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Mutual Coupling Reductions of Dielectric Resonator Antennas without Extra Circuits

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***Abstract*— This paper describes an effective strategy to reduce the mutual couplings of dielectric resonator antennas without using extra circuits. The strategy is enabled by etching an elliptical cylinder in a cube-shaped dielectric resonator along its diagonal direction. By optimizing the dimension and location of the elliptical cylinder, the mutual coupling of the orthogonal polarizations of the dielectric resonator antenna can be effectively reduced. For demonstration, a cube-shaped dielectric resonator antenna operating at 5.8 GHz is configured with a proper elliptical cylinder drilled in the right position. The simulated results demonstrate the mutual couplings of the orthogonal polarizations can be reduced to -25 dB from 5.6 to 5.95 GHz, where an average of 8 dB mutual coupling reduction can be obtained compared to the one without the ellipse cylinder drilled. The radiation patterns, realized gains, and total efficiencies of the dielectric resonator antenna with the elliptical cylinder drilled can still be maintained, verifying the effectiveness of the proposed strategy to reduce the mutual coupling.**

Index Terms—Mutual coupling, dielectric resonator, cross-polarization, radiation pattern, total efficiency.

I. INTRODUCTION

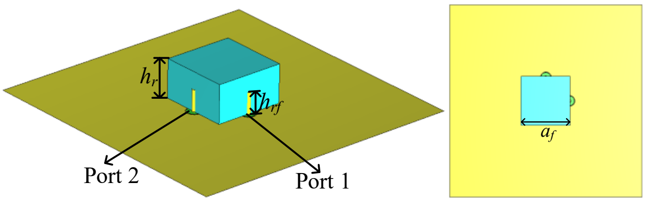
Compared to single-polarized antennas, dual-polarized antennas can offer larger channel capacity and adapt to more harsh electromagnetic environments. One of the concerns of dual-polarized antennas is the mutual coupling of orthogonal polarizations (mutual coupling of two orthogonal ports). A poor mutual coupling indicates that the power from one port directly transmits to the other port, thereby resulting in the low gain and low radiation efficiency of the dual-polarized antenna, which is not allowed for wireless applications.

One of the effective solutions to reduce the mutual coupling of orthogonal polarizations of a dual-polarized antenna is utilizing differential feeding networks to excite the radiating element [1]-[3]. Since the differential feeding technology can inherently cancel the electric fields in the cross-polarization, the mutual coupling of orthogonal polarizations can be significantly reduced. However, the introduction of the differential feeding circuits can increase the total loss and design complexity, especially at the millimeter-wave bands and large-scale antenna array, on the other hand, it also increases the total footprint of the holistic antenna as the differential feeding networks usually need some space to accommodate.

In [4], the authors proposed an effective solution to reduce the mutual coupling of orthogonal polarizations of a dual-polarized and stacked patch antenna without using extra circuits, where a slot was etching along the diagonal direction of the radiating patch. The results presented in [4] revealed that the mutual coupling of orthogonal polarization can be reduced to below -25dB from 4.5 to 5.0 GHz, where an around 8 dB mutual coupling reduction was achieved.

The dielectric resonator is a good candidate to act as the radiating element to implement an antenna that is generally called a dielectric resonator antenna (DRA). As the dielectric constant of the dielectric resonator antenna is relatively high (a typical value is around 10), this makes the total size of a dielectric resonator antenna quite small. Moreover, the bandwidth of a dielectric resonator antenna is usually wider than that of a patch antenna. As a result, DRAs have also been widely utilized in wireless communications. A dual-polarized DRA also holds the issue of the mutual coupling of orthogonal polarizations. The differential feeding networks are also applicable to dual-polarized DRAs to reduce the mutual coupling [5]-[7], but the impacts of the differential feeding networks on the holistic DRA still remain.

This paper describes an effective strategy to reduce the mutual coupling of orthogonal polarizations of a DRA. This strategy is derived from the technology reported in [4], where an ellipse cylinder is drilled in the cube-shaped dielectric resonator along the diagonal direction. The mutual coupling can be controlled by tuning the dimensions of the ellipse cylinder. The simulated results of mutual couplings, radiation patterns, realized gains, and total efficiencies validate the effectiveness of the proposed strategy.



