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# Design of novel microstrip patch antenna for millimeter-wave B5G communications

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**Introduction:** The simplicity of integration and co-type features of microstrip antennas make them intriguing for a broad variety of applications, particularly with the growing usage of mmWave bands in wireless communications and the constant rise in data transfer in communication situations.

**Method:** This paper proposes a novel design of microstrip patch antenna for mmWave B5G communication. The main idea is to realize four-mode antenna that operates in four different frequencies. The geometry is rectangular patch whose resonance frequency is adjusted by varying the walls and pins of the structure.

**Results:** Simulation results show that the proposed antenna design has improved fractional bandwidth and performance as compared with existing antennas.

**Discussion:** The observed curve indicates that, in agreement with the modeling findings, there are four resonance spots in the operational frequency region of 2.5–3.4 GHz: 2.68 GHz, 2.9 GHz, 3.05 GHz, and 3.3 GHz, which correspond to TM<sub>1/2,0</sub>, TM<sub>3/2,0</sub>, and TM<sub>RS</sub>, respectively, and TM<sub>1/2,2</sub> four resonant modes, within the frequency range, the observed antenna gain peak is around 9 dBi, which is consistent with the measured results.

## KEYWORDS

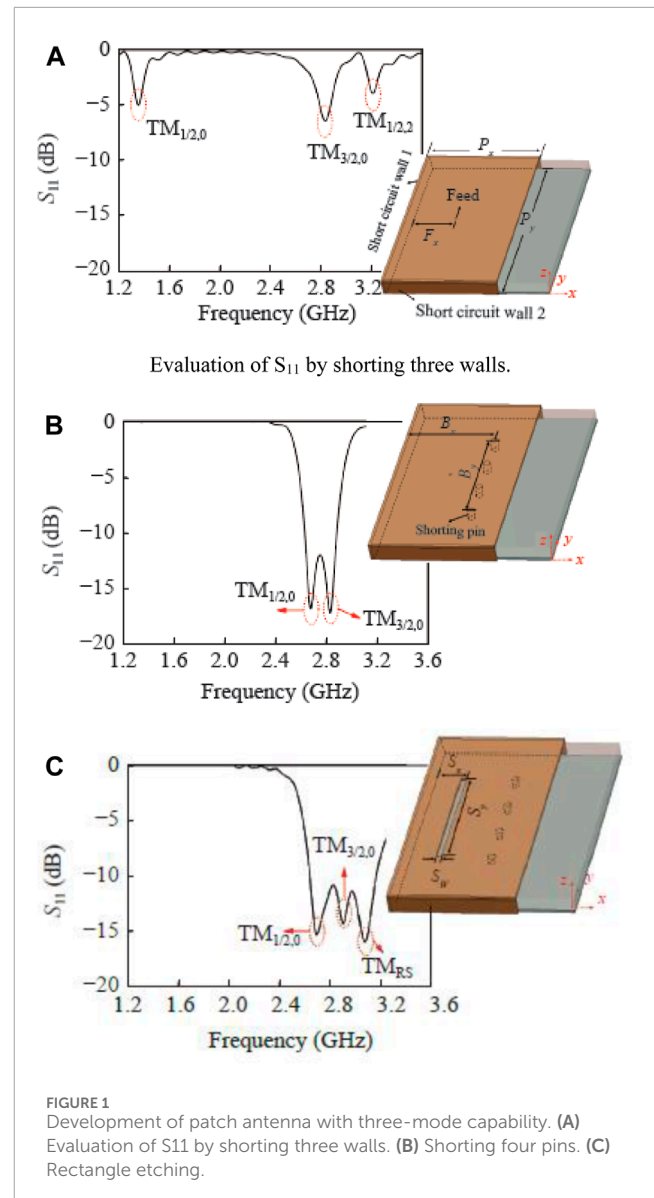
microstrip patch, antenna design, waveguide, resonator, beamform

## 1 Introduction

Millimeter-wave (mmWave) technologies, which need more capacity for high-speed data transmission, have been more in demand in the wake of beyond 5G (B5G) development. The low-profile planar structure of the microstrip antenna is easily conformable to carriers with shapes such as cylinders and curved surfaces, and has been widely used. However, the low-profile structure also causes the microstrip patch antenna to behave like a leaky wave cavity, with resonance characteristics similar to an RLC parallel resonant circuit and a high Q value, so the impedance bandwidth of the antenna is very narrow (Ullah et al., 2019; Kumar et al., 2022). Currently, there are three main methods to broaden the bandwidth of microstrip antennas: 1) Use high thickness or low dielectric constant dielectric substrates to reduce the equivalent circuit Q value, thereby increasing the impedance bandwidth

