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A Novel Compact Three-Port Dielectric Resonator Antenna with Reconfigurable Pattern for WLAN Systems

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Abstract—Splitting a cylinder dielectric resonator into four uniform quarters generates a new dielectric resonator antenna (DRA) shape, which is named a quarter volume of cylinder dielectric resonator antenna (QVCDRA) in the paper. On the basis, a novel compact three-port dielectric resonator antenna with reconfigurable radiation pattern is presented for WLAN systems at 5.2 GHz. A −10 dB impedance bandwidth of 16.20%, covering the frequency range from 4.75 GHz to 5.54 GHz, is obtained with an isolation of lower than −19 dB. The structure consists of three QVCDRAs that arrange evenly around Z axis, and as a result possesses the advantage of compact structure, wide impendence band and reconfigurable radiation patterns. The volume of the proposed three-port DRA without ground plane is only $0.0216\lambda_d^3$ (λ_d is the dielectric wave length at the central operation frequency). The proposed antenna is analyzed in detail. Antenna prototype is fabricated and tested. The simulation and test results are in good agreement.

1. INTRODUCTION

The propagation of signals always encounters the reflections and diffractions from buildings in modern communication systems. Space diversity technique can provide an increase in the quality of the transmission systems. Pattern reconfigurable antenna [1–4] is defined to steer its main radiation beam towards desired direction with the central operation frequency unchanged. The advantage of improving the capacity and performance of diversity systems due to its merits of directional radiating and receiving makes it a good candidate for wireless communication systems.

The dielectric resonators antenna (DRA) has received wide attention for its virtues of high radiation efficiency [5], low profile and compact size [6] in recent twenty years. DRAs of diverse shapes also have been widely researched. Professor Long brought forward and investigated the cylindrical [7], rectangular [8], and hemispheric DRA [9], which has laid a good foundation for the development of DRA. Other configurations including triangular, cylindrical-ring DRAs [10] were also studied.

A lot of researches have been carried out on the combination of DRA and reconfigurable technique in recent years. A hemispheric pattern reconfigurable DRA covered with radome was proposed in [11]. Beam agility is realized through varying the position of a regional dielectric discontinuity in the radome. Two rectangle DRAs have been integrated to implement pattern reconfigurable on three frequency bands in [3]. Slot-fed DRA is studied in [12]. By varying the slot length, the frequency of the DRA can be controlled which in turn helps to achieve reconfigurable radiation patterns.

The quarter volume of cylindrical DRA (QVCDRA) designed in this paper is, to our knowledge, first proposed. QVCDRA can work stably at HEM_{11}-like mode by proper settings of boundaries and exciting mechanism.

The proposed compact three-port antenna is composed of three QVCDRAs evenly arranged around Z axis, and slot-coupled microstrip feeding mechanism is used to feed every single QVCDRA. The

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total size of the antenna without ground is only $0.0216\lambda_d^3$ (λ_d refers to dielectric wave length at the central operation frequency). Reconfigurable radiation patterns can be achieved by exciting different combinations of feeding ports. This novel antenna can be applied as the indoor distribution antenna in WLAN systems for its simple structure, compact size and simplicity to be fabricated.

2. SINGLE QVCDRA

2.1. Design of the QVCDRA

A QVCDRA is designed and analyzed. The structure is shown in Figure 1, and its detailed dimension parameters are given in Table 1. The QVCDRA is placed on a circular floor with a radius of 50 mm. The radius and height of radiator are a and h, respectively. Dielectric materials with a dielectric constant of 10 are used in radiator.

It is known that HEM_{11} mode is the foundational mode of the full-size CDRA for its relatively high broadside radiation and efficiency [10]. The inner field distribution of two orthogonal planes when full-size CDRA is working at HEM_{11} mode is shown in Figure 2. Notice that the sketch is for the case without ground plane.

Table 1. Detailed dimensions of single QVCDRA.

