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# A Filtering Dielectric Resonator Antenna Using CPW Fed for Sub-6 GHz Applications

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**Abstract**—A filtering dielectric resonator antenna (FDRA) using an inductive CPW (coplanar waveguide) feed structure is proposed. Simultaneously, a pair of slotline stubs are respectively loaded on the signal line and ground of the CPW feed structure, which is used to generate radiation nulls near the edges of the passband. Furthermore, the two radiation nulls can be controlled independently by adjusting the length of the loaded two pairs of slotline stubs. In addition, it is interesting that $TE_{111}$ mode is split due to the different loading effects of slotline stubs in feed network, thereby three resonances in the passband are formed. Finally, an FDRA with quasi-elliptic function response is realized without additional filtering circuit. The prototype of the FDRA operating at 3.53 GHz was fabricated and measured to verify the design validity. The measured results show that the impedance bandwidth is 13.6% (3.29–3.77 GHz); the gain is basically stable at 5.7 dBi within the passband; and the two radiation nulls are located at 3.05 GHz and 3.88 GHz, respectively.

## 1. INTRODUCTION

Filtering antennas have attracted the attention of many researchers due to their multi-functional integration and compact structure [1, 2]. Compared with the microstrip antenna, dielectric resonator antenna (DRA) has the advantages of high degrees of design freedom, high gain, and low loss [3–5] which is suitable for a variety of application scenarios. Consequently, filtering dielectric resonator antenna (FDRA) has received some attention. At present, there are two main design approaches of filtering antenna: comprehensive design approach and fusion design approach. The comprehensive design approach is mainly to introduce filters in the feed structure. For example, in [6] a bandpass filter is cascaded in the feed network, and then a rectangular FDRA using slot coupling is implemented. In [7], by integrating two different pairs of band-stop resonators in the feed source, four transmission zeros are generated on two sides of the passband to provide a filtering response for the rectangular DRA. In [8], a four-leaf-clover-shaped dielectric resonator is excited with a pair of filtering baluns to realize the filtering response. However, comprehensive design approach increases circuit size and insertion loss. For the fusion design approach, the filtering function of the DRA can be realized by introducing parasitic elements on the feeding microstrip or in the DRA. In [9], a compact FDRA with a quasi-elliptic bandpass response is obtained and is fed by a microstrip-coupled slot, and two parasitic strips are parallelly added on two sides of the microstrip feedline to achieve better out-of-band suppression. In [10], a thin metal strip and two open stubs are used to establish cross coupling to generate two radiation nulls at their passband edges, enabling a DRA with a bandpass filtering response without any filtering circuit. In [11], by introducing a double-ring loop structure into the cylindrical DRA, the internal fields of the dielectric resonator at a needed frequency can cancel out, and two radiation nulls located on two sides of the passband are generated to realize the filtering response. This approach does not require additional filtering circuits, which makes the circuit structure more compact.

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Additionally, DRA can be easily excited by different feeding methods, such as coaxial probe [12], slot-coupled microstrip [13], microstrip [14], and coplanar waveguide (CPW) [15]. Compared with traditional microstrip feed, CPW has the characteristics of low loss and small dispersion, which provides a more efficient excitation mechanism for DRA [16]. In addition, the single-planar nature of CPW-feed makes it easier to fabricate than slot-coupled microstrip or probe feed. The active integration of the vias can be avoided by the ground and signal line in the same plane, and the simple structure is more convenient to connect with other devices [17, 18]. In [19] and [20], a coplanar-waveguide (CPW) series short stub is proposed, which is used as a band-stop structure, and the stopband center frequency can be controlled by changing the length of the short-end. In [21], a novel CPW-fed coupling scheme of a rectangular DRA is proposed and studied, but this design has no filtering function.