(Ullah et al., 2019; Kumar et al., 2022), but the surface wave leakage in this planar antenna increases (Liu et al., 2018a; Ge et al., 2018; Hao et al., 2019), resulting in poor radiation efficiency. 2) Improve the feeding method, such as electromagnetic coupling feeding (Fan et al., 2018; Soliman et al., 2022), L-shaped probe (Fan et al., 2018; Farooq et al., 2021; Soliman et al., 2022) or M-shaped probe (Yang et al., 2020a; Kumar et al., 2021) feeding, etc., but the antenna radiation pattern will change with frequency, and the cross-pole higher. 3) Use parasitic elements to combine multiple coupled resonance modes to increase the bandwidth, but its volume will increase a lot (Beguad et al., 2018; Srivastava et al., 2020; Karami et al., 2022). The authors in (Hannan et al., 2021; Dicarlofelice et al., 2022) etched U-shaped grooves on the radiation patch and introduced additional resonance modes near the main resonance point to broaden the bandwidth, but the thickness of the antenna was larger. Similar structures include single-layer E-shaped microstrip antenna, stacked E-shaped microstrip antenna (Dong et al., 2021), etc. Etching a slit on the surface of the patch antenna changes the surface current distribution to achieve dual-frequency resonance. Adjusting the position and size of the slit can make the resonant frequencies closer to each other, and construct dual-mode resonance to obtain wide-band characteristics. The authors in (Tewary et al., 2021) proposed loading multiple slits on a rectangular patch to simultaneously excite two orthogonal modes,  $TM_{10}$  and  $TM_{01}$ , to achieve bandwidth enhancement and compact structure, achieving 3.8% on the basis of a low profile of  $0.01\lambda_0$  impedance bandwidth, but due to the use of high-loss FR4 substrate and etching of multiple slits, the antenna gain is low and the cross-polarization is as high as  $-5$  dB. The authors in (Khan et al., 2022) loaded a short circuit on the circular patch needle, the resonant frequencies of the  $TM_{01}$  and  $TM_{02}$  modes are reconstructed, a wide impedance bandwidth of 18% is achieved in the monopole radiation mode, and the low profile characteristics of  $0.024\lambda_0$  can be maintained. The disadvantage is that the radiation peak cannot be stable within the operating frequency band. The authors in (Chinnagurusamy et al., 2021) placed short-circuit pins under the equilateral triangle patch and etched V-shaped gaps to excite the  $TM_{10}$  and  $TM_{20}$  modes, making the antenna bandwidth reach 32%, but the antenna thickness also increased to  $0.09\lambda_0$ . The authors in (Yang et al., 2020b) designed a patch antenna based on  $TM_{1/2,0}$ ,  $TM_{1/2,2}$  and  $TM_{3/2,2}$  three-mode resonance, and improved the radiation performance of the antenna by loading multiple short-circuit walls, which enhances the bandwidth to 26.2% at a profile height of  $0.059\lambda_0$ . The authors in (Lu et al., 2018) designed a broadband circular sector patch antenna based on  $TM_{4/3,1}$  and  $TM_{8/3,1}$  modes. The design criteria were determined by multi-mode dipole and cavity models. At  $0.05\lambda_0$ , a useable radiation bandwidth of 14.5% is achieved under low profile conditions. The authors in (Sharaf et al., 2020) designed a three-mode sector patch antenna based on  $TM_{12/17,1}$ ,  $TM_{36/17,1}$  and  $TM_{60/17,1}$  based on the zero-frequency scanning working principle of a direct electric dipole, the antenna operating bandwidth is enhanced to 24%, and the thickness is maintained at  $0.05\lambda_0$ .

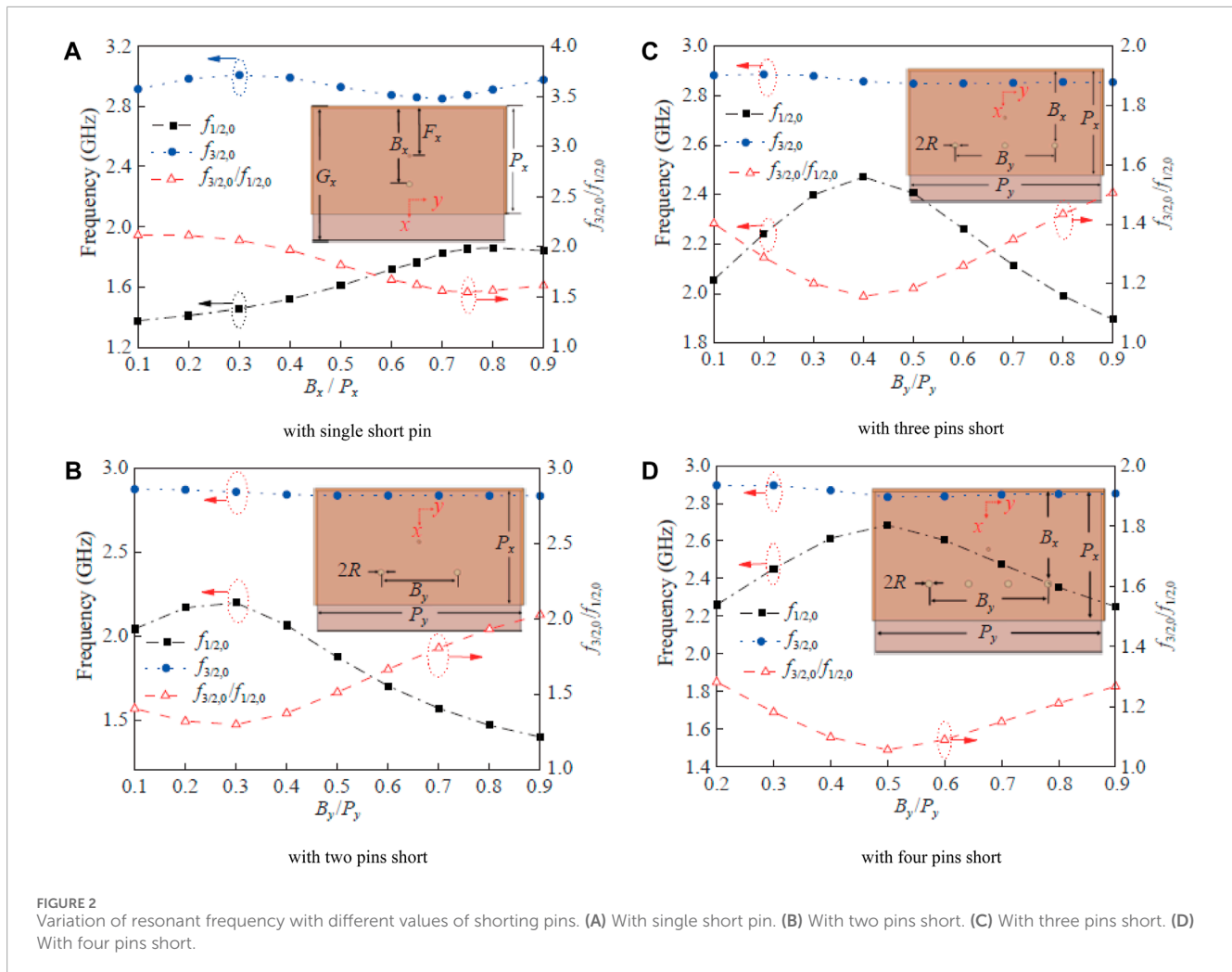
In order to address the above problem, this paper reduces the high cross-polarization of the H-plane pattern by loading a short-circuit wall on the non-radiating side of the rectangular patch, and loading a short-circuit pin under the patch to increase the resonant frequency of the  $TM_{1/2,0}$  mode.



