Wideband Dielectric Resonator Antenna Excited by a Closed Circular Loop GCPW Slot for WLAN 5.5 GHz Applications

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Abstract **─** A dielectric resonator antenna is designed for WLAN 5.5 GHz band applications in this study. The dielectric resonator antenna is fabricated on a cheap FR4 substrate with grounded CPW (GCPW) structure. A new closed circular loop GCPW slot structure is employed to obtain wideband impedance matching. Results of the designed dielectric resonator antenna show that good agreement between simulated and measured reflection coefficients, radiations, and antenna gains is observed. The measured -10 dB bandwidth of the dielectric resonator antenna is 1.6 GHz (28.5%, 4.8 – 6.4 GHz), which covers the WLAN 5.5 GHz band.

Index Terms **─** Dielectric resonator, DRA, GCPW, wideband, WLAN.

I. INTRODUCTION

Dielectric resonators [1-3] have the advantages of no conductor loss, low quality factor, and high dielectric constant; hence, they are widely used for designing dielectric resonator antennas (DRAs). Theoretical analyses for first few resonant modes in an isolated cylindrical dielectric resonator have been done [4-6]. DRAs have many advantages such as compact size, wideband, and high efficiency. Different excitation mechanisms such as coaxial probe [6, 7], slot-microstrip [8], microstrip [9, 10] and slot-coplanar waveguide (CPW) can excite the dielectric resonator [3]. Apparently, the excitation mechanism of using slot-microstrip outperforms the coaxial probe since coaxial probe fed are not easy to adjust the optimal feeding position to obtain good impedance matching. DRAs also can be fed by CPW lines [11, 12]. However, CPW fed structure without a ground plane on the backside has a drawback that decreases the antenna gain and efficiency due to backside radiations. To overcome this drawback, a grounded CPW (GCPW) structure can be used. The GCPW structure has an additional ground plane on the bottom layer of the substrate to block the backside radiations. Also, the ground plane can create an extra image radiator to improve the gain of the DRA.

In this study, a wideband DRA excited by a GCPW line with slot-CPW fed structure is proposed. The designed DRA operates at the WLAN 5.5 GHz (5.15 – 5.85 GHz) band. The proposed DRA has characteristics of wideband, high gain, and wide beamwidth. Details of the proposed DRA design are described. Results of the prototype are presented and discussed as well.

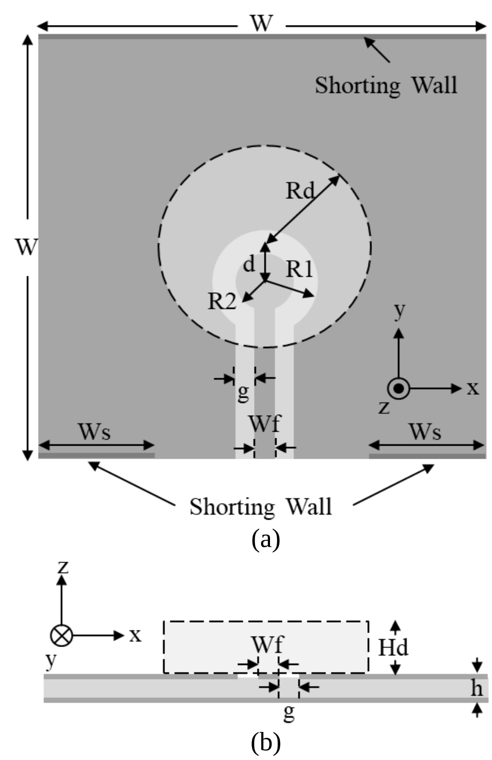

Fig. 1. The geometry of proposed wideband GCPW fed DRA: (a) top view and (b) side view.

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II. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed wideband DRA. The full-wave EM simulator, HFSS [13] is used to analyze the prototype of the DRA. The proposed antenna is to be fabricated on an FR4 substrate with a thickness (h) of 0.8 mm, dielectric constant of 4.4, and loss tangent of 0.02. The square size of the DRA is 60.0 mm (W) by 60.0 mm. The shorting walls are applied in the y-direction to block surface waves in the substrate. Wf is the width of the central fed line. g is the gap between the edge of the central fed line and the edge of the ground plane on the top layer of the FR4 substrate. The GCPW fed line becomes a closed circular loop line at the end. The closed circular loop GCPW slot line consists of a circular patch and a circular slot. They are concentric. The radii of the outer and inner edge of the circular slot are R1 and R2, respectively. The distance from the center of the cylindrical dielectric resonator to the center of the circular patch is d. This closed circular loop GCPW slot excites a ring of magnetic current. The magnetic current $\vec{\mathrm{M}}$ can be determined by:

$$\vec{\mathrm{M}} = -\hat{n} \times \vec{E} \,, \tag{1}$$

where $\vec{E}$ is the electric fields between the edges of the slot and $\hat{n}$ is the direction normal to the plane of the fed line. Figure 2 demonstrates the magnetic currents flow along the closed circular loop GCPW slot. The magnetic currents are obtained by HFSS at 5.7 GHz. The circular loop magnetic current is equivalent an electric dipole source, which then excites the cylindrical dielectric resonator [2]. By properly adjusting the orientation of the cylindrical dielectric resonator and dimensions of the closed circular loop GCPW slot structure, the desired hybrid $\mathrm{HEM}_{11\delta}$ mode can be excited. Meanwhile, wideband impedance matching of the DRA can be obtained [3]. The resonant frequency of dominant hybrid $\mathrm{HEM}_{11\delta}$ mode can be determined by [14]:

$$f_r = \frac{c}{2\pi \mathrm{Rd}} \frac{6.324}{\sqrt{\varepsilon_r + 2}} \left[0.27 + 0.36 \left(\frac{\mathrm{Rd}}{2\mathrm{Hd}}\right) + 0.02 \left(\frac{\mathrm{Rd}}{2\mathrm{Hd}}\right)^2 \right] , \tag{2}$$

where c is light speed in free space and ε_r is the dielectric constant of resonator. To achieve wider bandwidth, ε_r of resonator should be kept low. Hence, we choose an available cylindrical dielectric resonator with a height (Hd) of 4.2 mm, a radius (Rd) of 14.9 mm, ε_r of 9.8, and loss tangent of 0.01 applied in this antenna design. The resonant frequency f_r of dominant $\mathrm{HEM}_{11\delta}$ mode determined by (2) is 5.73 GHz, which is closed to the center of the operating band. Simulated electric and magnetic fields at 5.7 GHz are shown in Fig. 3. The electric fields are more concentrated on the surface close to the top of the cylindrical dielectric resonator while the magnetic fields are more concentrated at the center of the cylindrical dielectric resonator. The directions of electric fields and magnetic fields are orthogonal each other, which demonstrate the dielectric resonator operating at the dominate $\mathrm{HEM}_{11\delta}$ mode. Here, $\mathrm{HEM}_{11\delta}$ is the lowest resonant frequency.

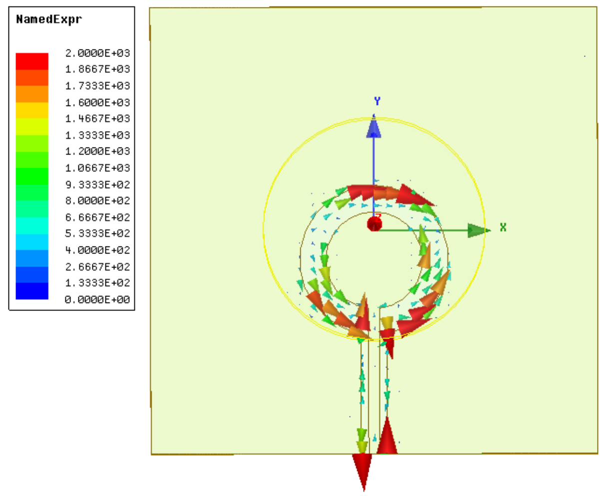


Fig. 2. The magnetic currents flow along the closed circular loop GCPW slot line. The magnetic currents are obtained by HFSS EM simulator at 5.7 GHz.

Parametric study is performed to reveal the influence of the magnitude of reflection coefficients (|S11|) by key parameters, R1, R2, and d. Other dimensions are fixed at values as shown in Table 1 when the parameter is investigated. In Fig. 4 and Fig. 5, |S11| is much sensitive in the variation of R2 than that of R1 and d. The variation of d slightly affects the |S11| as can be seen in Fig. 6. Based on the results, when designing the proposed DRA, we suggest firstly adjust the value of R2 to obtain wideband impedance matching at the desired band. The next step is to slightly adjust R1 and d to achieve better |S11| performance of the DRA.

Detailed dimensions of the designed wideband DRA are listed in Table 1 as well. A prototype has been physically realized. Figure 7 shows the pictures of the designed wideband DRA without and with the cylindrical dielectric resonator.