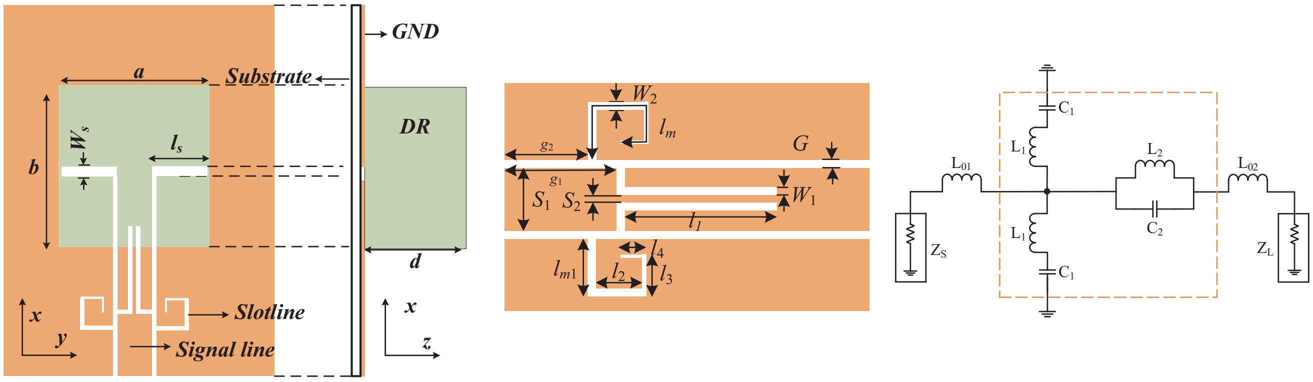
In this letter, a CPW-fed FDRA based on the fusion design method is proposed. Slotline stubs of different lengths are respectively loaded on the signal line and ground of the CPW feed to obtain two radiation nulls, and the position of the radiation nulls can be controlled separately by changing the length of the slotline stubs. Also, due to the loaded slotline stubs, the antenna bandwidth is widened. Relative analysis and discussion are provided in the following contents of this letter.

## 2. ANTENNA DESIGN

In this design, the fusion design of filtering DRA is realized by loading slotline stubs on the CPW fed structure, which makes full use of the advantages of easy integration of CPW fed structure. Finally, a compact FDRA is implemented, and the specific structure and design process of the antenna are as follows.

### 2.1. Antenna Configuration

Figure 1 shows the configuration of the proposed FDRA. It is mainly composed of a dielectric substrate and a rectangular DR. The antenna adopts a CPW inductive feed structure, and two pairs of slotline stubs are etched on the signal line and the ground of the CPW feed structure, respectively. Fig. 1(c) shows the equivalent circuit model of the FDRA, and the equivalent model of the loaded slotline stubs is marked by the dashed line box. The slotline stubs on the ground are modeled as a series $C_1$ and $L_1$. When it resonates, the circuit is in a short-circuit state, which can form a radiation null. Then, the slotline stubs on the signal line are modeled by parallel $C_2$ and the $L_2$. When it resonates, the circuit is in an open state, and a radiation null is also formed. The dielectric substrate adopts F4BRM with a relative permittivity of $\varepsilon_{r1} = 4.5$ and thickness of 1.6 mm. The overall size of antenna is 40 mm $*$ 60 mm. The rectangular DR uses TMC composite material with a relative permittivity of $\varepsilon_{r2} = 10$, and the operating mode selects the fundamental mode of the dielectric resonator, that is, the $\text{TE}_{111}$ mode. The main parameters of the antenna are shown in Table 1.