Parameters	w_s	y_s	x_s	l_s	**lstub**
Value (mm)	0.6	4	4	22	5.5
Parameters	w_f	x_f	a	h	**lstrip**
Value (mm)	2.25	5.5	18	17	35

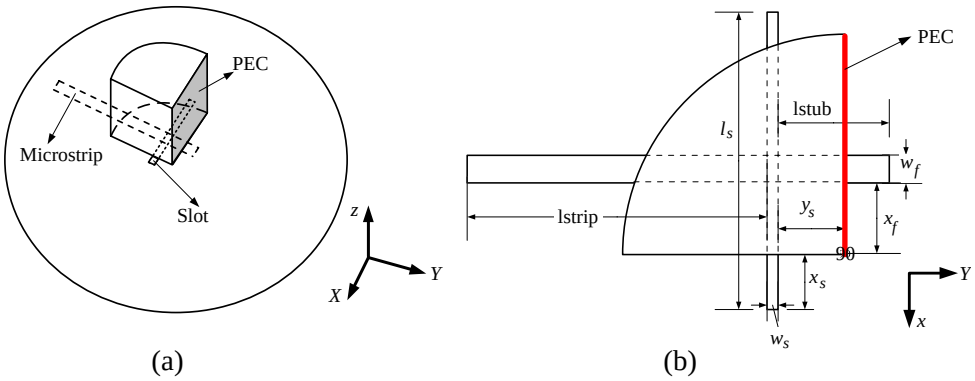


Figure 1. (a) 3D view of QVCDRA. (b) Top view and geometry of QVCDRA.

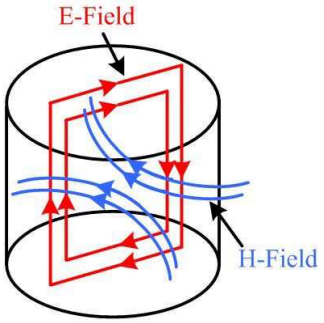


Figure 2. Sketch for the field distribution of the HEM_{11} mode.

The inner field distribution of the dielectric resonator antenna (DRA) depends on the boundary conditions [10]. As we all know, inserting a PEC symmetry plane will have no influence on the original field distribution when the electric field tangential to the symmetry plane is zero. Thus half of the CDRA can be removed by placing a finite conducting plane orthogonal to the ground plane, which is shown in Figure 3(b).

Similarly, if a plane is symmetric about the DRA, as well as parallel to the E plane, the original field distribution will remain the same when utilizing an infinite perfect magnetic conductor to replace the plane. It can be found from Figure 2 that the circumferential surface of the CDRA can be treated as almost a magnetic conductor. So the magnetic conducting surface orthogonal to the PEC excites naturally when half of the CDRA is also removed as illustrated in Figure 3(c).

Figure 4 shows the inner electromagnetic field distribution of the QVCDRA at 2.69 GHz. It can be observed that the field distribution of the proposed QVCDRA is nearly the same with that of the full-size CDRA and $\mathrm{HEM}_{11}\delta$-like mode is the main working mode of the QVCDRA.

The above study on the inner filed distribution when QVCDRA is working at $\mathrm{HEM}_{11\delta}$-like mode helps to choose a proper feeding mechanism. Slot-coupled microstrip feeding mechanism is used to excite the QVCDRA, and the dielectric constant of the substrate is chosen to be 2.65, with the thickness of 1 mm and width of 2.25 mm.

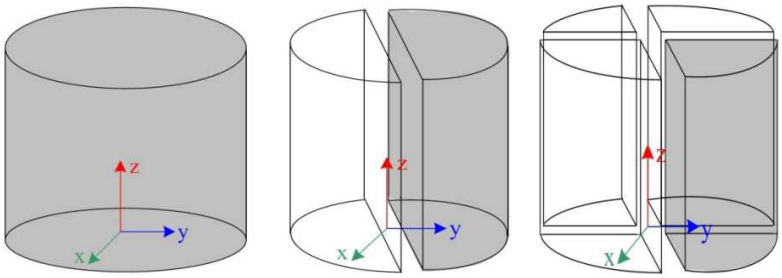


Figure 3. (a) Cylinder DRA (CDRA). (b) CDRA split to form half-CDRA. (c) CDRA split twice to form quarter volume CDRA (QVCDRA).