The main contributions of this work are as follows.

- In the  $TM_{3/2,0}$  mode, a rectangular slot is cut at the zero current position to excite the radiation slot mode, forming a three-mode resonant patch antenna with low profile, wide bandwidth and reduced H-plane cross-polarization performance.
- The antenna is only 3 mm thick ( $0.029\lambda_0$ ). In this case, an impedance bandwidth of 18% (2.64–3.17 GHz) is achieved, and the H-plane cross-polarization is reduced to below  $-20$  dB.
- By appropriately increasing the patch width and adjusting the antenna structure, the frequency of the  $TM_{1/2,2}$  mode is reduced and brought closer to the  $TM_{1/2,0}$ ,  $TM_{3/2,0}$  and  $TM_{RS}$  modes, thereby further achieving four-mode resonance while maintaining the antenna with the thickness unchanged (3 mm), the bandwidth is further increased to 21.7% (2.67–3.32 GHz).

The remaining of this paper is organized as follows. In Section 2, the proposed model design and working principle is discussed. In Section 3, the practical implementation of the proposed antenna



is presented and the experimental analysis is performed with comparative evaluation. Finally, Section 4 concludes the paper.

## 2 Model design and working principle

### 2.1 Developing three-mode broadband patch antennas

The illustration in Figure 1A shows a rectangular microstrip patch antenna ( $P_x = 56$  mm,  $P_y = 100$  mm). By loading short-circuit walls on three sides. It is even-order mode can be suppressed and the E-plane ( $x$ - $z$  plane) high side lobes of the pattern and high cross-polarization of the H-plane ( $y$ - $z$  plane) pattern (Srivastava et al., 2020; Subha et al., 2020; Koutinos et al., 2022), the resonance of the antenna in the three modes are  $TM_{1/2,0}$ ,  $TM_{3/2,0}$ ,  $TM_{1/2,2}$ , and frequencies  $f_{1/2,0}$ ,  $f_{3/2,0}$ ,  $f_{1/2,2}$  are 1.35 GHz, 2.84 GHz, and 3.21 GHz respectively. An array of four short-circuiting pins (shown in the inset of Figure 1B) is then loaded under the radiation patch, boosting  $f_{1/2,0}$  to around 2.68 GHz while keeping  $f_{3/2,0}$  at 2.83 GHz,  $f_{1/2,2}$  is also boosted to 3.75 GHz. Finally, a rectangular gap is etched near the zero current line of the  $TM_{3/2,0}$  mode (as shown in the inset of Figure 1C) to excite the gap radiation mode  $TM_{RS}$  (Subha et al.,

2020; Koutinos et al., 2022). The  $TM_{RS}$  mode operates at 3.07 GHz, close to  $f_{1/2,0}$  and  $f_{3/2,0}$ , the impact of this gap on the  $TM_{1/2,0}$  and  $TM_{3/2,0}$  modes is controllable, achieving three-mode resonance based on  $TM_{1/2,0}$ ,  $TM_{3/2,0}$  and  $TM_{RS}$ . Through these measures, the bandwidth and radiation performance of the antenna are improved.

### 2.2 Design parameters and analysis

The number and position of short-circuit pins, the length, width and position of the gap are several key parameters that affect the performance of the patch antenna, and they will be analyzed in depth.

#### 2.2.1 Load short circuit pin reassign $TM_{1/2,0}$ mode

By appropriately adding short-circuit pins, the resonant frequency of the  $TM_{1/2,0}$  mode can be effectively controlled, while it has little effect on the  $TM_{3/2,0}$  mode, and the frequency ratio can be significantly reduced:  $f_{3/2,0}/f_{1/2,0}$ . Figure 2 shows how the resonant frequency and frequency ratio of the antenna change with the position and number of short-circuit pins. Figure 2A shows the case where a single pin is located  $B_x$  from the short-circuit wall along the  $x$ -direction at the center plane of the patch (Lu et al.,