Table 1: Dimensions of the proposed dielectric resonator antenna (Unit: mm)

Parameter	**Size**	**Parameter**	**Size**
W	60.0	R1	10.0
Wf	2.52	R2	6.5
g	1.0	d	4.0
h	0.8	Rd	14.9
Hd	4.2	Ws	12.0

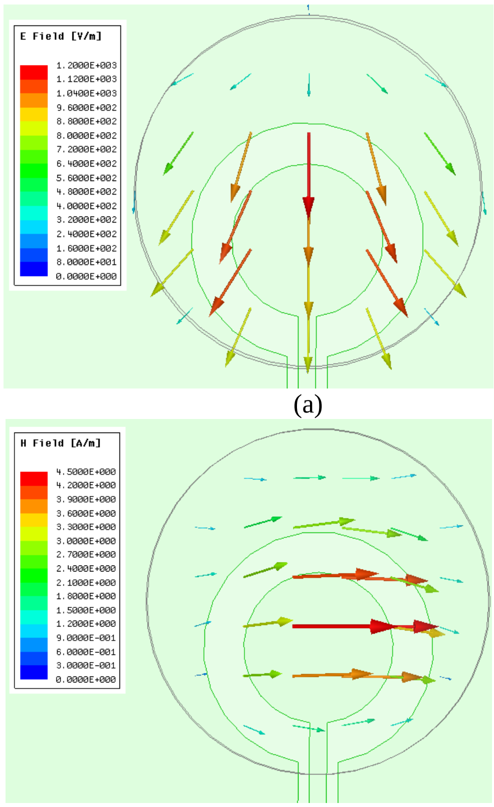


Fig. 3. Simulated top view field distributions at 5.7 GHz. (a) E-Fields close to the top surface of the dielectric resonator, and (b) H-Fields on the cross section at the center of the dielectric resonator.

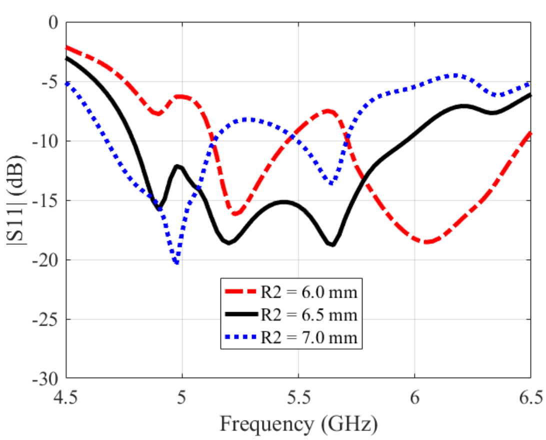


Fig. 4. Simulated reflection coefficients of the proposed DRA with varying of R2.

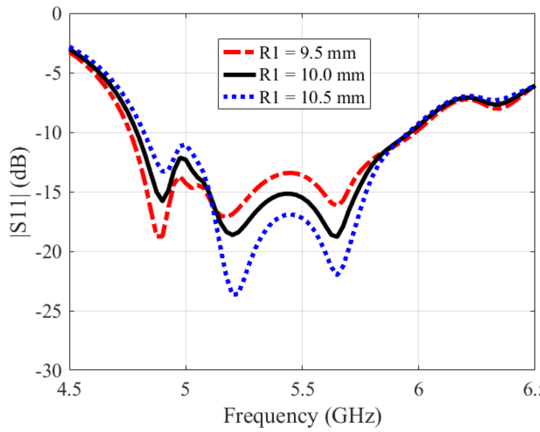


Fig. 5. Simulated reflection coefficients of the proposed DRA with varying of R1.

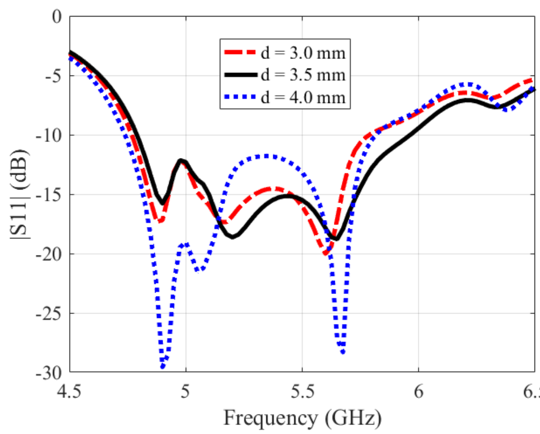


Fig. 6. Simulated reflection coefficients of the proposed DRA with varying of d.