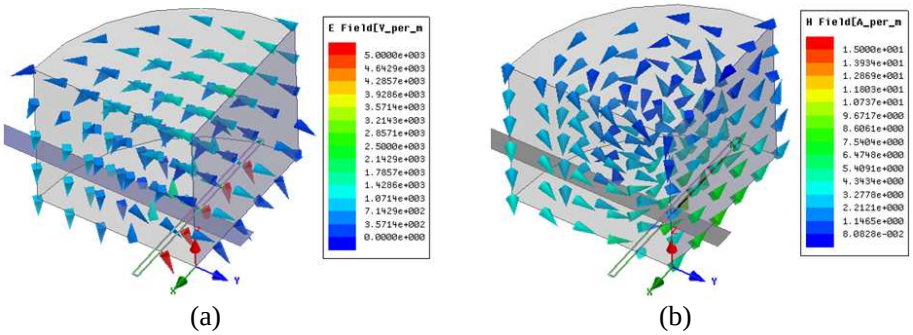


Figure 4. (a) The E-field distribution of the QVCDRA working at HEM_{11}-like mode. (b) The H-field distribution of the QVCDRA working at HEM_{11}-like mode.

2.2. Performance of the QVCDRA

Ansoft HFSS is used to optimize the QVCDRA, and the simulated S-parameters and radiation patterns are given in Figures 5 and 6, respectively. The dimensions and dielectric constant of the DRA are the main factors that influence the antenna performance. Professor Long brought forward, in [7], the magnetic wall model to validate that resonance frequency decreases with the increase of the antenna

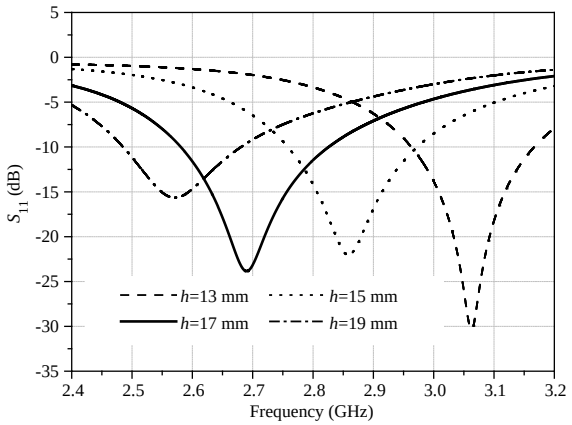


Figure 5. Variations of S_{11} against frequency with the height (h) of QVCDRA.

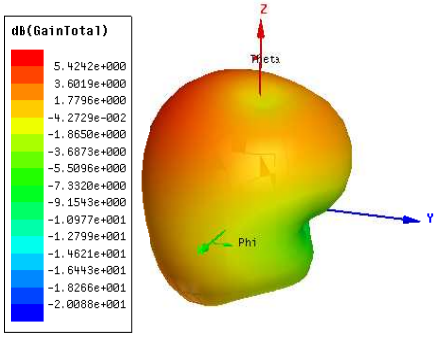


Figure 6. Simulated 3D radiation pattern for QVCDRA at 2.69 GHz.

volume. Figure 5 shows the simulation results of the variation of S_{11} with the height of the single QVCDRA, which has validated the theory concluded by Professor Long. It can also be seen from Figure 5 that the central operation frequency of the proposed single QVCDRA is 2.69 GHz, and a relatively narrow impendence bandwidth of 250 MHz is obtained. Certain methods will be adopted to broaden the bandwidth in the following chapters. Figure 6 indicates that a directional radiation pattern with the gain of 5.42 dB is achieved.

3. THREE-PORT DIELECTRIC RESONATOR ANTENNA

3.1. The Configuration

Three QVCDRAs are placed on a circular floor and arranged together around Z axis to form a novel three-port DRA centered at 5.2 GHz, which is successfully designed, fabricated and tested. Reconfigurable patterns can be achieved by exciting different combinations of feeding ports shown in Table 2. The structure of the antenna is given in Figure 7.

In order to cover the WLAN band at 5.2 GHz, a smaller volume is used in the design. The final dimensions of the proposed three-port antenna are given in Table 3 after optimization.

A 25-degree metal patch is attached to the side wall of each QVCDRA, which will disturb the electromagnetic field around. The effect of the metal patches on bandwidth is shown Figure 8. The

Table 2. Different combinations of feeding ports.

State	1	2	3	4	5	6	7
Port1	√			√	√		√
Port2		√		√		√	√
Port3			√		√	√	√

Table 3. Detailed dimensions of the novel three-port antenna.