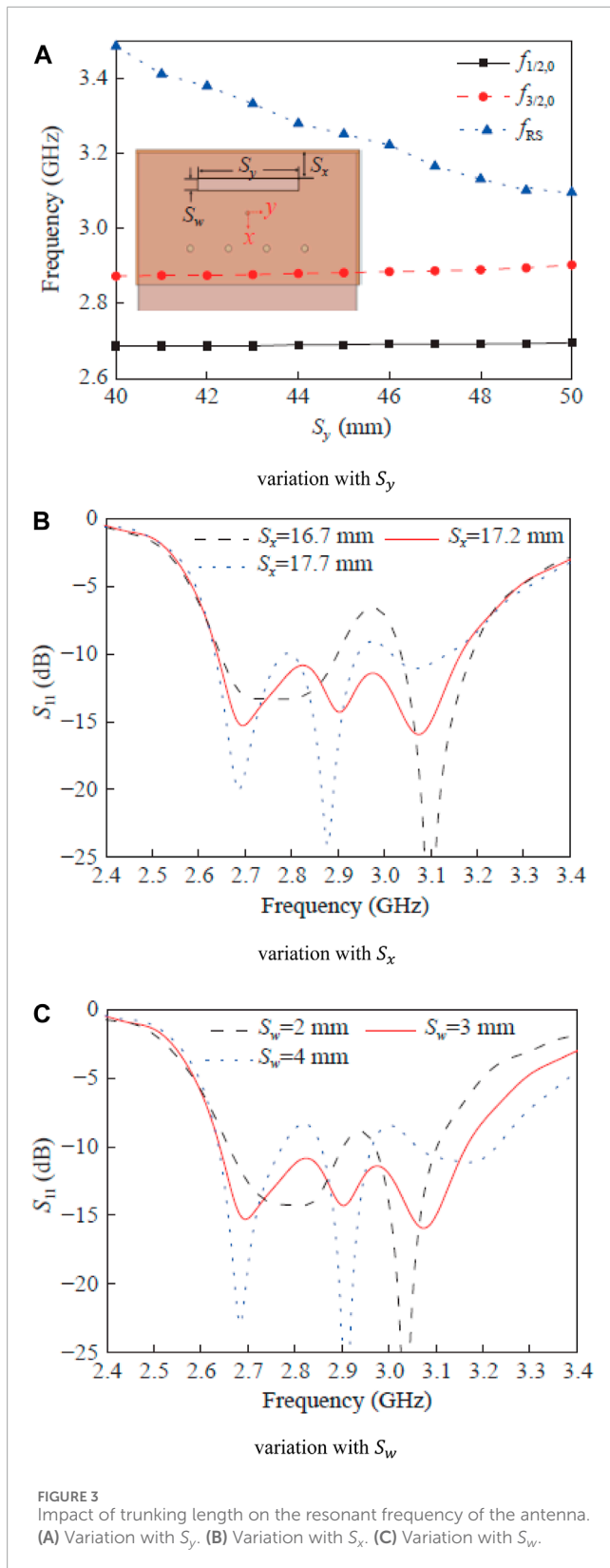


FIGURE 3  
Impact of trunking length on the resonant frequency of the antenna. (A) Variation with  $S_y$ . (B) Variation with  $S_x$ . (C) Variation with  $S_w$ .

2017; Liu et al., 2018b; Lee et al., 2019). When  $B_x/P_x = 0.1$ ,  $f_{1/2,0}$  and  $f_{3/2,0}$  are approximately 1.4 GHz and 2.9 GHz respectively, resulting in a large frequency ratio of  $f_{3/2,0}/f_{1/2,0} = 2.1$ . When  $B_x/P_x$  reaches about 0.75, because the short-circuit pin is properly placed around the node line of the electric field of the  $TM_{3/2,0}$  mode, a minimum

$f_{3/2,0}/f_{1/2,0}$  of about 1.55 is obtained. After  $B_x/P_x$  is greater than 0.75, the frequency ratio of the dual modes gradually increases (Liu et al., 2017a; Jian et al., 2020; Wu et al., 2020), moving away from each other. The results show that the minimum frequency ratio can be obtained when  $B_x$  is  $0.75P_x$ .

Figure 2B shows the analysis of loading two short-circuit pins when  $B_x/P_x = 0.75$ . As  $B_y/P_y$  increases from 0.1 to 0.9,  $f_{1/2,0}$  has a maximum value of 2.2 GHz at  $B_y/P_y = 0.3$ , whereas  $f_{3/2,0}$  almost remains around 2.85 GHz. Therefore, by choosing  $B_x/P_x = 0.75$  and  $B_y/P_y = 0.3$ , the minimum value of  $f_{3/2,0}/f_{1/2,0} \approx 1.30$  can be achieved. Figures 2C, D further study  $f_{1/2,0}$ ,  $f_{3/2,0}$  and  $f_{3/2,0}/f_{1/2,0}$  when loaded with three and four short-circuit pins respectively at  $B_x/P_x = 0.75$  (Liu et al., 2017b; Gao et al., 2019; Ma et al., 2021). Compared with Figures 2A, B, similar trends for  $f_{1/2,0}$  and  $f_{3/2,0}$  are obtained. Therefore, when four short-circuit pins are loaded, and  $B_x/P_x = 0.75$  and  $B_y/P_y = 0.5$ , the minimum value of  $f_{3/2,0}/f_{1/2,0} \approx 1.06$  can be reached.