(a) (b) (c)

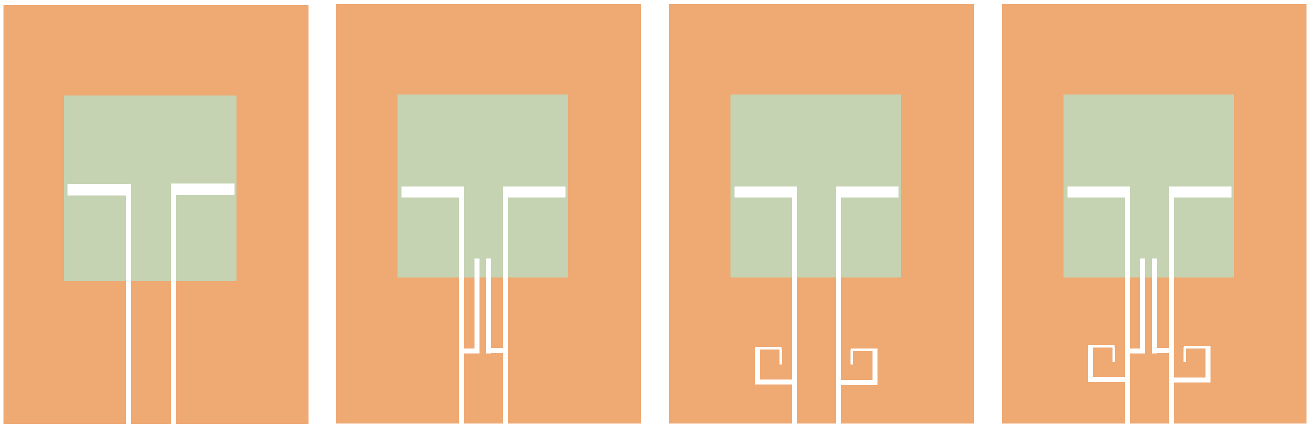
**Figure 1.** Configuration of the proposed FDRA. (a) Top and side views. (b) Feeder structure. (c) Equivalent circuit model of the FDRA.

**Table 1.** Main design parameters of antenna (mm).

| $a$ | $b$ | $d$ | $S_1$ | $S_2$ | $G$ | $g_1$ | $g_2$ | $l_s$ | $l_1$ | $l_m$ | $l_2$ | $W_s$ | $W_1$ | $W_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20.42 | 22.8 | 10.4 | 3.9 | 0.2 | 0.3 | 7.68 | 6 | 6.3 | 13 | 12.35 | 3.85 | 0.5 | 0.3 | 0.9 |

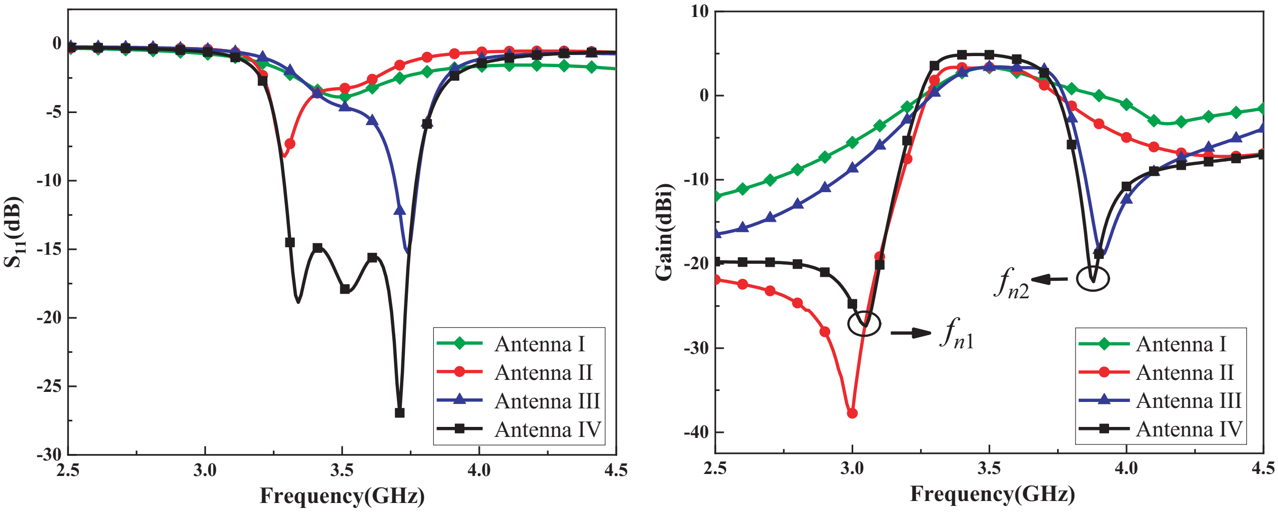
## 2.2. Operating Principle of FDRA

In order to better explain the operating principle of FDRA, the evolution process of the proposed antenna feeding network is given, as shown in Fig. 2. Their corresponding simulated gain and $S_{11}$ results are shown in Fig. 3.