Parameters	w_s	y_s	x_s	l_s	lstub
Value (mm)	0.6	4.4	1	13	7.5
Parameters	w_f	x_f	a	h	lstrip
Value (mm)	2.25	5.5	10.5	12	44

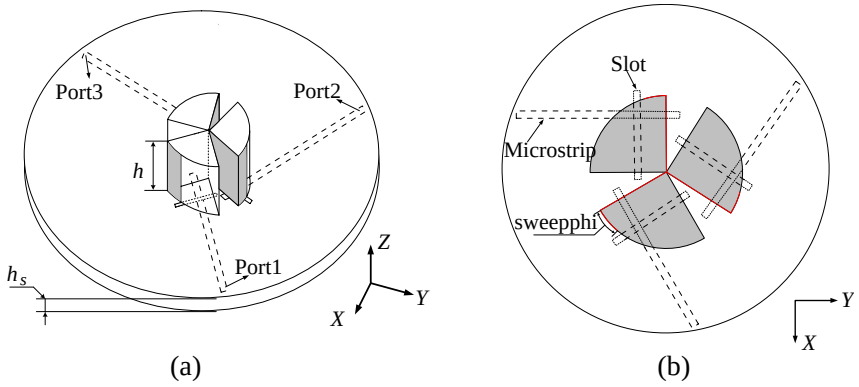


Figure 7. (a) 3D view of three-port DRA. (b) Top view of three-port DRA.

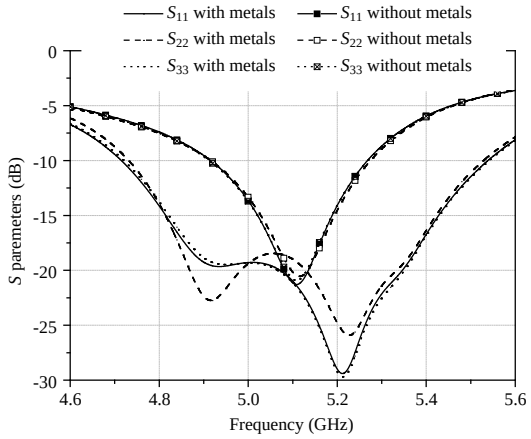


Figure 8. Simulated S-parameters for the three-port DRA with and without metals.

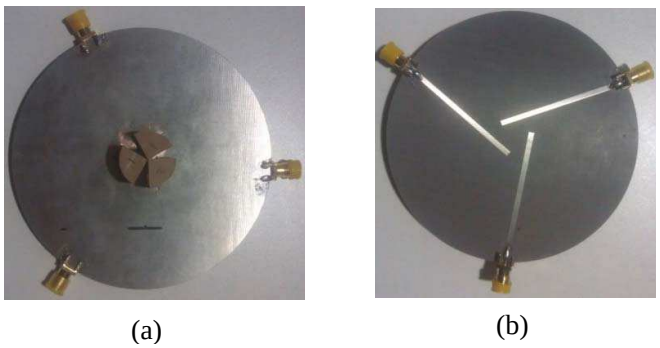


Figure 9. (a) Photograph of 3D view of three-port DRA. (b) Photograph of bottom view of three-port DRA.

bandwidth only covers from 4.91 GHz to 5.27 GHz with a relative bandwidth of 7.07% without metal patches. A new resonant frequency is brought by the metal patches, which has consequently broaden the relative bandwidth to 16.20%.

A prototype has been fabricated as shown in Figure 9 to validate the accuracy of the simulated results. The radiators are made of ceramic material with the dielectric of 10 and each QVCDRA is excited by a slot-coupled microstrip fed coaxial cable. Resonators have been pressed onto the PCB to avoid the air gaps between radiators and floor, which will bring the frequency shift to DRA [10].

3.2. Measured and Simulated Performance of the Three-Port Antenna

3.2.1. S-Parameters

It can be seen from Figure 10 that a −10 dB relative bandwidth of 16.20% is obtained, which is wide enough to cover the WLAN band. Good agreement between the simulated and measured results is observed, and the slight discrepancies are mainly caused by fabrication tolerance.