(a) (b)

Fig. 1. The geometry of the DRA for reference. (a). Perspective view. (b). Front view. (a_f= 10.1 mm, h_r = 5.58 mm, h_{rf} = 3.1 mm)

II. DIELECTRIC RESONATOR ANTENNA WITH AN ELLIPSE CYLINDER FOR MUTUAL COUPLING REDUCTION

A. DRA for reference

The geometry of the DRA for reference is shown in Fig. 1, where a cube-shaped dielectric resonator is adopted as the radiating element. The dielectric resonator is characterized by a length of *a*, a width of *b*, and a length of *h*. The dielectric constant and loss tangent of the dielectric resonator are 15 and 0.02, respectively. The dimensions of the cube-shaped dielectric resonator are properly selected to make it resonant at 5.8 GHz. Two probes are attached to the side surfaces to excite the dielectric resonator for radiation as shown in Fig. 1(a). The size of the metal ground is 40 mm x 40 mm. The S-parameter of the DRA is simulated with CST Studio Suite and shown in Fig. 2. As seen in Fig. 2, the DRA can work well from 5.6 to 5.95 GHz with a reflection coefficient below -10 dB, and the mutual coupling of orthogonal polarizations is below -18dB within the entire operating band.

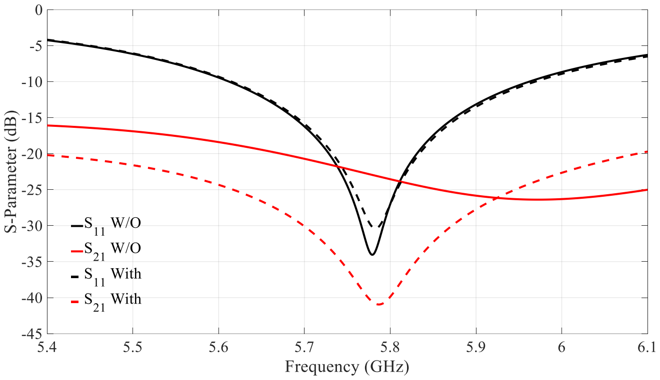
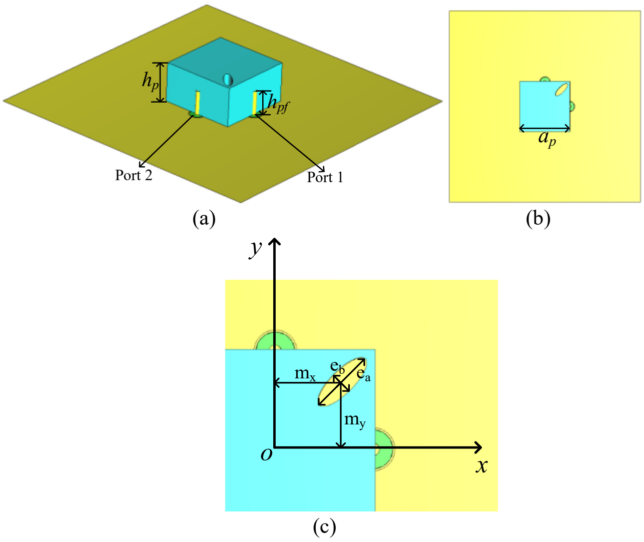


Fig. 2. The S-parameter of the DRA with and without the ellipse cylinder.



(a)

(b)

(c)

Fig. 3. The geometry of the DRA with an ellipse cylinder drilled. (a). Perspective view. (b). Front view. (c). Zoom-in view of the ellipse cylinder. (a_f= 10.4 mm, h_r = 5.5 mm, h_{rf} = 3.3 mm)

B. DRA with an ellipse cylinder drilled.

The geometry of the DRA capable of reducing the mutual coupling of orthogonal polarizations is shown in Fig. 3, where it is still originated from Fig. 1 but only with an ellipse cylinder drilled along the diagonal direction of the dielectric resonator and other minor dimension modifications. The S-parameter of the DRA with the ellipse cylinder drilled in the right position is simulated and presented in Fig. 2 for comparison. As seen in Fig. 2, the introduction of the ellipse cylinder can maintain the operating band of the DRA (still from 5.6 to 5.95 GHz with a reflection coefficient below -10 dB), while the mutual coupling of orthogonal polarizations is notably reduced that is below -25 dB from 5.6 to 5.95 GHz. Particularly, the mutual coupling of orthogonal polarizations has been reduced from -24 dB to -40 dB at 5.8 GHz after drilling the ellipse cylinder.