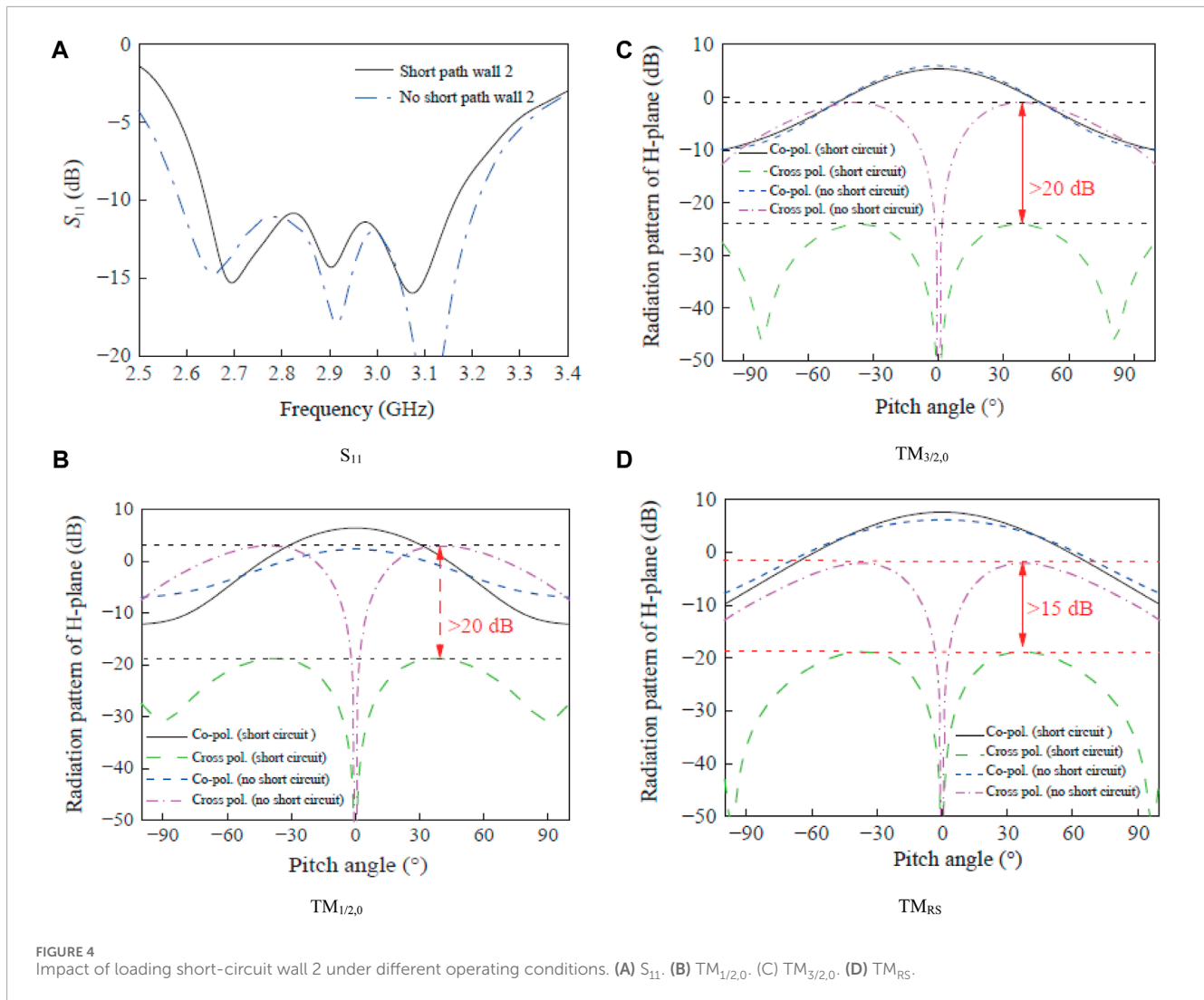
## 2.2.2 Etching gap to excite $TM_{RS}$ mode

To further broaden the impedance bandwidth of the antenna, a linear groove is etched on the radiation patch near the  $TM_{3/2,0}$  mode zero current line to excite the  $TM_{RS}$  mode of the patch antenna and move it closer to  $TM_{1/2,0}$  and  $TM_{3/2,0}$  mode (Cao et al., 2021; Liu, 2021; Cao et al., 2022). By appropriately modifying the trunking length ( $S_y$ ),  $TM_{3/2,0}$  and  $TM_{RS}$  modes can be combined to extend the bandwidth. It can be seen from Figure 3A that as  $S_y$  increases from 40 mm to 50 mm,  $f_{RS}$  drops sharply from 3.5 GHz to 3.1 GHz, but  $f_{1/2,0}$  and  $f_{3/2,0}$  remain unchanged, so to obtain the widest bandwidth,  $S_y = 50$  mm (Chung et al., 2022; Jiang and Li, 2022). Further adjust the gap position ( $S_x$ ) and width ( $S_w$ ) to analyze the impedance matching problem. Figures 3B, C show that  $S_x$  increases from 16.7 mm to 17.7 mm (Wu et al., 2020),  $S_w$  increases from 2 mm to 4 mm. The impedances are not always well matched, and only when  $S_x = 17.2$  mm and  $S_w = 3$  mm can a wider bandwidth and good impedance matching be achieved.

What needs to be pointed out here is that the  $TM_{RS}$  mode excited by the loading gap also radiates electromagnetic energy. Since the resonant frequencies of the  $TM_{RS}$  mode and the  $TM_{3/2,0}$  mode are close to each other, when the two slots operate at the same time (Mao et al., 2022a; Mao et al., 2022b; Dai et al., 2023), they will affect the pattern of the  $TM_{3/2,0}$  mode, causing the main beam direction to be deflected. The resonant frequency of  $TM_{1/2,0}$  mode is lower, and the frequency separation from  $TM_{RS}$  is large. The electrical distance between them is very small for the  $TM_{1/2,0}$  mode. Therefore, the loading gap has little impact on the pattern of the  $TM_{1/2,0}$  mode.

## 2.2.3 The impact of loading short-circuit wall 2

To verify the effect of loading short-circuit wall 2 on H-plane cross-polarization, this paper uses a three-mode resonant broadband antenna without loading short-circuit wall 2 for comparison. To make both antennas resonate in the same mode and have close operating frequencies, the structure is optimized by adjusting the short-circuit pins, the position and size of the gaps, etc (Li et al., 2021a; Dai et al., 2022; Zhang et al., 2023a). Figure 4A shows the port reflection coefficients of the two antennas. It can be seen that they have three identical resonance modes, but the bandwidth of the antenna without short-circuit wall 2 is slightly



wider. Figures 4B–D is a comparison of the H-plane radiation patterns of the two antennas in three modes (Zhang et al., 2023b; Wang et al., 2023). It can be seen that the cross-polarization of the H-plane of the antenna loaded with short-circuit wall 2 is reduced by more than 15 dB, proving that short-circuit wall 2 can greatly improve the radiation performance of the antenna in the far area.