(a) Antenna I (b) Antenna II (c) Antenna III (d) Antenna IV

**Figure 2.** Antenna configurations. (a) Reference Antenna I. (b) Reference Antenna II. (c) Reference Antenna III. (d) Proposed Antenna IV.

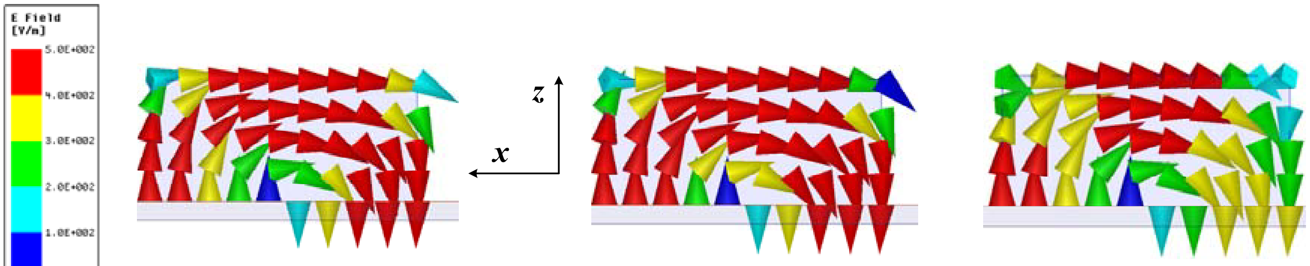


(a) (b)

**Figure 3.** $S_{11}$ and gain of the reference antennas and the proposed filtering antenna. (a) $S_{11}$. (b) Gain.

As shown in Fig. 3(a), Antenna Ihasonlyone resonant mode is the $TE_{111}$ mode of the DRA. However, there is no filtering function. In order to achieve the filtering function, two pairs of slotline stubs are loaded on the signal line and ground of CPW-fed structure. In Antenna II and Antenna III, besides the DR resonant mode, another resonant mode is obtained in the passband due to the effect of the loaded slotline stubs respectively. More importantly, it can be seen from Fig. 3(b) that the loaded slotline stub can introduce a radiation null($f_{n1}$ or $f_{n2}$) at one side of the antenna passband. Antenna IV is the proposed FDRA in this paper when two pairs of slotline stubs are loaded in Antenna IV simultaneously, and two radiation nulls ($f_{n1}$ and $f_{n2}$) are generated at both sides of the passband of the proposed FDRA, which realizes the filtering function. Moreover, according to the analysis of Antenna II and Antenna III, three resonances should be formed in the passband as shown in Fig. 3(a), and the resonance frequencies are 3.33, 3.51, and 3.71 GHz, respectively.

Figure 4 shows the E-field distributions at three resonances within the passband of the proposed antenna. According to the E-field distributions, it can be seen that the three resonant frequencies are all $\mathrm{TE}_{111}$ mode of the DRA. It can be considered that the $\mathrm{TE}_{111}$ mode is split due to the different loading effects of slotline stubs [22], so three resonances are formed. Compared with the traditional CPW inductive feed DRA, the proposed FDRA broadens the bandwidth and flattens the in-band gain of the antenna.