The reason that the mutual coupling can be reduced lies in the field perturbations with the presence of the ellipse cylinder. The field perturbations primarily consist of the perturbations within the dielectric resonator and on the metal ground. The magnitudes of the field perturbations are closely related to the dimension and position of the ellipse cylinder that can be fully leveraged to control the mutual coupling, which will be examined in the following parameter study.

III. PARAMETER STUDY

This section performs some parametric studies to examine and conclude the effects of the dimension and position of the ellipse cylinder (i.e., the distance of the ellipse cylinder from the origin, the long side of e_a and short side of e_b of the ellipse cylinder) on the mutual coupling reduction of the DRA with the ellipse cylinder drilled.

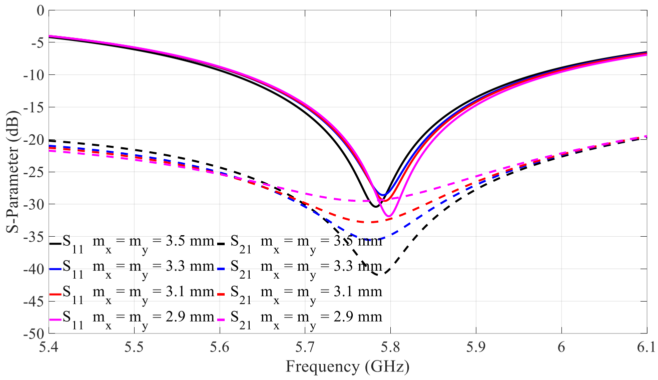


Fig. 4. The S-parameter of the DRA with the ellipse cylinder drilled when the ellipse cylinder is located along the diagonal direction but at a different distance from the origin.

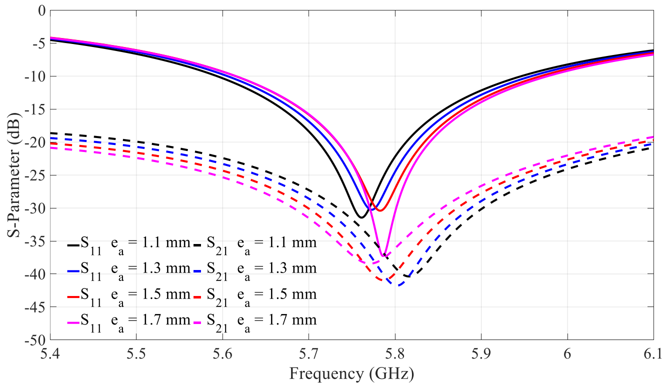


Fig. 5. The S-parameter of the DRA with the ellipse cylinder drilled with different e_a.

The S-parameter of the DRA with the ellipse cylinder drilled is examined when the location of the ellipse cylinder is located along the diagonal direction but at a different distance from the origin. As seen in Fig. 4, with the ellipse cylinder away from the origin, the mutual coupling of orthogonal polarizations (i.e., S_{21}) can be greatly reduced while the reflection coefficients (bandwidth and frequency) are still maintained.

