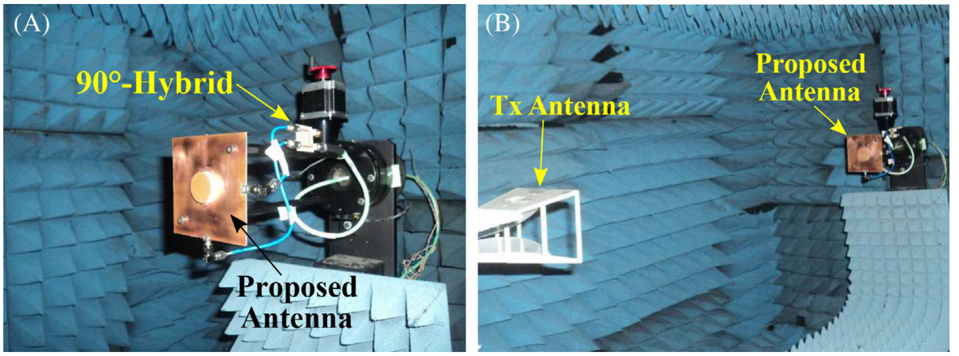

FIGURE 9 Measurement setup with the dual-fed CDRA connected to an external 90°-hybrid. CDRA, cylindrical dielectric resonator antenna [Color figure can be viewed at wileyonlinelibrary.com]

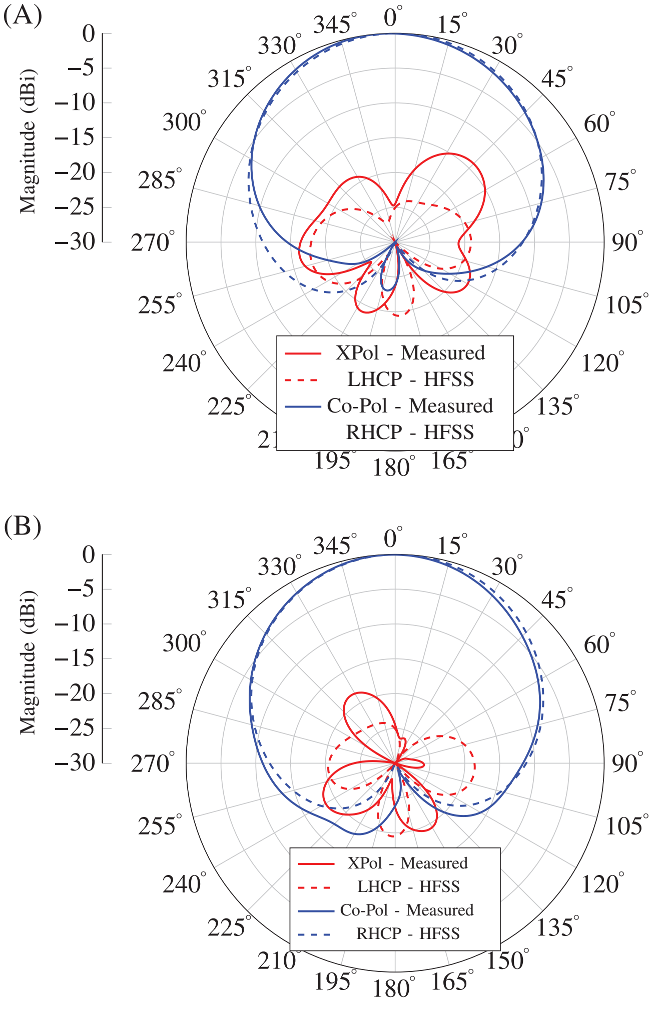

FIGURE 10 Comparison between simulated and measured radiation patterns at 2.26 GHz: A, pattern in the *xy*-plane; B, pattern in the *xz*-plane [Color figure can be viewed at wileyonlinelibrary.com]

In order to test the performance of this antenna to generate circular polarization, the two ports have been connected to an external 90° hybrid. The CDRA prototype installed in the measurement setup is presented in Figure 9. The comparison between measured and simulated radiation patterns in the *xz* and *yz*-planes are shown in Figure 10A,B, respectively. Good agreement for the principal polarization has been obtained in two orthogonal cuts and high cross-polarization decoupling, especially in the boresight, has been obtained.

5 | CONCLUSION

In this letter, an investigation of a feeding technique for CDRA has been presented. A prototype has been manufactured and the sensitivity to fabrication tolerances has been analyzed. The prototype has been designed with two orthogonal ports so as to allow circular polarization, whereby good agreement between simulations and measurements in terms of radiation pattern has been obtained.

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