## 2.2.4 Implementation of three-mode antenna and experimental results

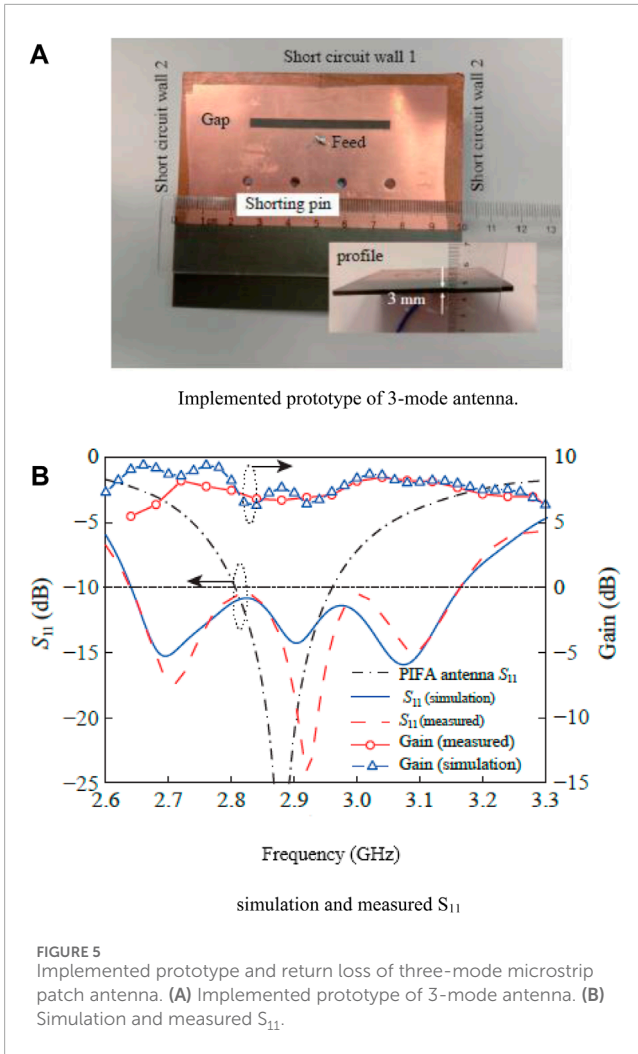
Figure 5A shows the top view and side view of the three-mode patch antenna, and its cross-sectional height is  $0.029\lambda_0$  (3 mm). Figure 5B shows the simulated and measured port return loss  $|S_{11}|$ , and compares it with a conventional planar inverted-F antenna (PIFA) (Zhou et al., 2022a; Zhou et al., 2022b; Wen et al., 2023). It can be found from Figure 5B that there are three minimum values in the operating frequency band of 2.6–3.2 GHz, which are consistent with the three simulated resonance modes, namely,  $TM_{1/2,0}$ ,  $TM_{3/2,0}$  and slot mode ( $TM_{RS}$ ). Due to the combination of three resonance modes, the measured center bandwidth extends to 18% (from 2.64 to

3.17 GHz), which is 3.4 times the traditional PIFA center bandwidth (5.2%, 2.81–2.96 GHz).

Figure 6 further shows the simulation and test pattern of the antenna at three resonance points. Due to the asymmetric structure of the antenna along the  $x$ -direction, the radiation pattern is slightly tilted, and the simulation results are in good agreement with the measured results (Gao et al., 2019; Yang et al., 2023a; Jannat et al., 2023). In addition, due to the loading of short-circuit wall 1, the side lobes of the E-plane ( $x$ - $z$  plane) radiation pattern are lower. After loading the short-circuit wall 2, the cross-polarization of the H-plane ( $y$ - $z$  plane) radiation pattern is better. The overall gain within the frequency band is greater than 6.5 dB<sub>i</sub>, and the peak gain is about 8 dB<sub>i</sub>.

## 3 Implementation and analysis of four-mode microstrip antenna

It can be seen from Figure 1B that as the short-circuit pin is loaded, the resonant frequency  $f_{1/2,2}$  of the  $TM_{1/2,2}$  mode will be far away from  $f_{3/2,0}$  and cannot be directly used to increase the



bandwidth (Chen et al., 2022a; Yin et al., 2022; Jiang and Xu, 2023). The resonant frequency ( $f_{mn}$ ) of  $TM_{mn}$  in traditional PIFA can be obtained from the cavity model theory:

$$f_{mn} = \frac{c}{2\sqrt{\epsilon_r}} \sqrt{\left(\frac{m}{P_x}\right)^2 + \left(\frac{n}{P_y}\right)^2} \quad (1)$$

In the formula:  $m = 1/2, 3/2, 5/2, \dots$ ;  $n = 0, 2, 4, \dots$ ;  $c$  is the speed of light. Eq. 1 shows that increasing the patch width ( $P_y$ ) can effectively reduce  $f_{1/2,2}$ . The  $f_{RS}$  can be adjusted by adjusting the gap length  $S_y$ . To further increase the center bandwidth, the patch width can be increased to reduce  $f_{1/2,2}$  (Jiang et al., 2022; Xu et al., 2023a; Fang et al., 2023). Make it close to  $f_{3/2,0}$  and  $f_{RS}$ , and simultaneously correct other parameters of the antenna, such as the size of the short-circuit pin and the position of the gap, etc., so that  $TM_{1/2,0}$ ,  $TM_{3/2,0}$ ,  $TM_{RS}$  and  $TM_{1/2,2}$  four modes are close to each other, further broadening the bandwidth.