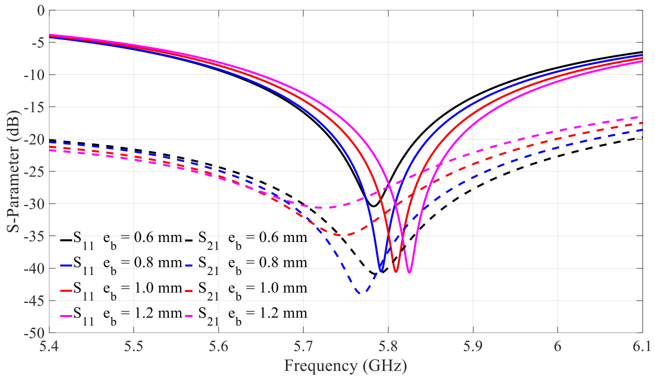


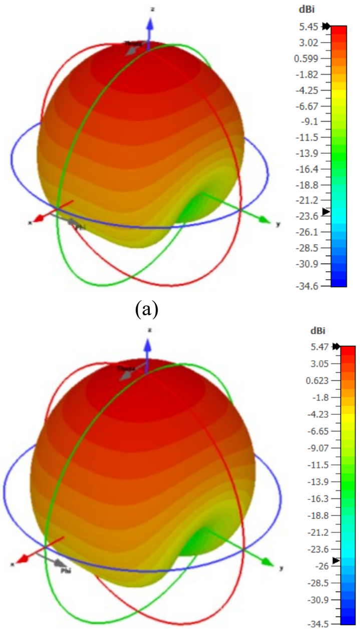
Fig. 6. The S-parameter of the DRA with the ellipse cylinder drilled with different e_b.

The S-parameter of the DRA with the ellipse cylinder drilled is checked with different e_a and e_b of the ellipse cylinder while the distance from the origin is fixed (i.e., $m_x = m_y = 3.5$ mm). As seen in Figs. 5 and 6, the values of e_a and e_b have effects on the reflection coefficient and the mutual coupling simultaneously. Specifically speaking, with a smaller e_a or e_b, the frequency band of the mutual coupling is shifting towards a higher one while the reflection coefficient is shifting towards a lower frequency band. However, it is found the reflection coefficient moving towards a higher frequency band is faster while the bandwidth of the mutual coupling is gradually reduced with the increasing value of e_b as observed from Figs. 5 and 6. Based on the parametric studies, the values of e_a, e_b, m_x, and m_y are selected as 1.5 mm, 0.6 mm, 3.5 mm, and 3.5 mm, respectively, to maintain good mutual coupling levels and reflection coefficient from 5.6 to 5.95 GHz.

IV. COMPARISON OF RADIATION PERFORMANCE

In general, the radiation performance of an antenna should be maintained after adopting some technologies to reduce the mutual coupling of orthogonal polarization of an antenna. It is not allowed that the reduced mutual coupling is achieved at the expense of the radiation performance degradation of the antenna. To this end, this section compares the radiation performance (e.g., radiation pattern, realized gain, total efficiency, etc.) of the DRAs with and without the ellipse cylinder drilled.

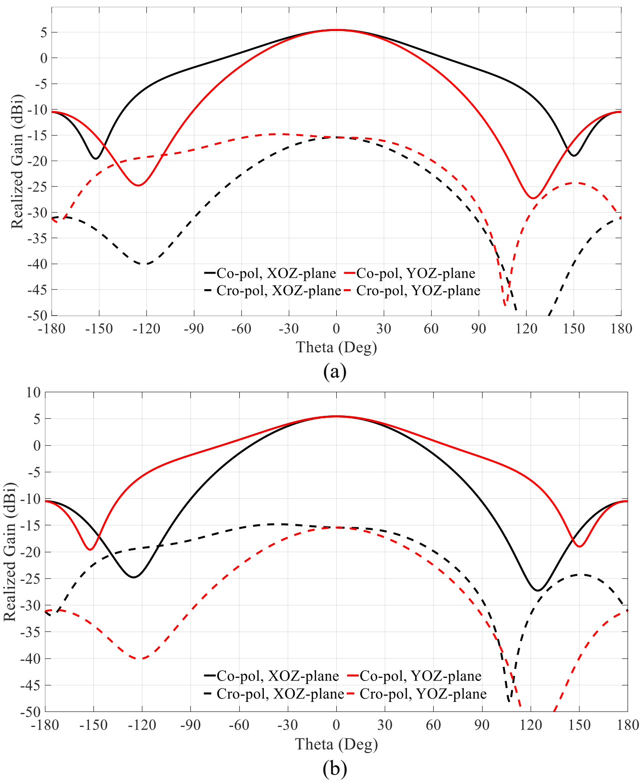
The 3D radiation patterns of the DRAs with and without the ellipse cylinder drilled are simulated at 5.8 GHz. For simplicity, only port 1 is excited to examine the radiation pattern with the other port is terminated with a matching load. As seen in Fig. 7, both the DRAs can radiate directional radiation beams, and the realized gains of the two DRAs are almost the same (5.45 dBi for the DRA without the ellipse cylinder drilled and 5,47 dBi for the DRA with the ellipse cylinder). Fig. 7 indicates that the introduction of the ellipse cylinder does not affect the radiation pattern of the DRA, which is highly desired in the mutual coupling reduction.