(a) (b)

Fig. 7. The pictures of the proposed wideband DRA: (a) without the cylindrical dielectric resonator, and (b) with the cylindrical dielectric resonator.

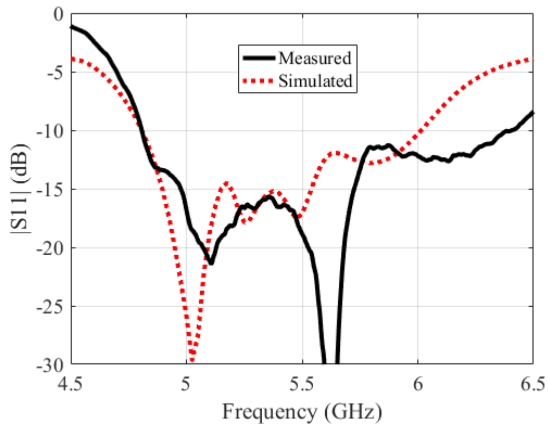


Fig. 8. The reflection coefficients of the proposed DRA.

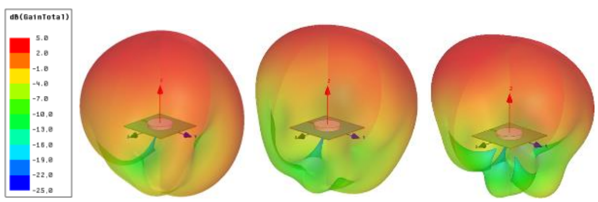
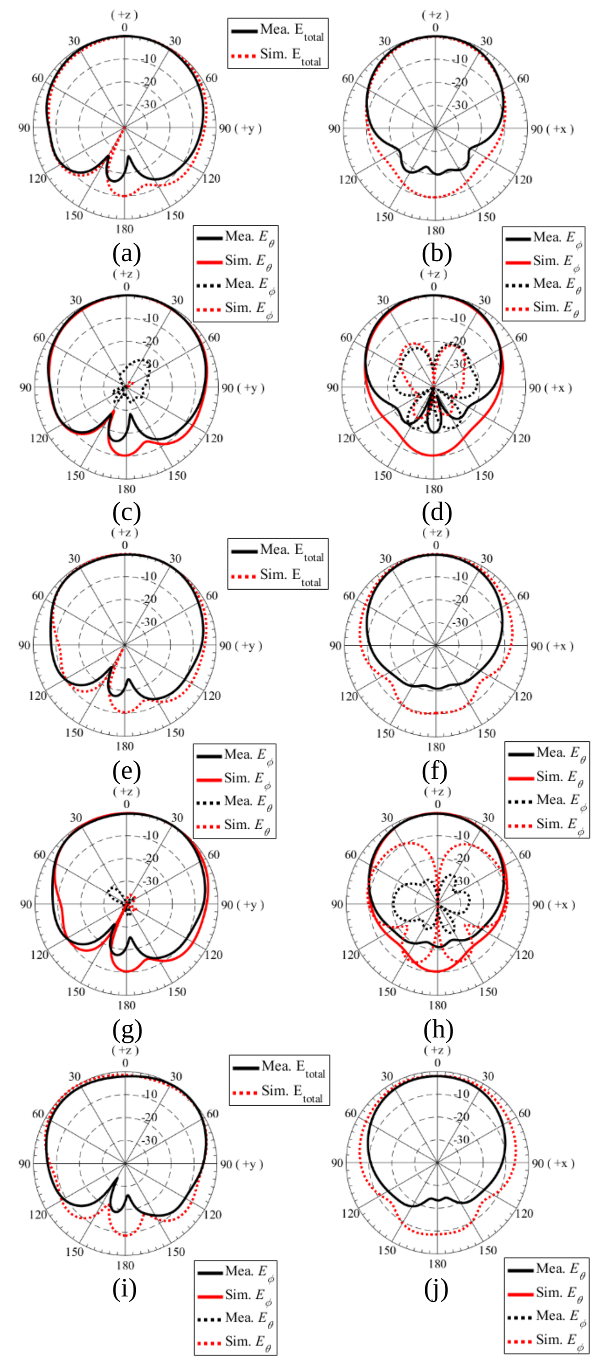
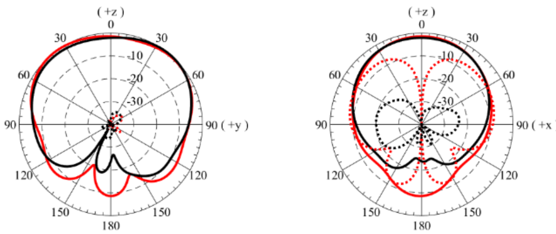


Fig. 9. Simulated 3-D radiation gain patterns of the proposed DRA at frequencies of: (a) 5.15 GHz, (b) 5.5 GHz, and (c) 5.85 GHz.