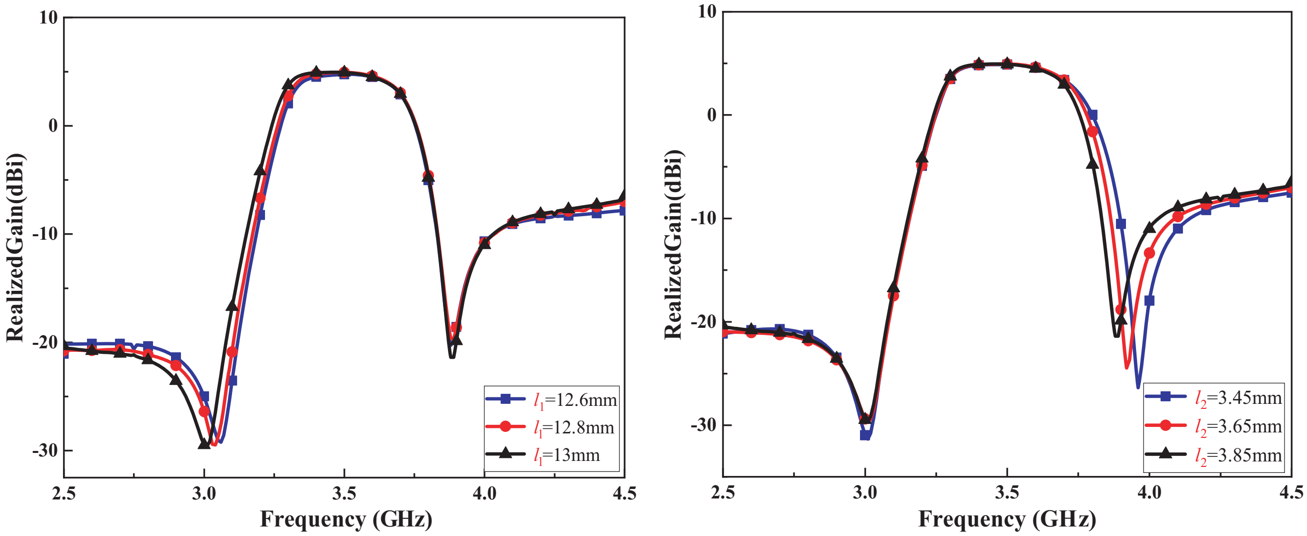


(a) (b) (c)

**Figure 4.** Simulated E-fields variation within DRA. (a) 3.33 GHz. (b) 3.51 GHz. (c) 3.71 GHz.

## 2.3. Parameter Analysis

In this section, the effect of the loaded slotline stubs on the two radiation nulls respectively are analyzed in detail. According to the simulation results, the frequencies of the radiation nulls can be adjusted by changing the corresponding the length of the slotline stubs. As shown in Fig. 5(a), it can be observed



(a) (b)

**Figure 5.** Simulated realized gains of the proposed FDRA for different (a) $l_1$, (b) $l_2$.

that $f_{n1}$ moves to the low frequency with the increase of $l_1$, while $f_{n2}$ is almost unchanged, so $f_{n1}$ can be changed by adjusting the length $l_1$ of the slotline stubs on the signal line of the CPW feed structure. As shown in Fig. 5(b), as $l_2$ increases, $f_{n2}$ moves to the low frequency, and $f_{n1}$ is basically unchanged; therefore, $f_{n2}$ is controlled by the length $l_2$ of the slotline stubs on the ground of the CPW feed structure. It can be deduced from Fig. 1(b) that $l_m$ denotes the total length of the slotline stubs on the ground, that is $l_m = l_{m1} + l_2 + l_3 + l_4$, so the influence of $l_{m1} l_3$ and $l_4$ on $f_{n2}$ is similar to that of $l_2$, which will not be described in detail due to space limitation.

## 3. RESULTS AND DISCUSSION

To verify the correctness of the design, as shown in Fig. 6, a prototype of the proposed FDRA operating at 3.53 GHz is fabricated and measured. The simulated and measured results of $S_{11}$ and realized gain of the prototype are shown in Fig. 7. It can be seen that the simulated and measured results are basically consistent. The measured 10 dB impedance bandwidth is about 13.6% (3.29–3.77 GHz), and the peak gain within the passband is about 5.7 dBi. The two radiation nulls are located at 3.05 GHz and 3.88 GHz, and the out-of-band suppression levels reach $-25$ dB and $-17$ dB, respectively.