(a)

(b)

Fig. 7. The simulated 3D radiation patterns of the DRAs at 5.8 GHz. (a). Without the ellipse cylinder drilled. (b). With the ellipse cylinder drilled.



(a)

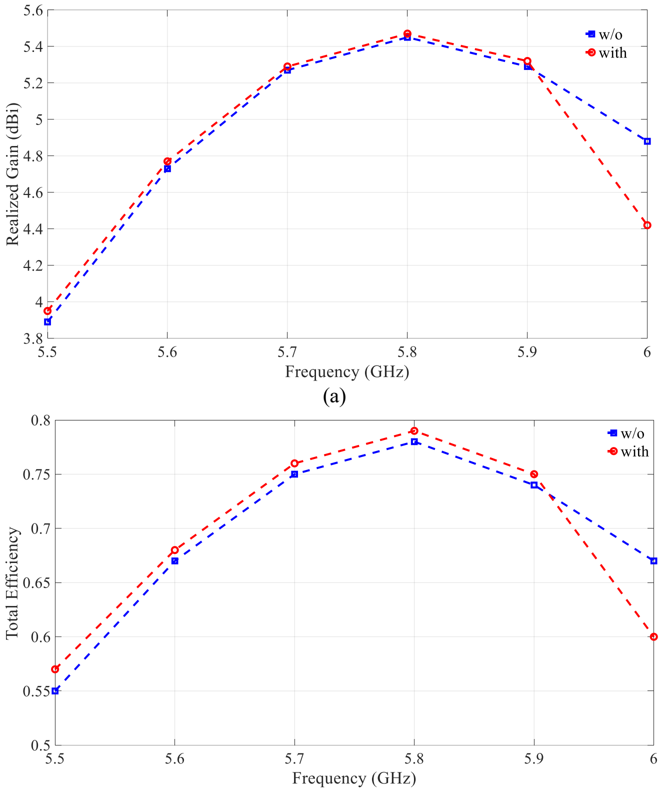
(b)

Fig. 8. The simulated 2D radiation patterns of the DRA with the ellipse cylinder drilled at 5.8 GHz. (a). Port 1 is excited. (b). Port 2 is excited.

To demonstrate the detailed features of the radiation patterns, the 2D radiation patterns of the DRA with the ellipse cylinder drilled are simulated and presented when ports 1 and 2 are excited at 5.8 GHz, respectively. As seen in Fig. 8, the 3-dB beamwidth in the XOZ-plane is around 70º, while it is around 110º in the YOZ-plane. The cross-polarization (cro-pol) levels in XOZ and YOZ planes are both better than -20 dB.

The realized gains and total efficiencies of the DARs with and without the ellipse cylinder drilled are simulated and compared with different frequencies. As seen in Fig.9(a), the DRA with the ellipse cylinder drilled achieves comparable realized gains as the DRA without the ellipse cylinder drilled.

Also, the total efficiencies of the DRA with the ellipse cylinder drilled are slightly higher than the counterparts of the DRA without the ellipse cylinder drilled as can be observed from Fig. 9(b). The radiation performance comparison shown in Figs. (7)-(9) sufficiently demonstrate that the proposed strategy can maintain the radiation performance while performing effective mutual coupling reduction of orthogonal polarizations of the DRA.



(b)

Fig. 9. The simulated realized gain and total efficiency with frequency of the DRAs with and without the ellipse cylinder drilled when port 1 is excited. (a). Realized gain. (b). Total efficiency.

V. CONCLUSIONS

This paper describes an effective strategy to reduce the mutual coupling of orthogonal polarizations of a dual-polarized DRA without using extra circuits. By tuning the dimension and location of the ellipse cylinder drilled in the DRA, the mutual coupling of orthogonal polarizations can be flexibly reduced and controlled. The simulated results demonstrate that the radiation performance of the DRA can be maintained when the mutual coupling is reduced. Due to the simplicity and effectiveness of the proposed strategy, it is a promising technology to be widely adopted to reduce the mutual coupling of a DRA at the microwave and millimeter-wave bands.

ACKNOWLEDGMENT

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