The specific parameter analysis of the four-mode resonant antenna is similar to that in Section 2.2 and will not be repeated here. The specific structure of the four-mode resonant broadband antenna is shown in Figure 7A, and the antenna structural parameters are shown in Table 1. Figure 7B shows the simulated and measured return loss and gain (Hu et al., 2019; Liu et al., 2022). It can be found from the measured curve that there are four resonance

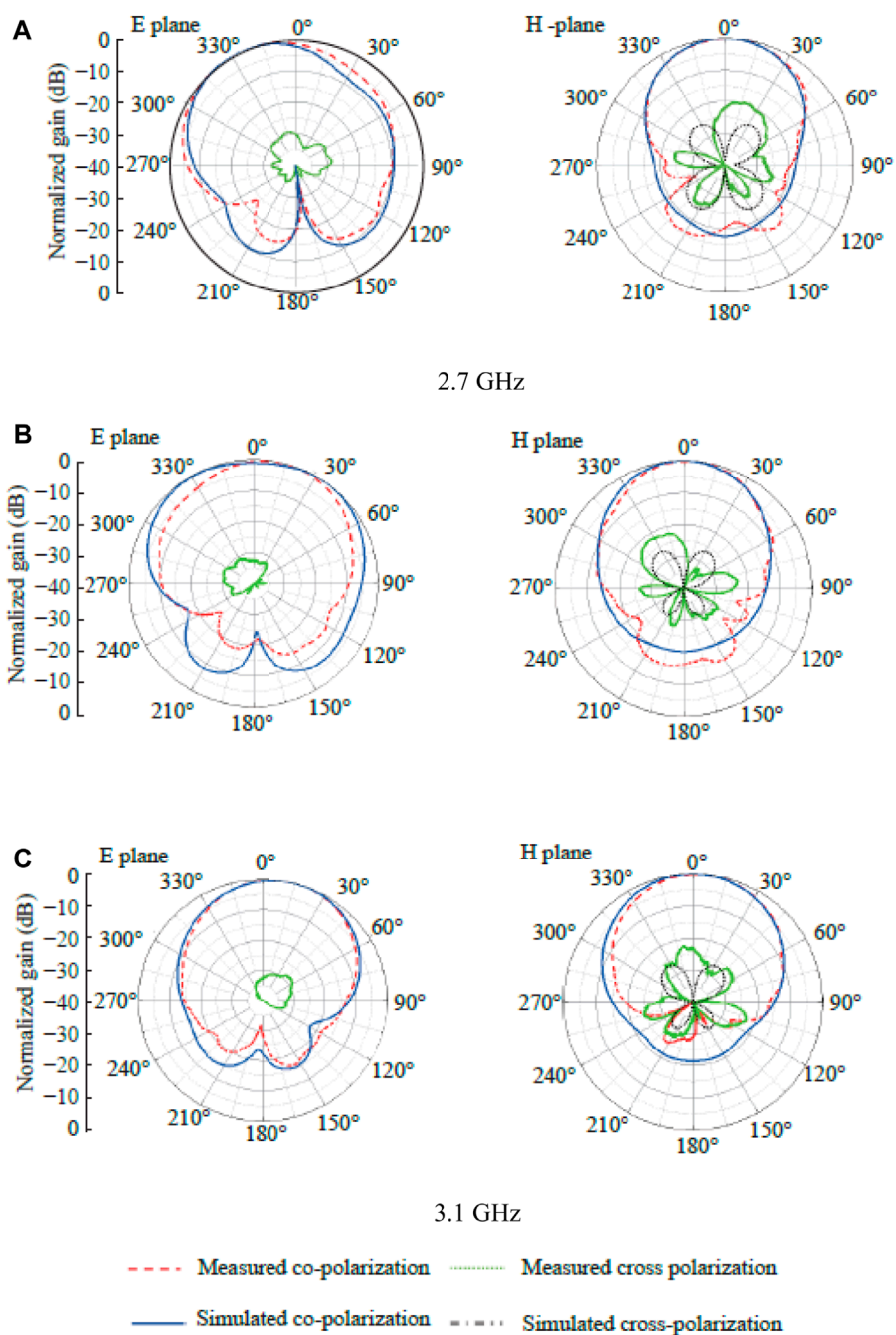
TABLE 1 Physical parameters of the proposed four-mode antenna.

| Parameter | Value (mm) |
|-----------|------------|
| $P_x$     | 56         |
| $P_y$     | 122        |
| $G_x$     | 86         |
| $R$       | 3.15       |
| $B_x$     | 40         |
| $B_y$     | 30.9       |
| $S_x$     | 16         |
| $S_y$     | 57         |
| $S_w$     | 4          |
| $F_x$     | 25         |
| $H$       | 3          |

points in the operating frequency band of 2.5–3.4 GHz: 2.68 GHz, 2.9 GHz, 3.05 GHz, 3.3 GHz, corresponding to  $TM_{1/2,0}$ ,  $TM_{3/2,0}$ ,  $TM_{RS}$  respectively, and  $TM_{1/2,2}$  four resonant modes, consistent with the simulation results. The measured antenna gain peak within the frequency band is approximately 9 dB. The small differences between simulation and actual measurements of return loss and gain are mainly caused by processing errors (Chen et al., 2022b). Due to the combination of four resonant modes, the measured center bandwidth of the antenna is further extended from 18% (2.64–3.17 GHz) of the three-mode antenna to 21.7% (2.67–3.32 GHz).