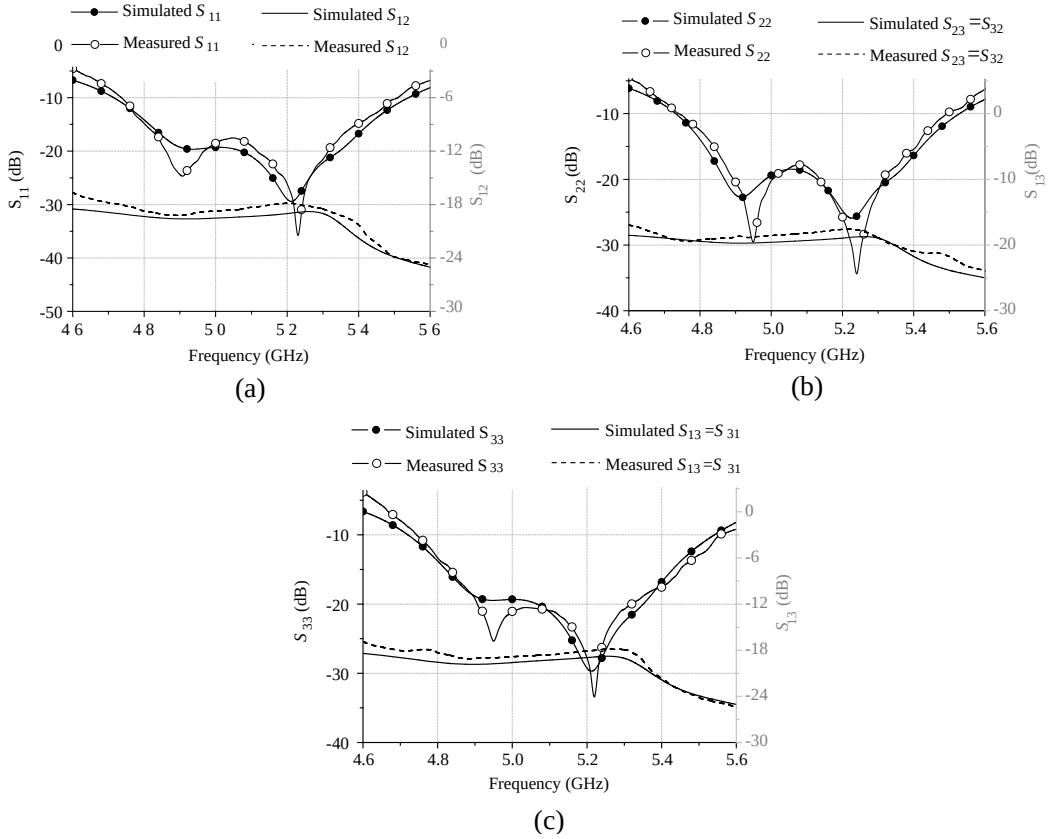


Figure 10. Simulated and measured S-parameters for three-port antenna. (a) S_{11} and S_{12}. (b) S_{22} and S_{23}. (c) S_{33} and S_{13}.

3.2.2. Total Efficiency and Realized Gain

Figure 11 illustrates the simulated and measured total efficiencies and realized gains of the three-port DRA. The antenna and connector losses have been taken into account. The realized gain is higher than 7 dB at 5.2 GHz. The total efficiency is around 30% over the frequency band. The discrepancies between the simulated and measured results are due to fabrication tolerances and measurement errors.

3.2.3. Radiation Patterns

The simulated and measured corresponding *xoy*-plane radiation patterns of the designed three-port DRA working in different states are given in Figure 12. It can be observed that the minimum difference of the adjacent main beams is about 122°. Thus these states can cover the whole azimuth plane. Only the corresponding certain ports are excited during the measurement for a certain work state, while the other ports were loaded with a 50 Ω resistance and vice versa.

As the direction of main beam for the three-port DRA is different from each other when working in different states, 3D radiation patterns are given in Table 4 to explain the maximum gain of the