Figure 8 shows the radiation patterns of the $E$-plane ($\phi = 0°$) and $H$-plane ($\phi = 90°$) of the prototype at 3.33, 3.51, and 3.71 GHz, respectively. Since the three frequencies are all $\text{TE}_{111}$ modes, the radiation patterns are basically similar. It can be seen that the DRA has a good radiation performance, and the main radiation performance of the antenna is stable. The co-polarization of the antenna is lower than $-20$ dB. The small deviations between measured and simulated results can be attributed to the inaccuracy in fabrication and implementation, especially the air gap between DR and the substrate due to glue bonding.

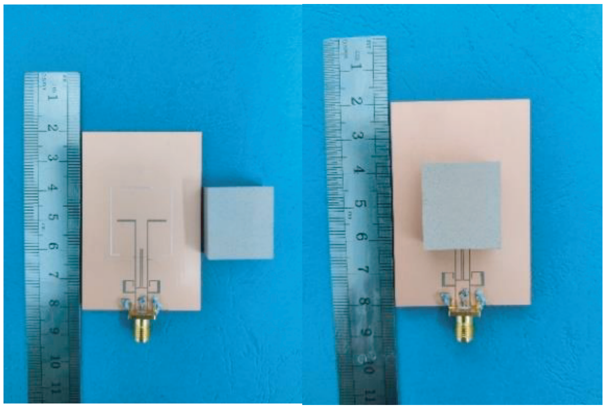


**Figure 6.** A prototype of the proposed FDRA.

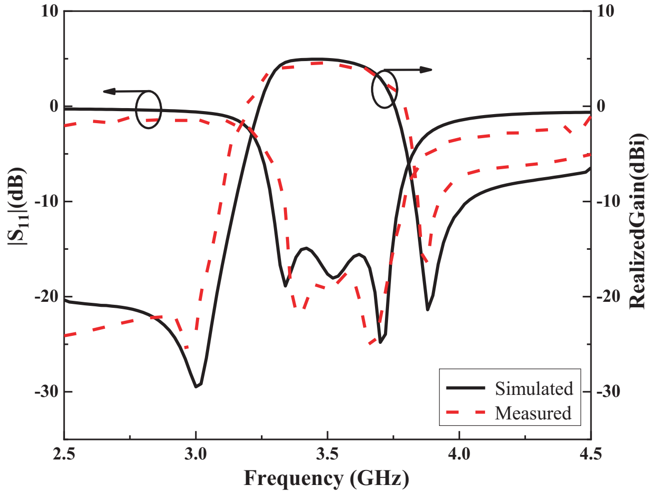
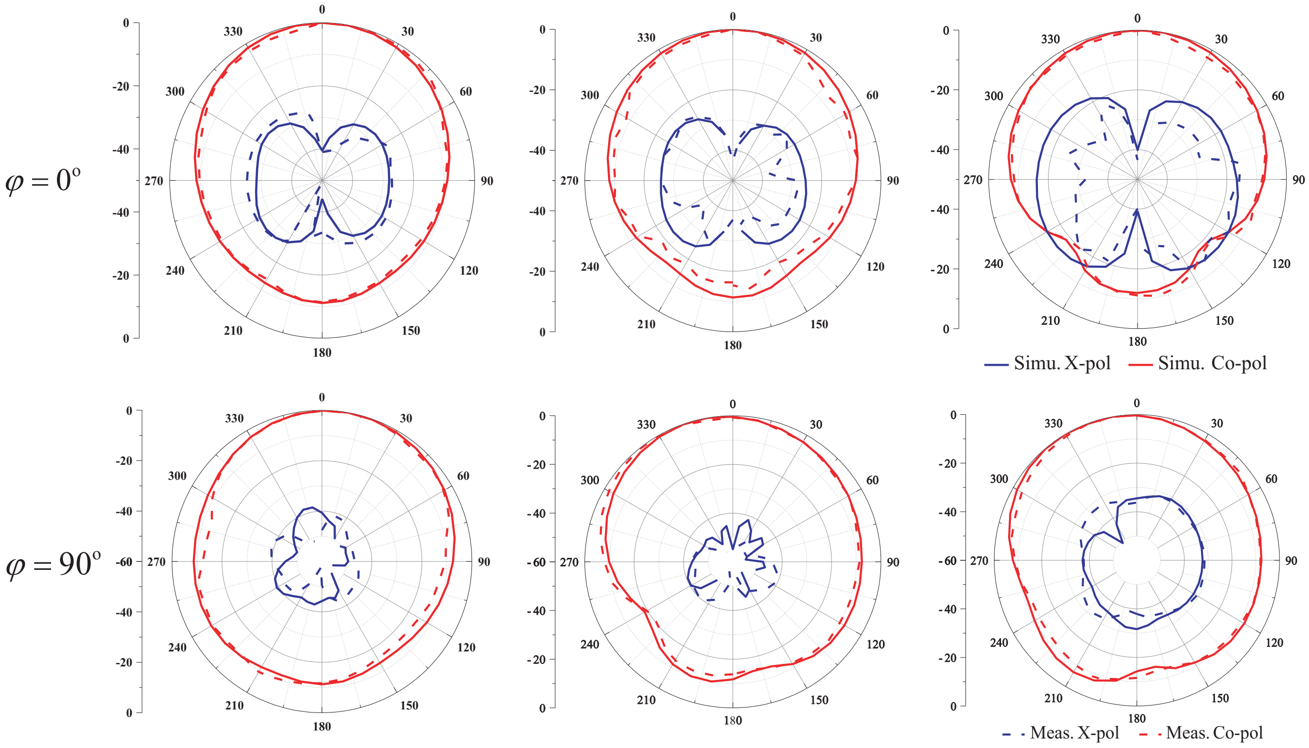