III. RESULTS AND DISCUSSIONS

The prototype of the proposed wideband DRA is measured by an Agilent's N5230A vector network analyzer (VNA) to obtain measured |S11|. The simulated and measured |S11| of the proposed DRA are shown together in Fig. 8. The simulated |S11| agrees with the measured one. The measured -10 dB impedance bandwidth is 1.6 GHz (28.57%, 4.8-6.4 GHz), which covers the WLAN 5.5 GHz band and can be considered a wideband impedance matching. Figure 9 shows simulated 3-D radiation gain patterns of the proposed DRA at frequencies of 5.15 GHz, 5.5 GHz, and 5.85 GHz. The gain patterns reveal broadside radiations. Gain patterns are similar each other at the three frequencies and near omnidirectional in the +z direction with small back lobe levels. Measured radiation properties of the proposed DRA are obtained by an MVG SG-24 antenna measurement system. Figure 10 shows the normalized far-field radiation patterns of the DRA in the y-z and x-z planes at 5.15 GHz, 5.5 GHz, and 5.85 GHz, respectively. The DRA has broadside radiations with wide beamwidths. Good agreement between simulated and measured radiation patterns is observed. It shows the validity of the simulation. The measured 3 dB beamwidths in the y-z plane are larger than those in the x-z plane. The beamwidth is around 84 degrees in the x-z plane at 5.5 GHz. Cross-polarized patterns show more than 20 dB isolation from the peak. It indicates excellent linearly polarized radiation along the broadside direction. Figure 11 shows the peak gains of the proposed DRA. The measured peak gain is 3.64 dBi at 5.5 GHz and 4.77 dBi at 5.9 GHz. Measured radiation properties of the proposed DRA at 5.15, 5.5, and 5.85 GHz are summarized in Table 2. The DRA has high gain, wide beamwidth, and good front-to-back (F/B) ratio. Based on the results of reflection coefficients and radiation properties, the designed DRA has good performance and is suitable for operating at the WLAN 5.5 GHz band.





(k) y-z plane (l) x-z plane

Fig. 10. Radiation patterns (normalized) of the proposed DRA. (a), (b), (c), and (d) at 5.15 GHz. (e), (f), (g), and (h) at 5.5 GHz. (i), (j), (k), and (l) at 5.85 GHz.

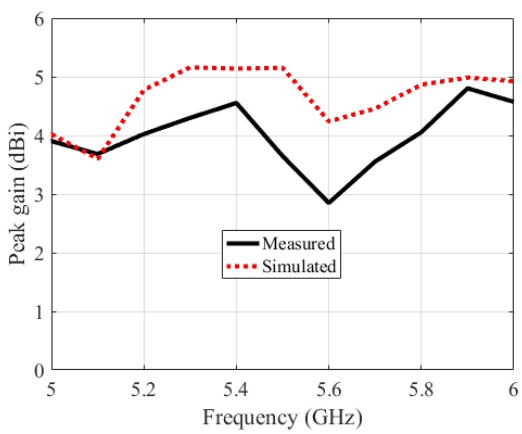


Fig. 11. The measured and simulated peak gains of the proposed antenna.

Table 2: Measured radiation properties of the proposed DRA at 5.15, 5.5, and 5.85 GHz

Frequency (GHz)	**5.15**	**5.5**	**5.85**
Gain (dBi)	3.26	3.64	4.24
Efficiency (%)	50.4	53.3	55.7
3 dB beamwidth in the y-z plane (Deg.)	124	130	138
3 dB beamwidth in the x-z plane (Deg.)	84	84	102
F/B ratio (dB)	20.08	20.67	21.34

VI. CONCLUSION

A wideband dielectric resonator antenna has been designed in this study. The proposed DRA used a closed circular loop GCPW slot line to excite the cylindrical dielectric resonator. Numerical experiments and measurements have shown the antenna's good characteristics. Antenna design and discussion have been given. Results made on the proposed wideband dielectric resonator antenna have shown a very promising performance that can be practically and effectively applied to WLAN communication systems.

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