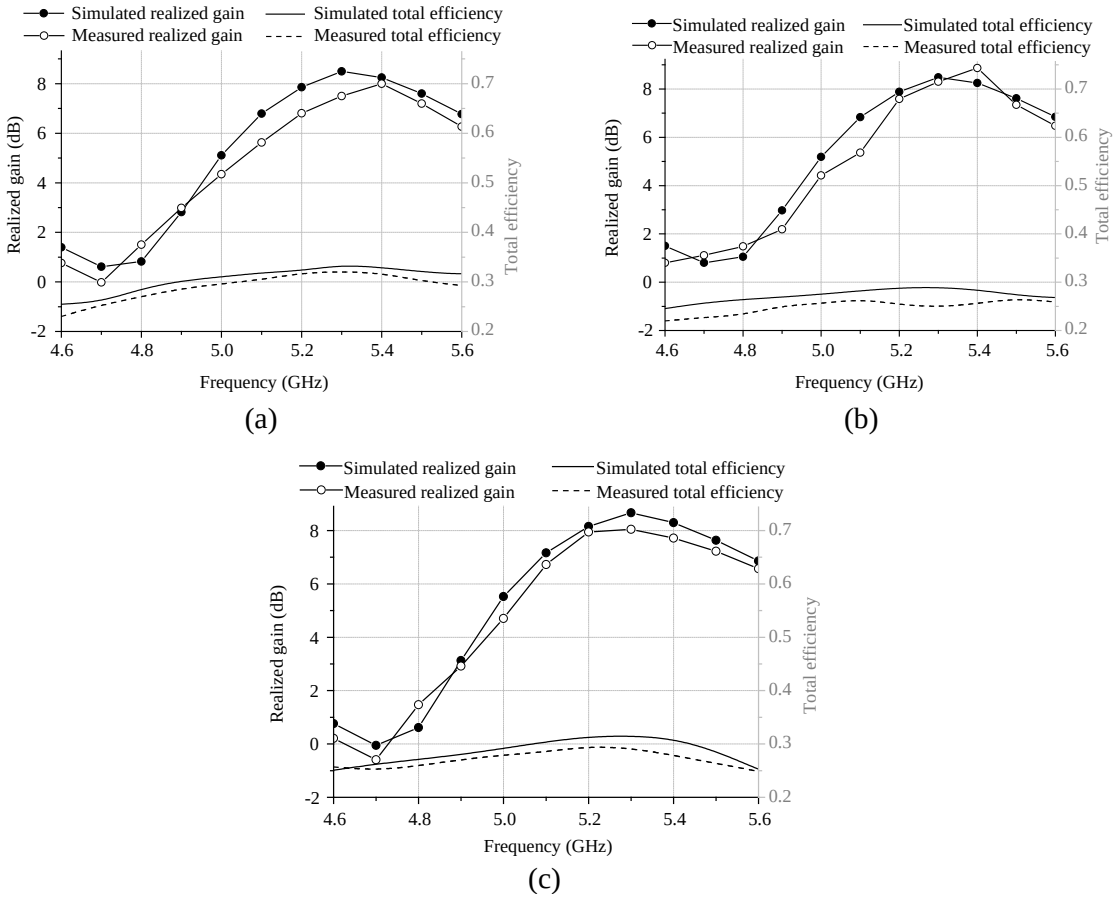
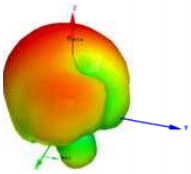
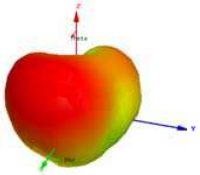
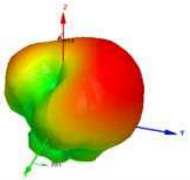
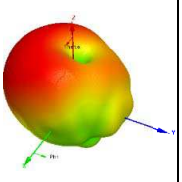
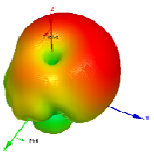
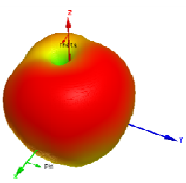
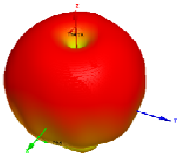


Figure 11. Simulated and measured realized gain and total efficiency for three-port antenna. (a) State1. (b) State2. (c) State3.

Table 4. Simulated 3D radiation patterns at 5.2 GHz for three-port DRA in different states.

	State1	State2	State3	State4
Simulated Radiation Pattern				
	State5	**State6**	**State7**	
Simulated Radiation Pattern				