**Figure 7.** Simulated and measured $S_{11}$ and realized gain of the prototype.

**Table 2.** Performance comparison between the proposed antenna and other published antennas.

| Ref. | Center frequency (GHz) | Bandwidth (%) | Gain (dBi) | Extra filtering circuits | Radiation nulls individual control |
|---|---|---|---|---|---|
| [6] | 8.15 | 6.13 | 5.3 | Yes | No |
| [8] | 2.6 | 9.10 | 5.5 | Yes | No |
| [10] | 5 | 20.4 | 5 | No | No |
| proposed | 3.52 | 13.6 | 5.7 | No | Yes |



(a) (b) (c)

**Figure 8.** Simulated and measured radiation patterns of the FDRA. (a) 3.33 GHz. (b) 3.51 GHz. (c) 3.71 GHz.

The comparison between the proposed structure and other published articles is shown in Table 2. It can be seen that the proposed filtering DRA has higher gain and bandwidth, and compared with other antennas, it has the advantages of independently controllable radiation nulls and does not need a cascade filtering circuit.

## 4. CONCLUSION

In this letter, a novel FDRA using CPW-fed is proposed. By introducing two pairs of slotline stubs into the signal line and the ground on the CPW feed structure, respectively, two independently controllable radiation nulls are generated, which improves the out-of-band selectivity of the antenna. In addition, since the loading slotline stubs affect the impedance characteristics of the antenna, the $TE_{111}$ mode is separated, and three resonances are generated in the passband, which effectively broaden the antenna bandwidth to 13.6%, and the gain of the antenna in the passband tends to be flattened. The maximum gain reaches 5.7 dBi. Meanwhile, since the antenna adopts CPW-feed, the antenna structure is simple and easy to manufacture. The operating frequency of the antenna covers the Sub-6 GHz, which can reduce the use of filtering circuit components in the applied communication system to a certain extent.

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