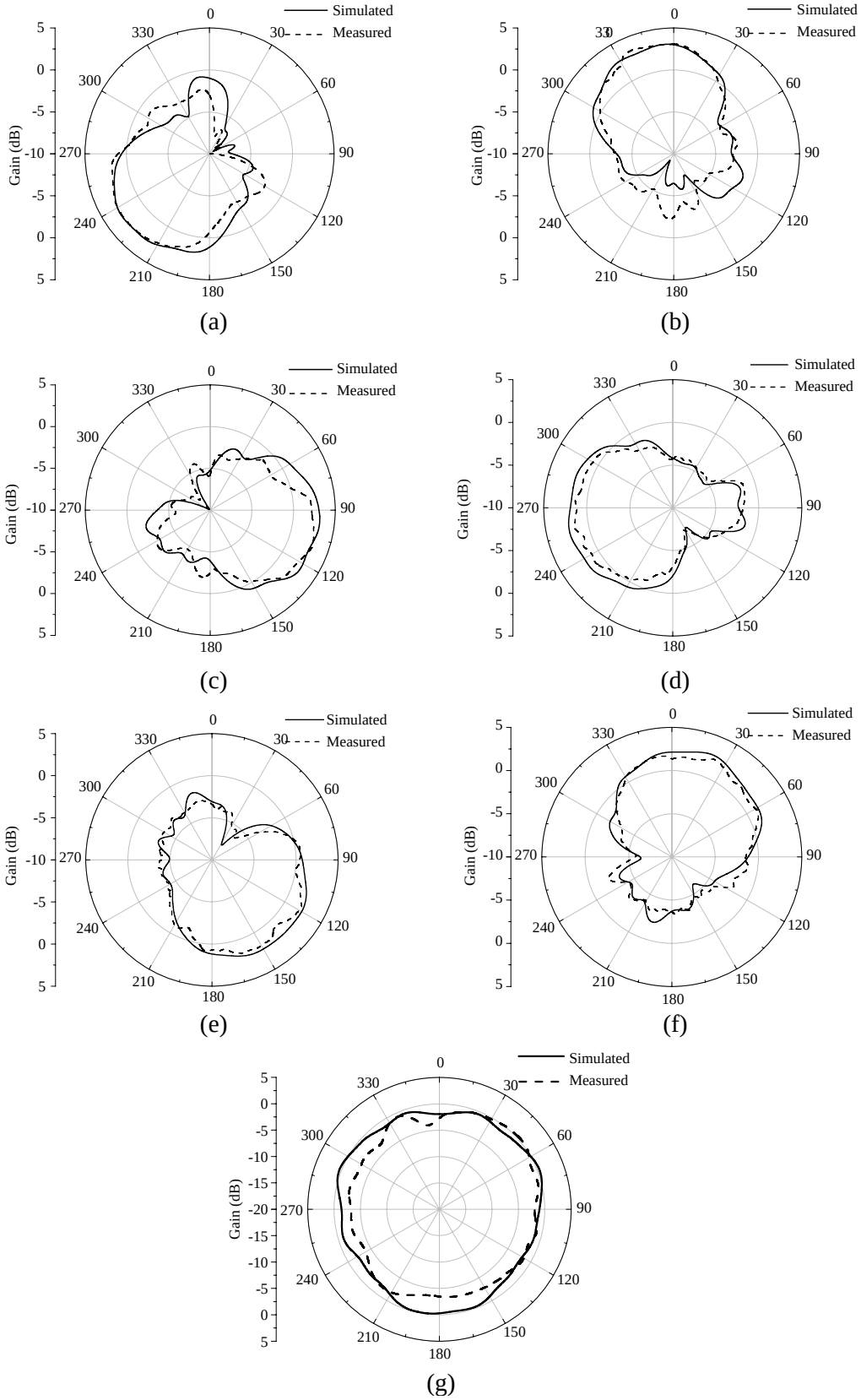


Figure 12. Simulated and measured radiation patterns at 5.2 GHz in the *xoy*-plane for three-port DRA in different states. (a) State1. (b) State2. (c) State3. (d) State4. (e) State5. (f) State6. (g) State7.

three-port DRA. The radiation patterns of the novel three-port DRA in different states are mutually independent and are directed toward a broad range of distinct directions.

4. CONCLUSION

A quarter volume of cylinder dielectric resonator antenna (QVCDRA) is first presented and investigated in the paper. Slot-coupled microstrip feeding mechanism is used to stimulate the HEM_{11}-like mode effectively. Three QVCDRAs are evenly arranged along the z axis to form a new three-port DRA with reconfigurable radiation patterns. The proposed three-port DRA is demonstrated at 5.2 GHz, and a relative bandwidth of 16.20% is obtained. Through the different combinations of the three feeding ports, seven radiation patterns with different main beam directions can be achieved. The radiation beam that can be rotated through 360 degrees in the azimuth plane is obtained. Meanwhile, the maximum realized gain over the whole operation band remains higher than 8 dB consistently. The proposed three-port DRA can be applied in the WLAN diversity systems to realize directional radiating and receiving.

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