Figure 8 further shows the electric field distribution corresponding to these four modes. In Figure 8A, there is only one zero value line in the  $y$  direction, corresponding to the  $TM_{1/2,0}$  mode. In Figure 8B, two zero value lines in the  $y$  direction appear, corresponding to the  $TM_{3/2,0}$  mode (Li et al., 2021b; Xu et al., 2022; Xu et al., 2023b). In Figure 8C, only the radiation around the gap is strong (Huang et al., 2018; Min et al., 2023; Min et al., 2024), and the rest are weak, corresponding to the  $TM_{RS}$  mode. In Figure 8D, there is a zero value line in the  $y$  direction, and two zero points appear in the  $x$ -direction, corresponding to the  $TM_{1/2,2}$  mode (Huang et al., 2023; Huang and Liu, 2023; Lan et al., 2024). Figures 9A–D further shows the four resonance modes of the four-mode broadband antenna (Lu and Osorio, 2018; Yang et al., 2023b; Gao et al., 2023). The simulation and measured diagrams at the points are in good agreement with the actual measurement results (Chen et al., 2022c; Xu et al., 2023c).

Table 2 further shows the comparison between the antenna designed in this article and the reference broadband antennas. It can be seen that the proposed antenna has comprehensive advantages in terms of thickness and electrical performance.



**FIGURE 6** Comparison of radiation pattern and normalized gain of three-mode antenna. (A) 2.7 GHz. (B) 2.9 GHz. (C) 3.1 GHz.

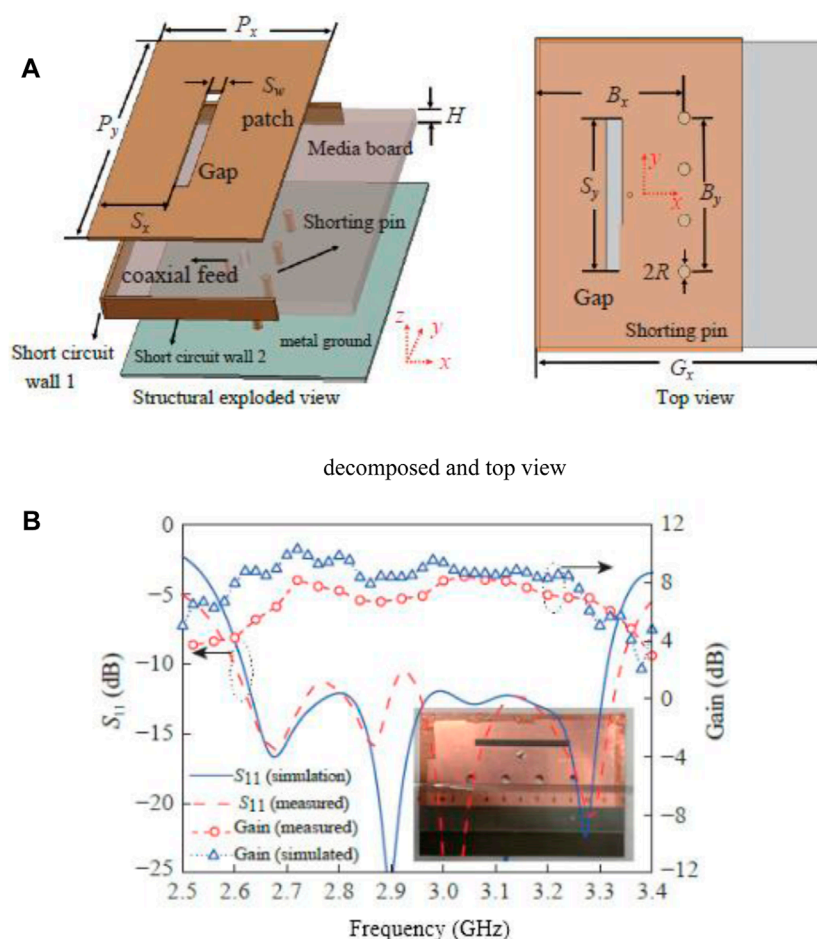
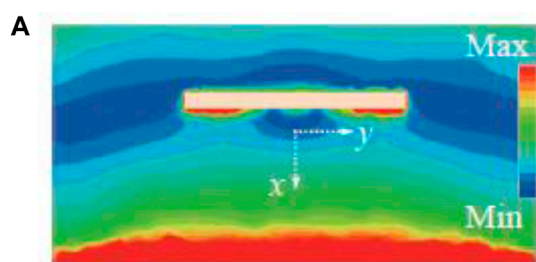


FIGURE 7 Implemented prototype of four-mode antenna and evaluation of return loss. (A) Decomposed and top view. (B)  $S_{11}$  and gain comparison.

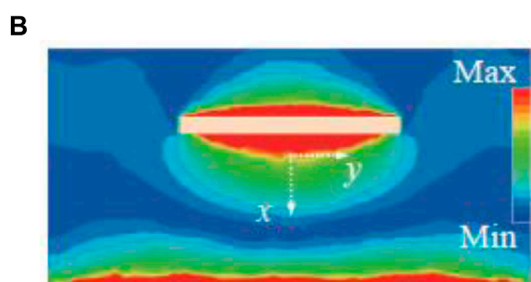
TABLE 2 Performance comparison of the proposed and existing antenna designs.

| References                   | Dimension                  | Peak gain (dB <sub>i</sub> ) | Maximum cross-polarization (dB) | Impedance bandwidth (%) |
|------------------------------|----------------------------|------------------------------|---------------------------------|-------------------------|
| Dicarlofelice et al. (2022)  | $0.059 \lambda_0$          | 8.0                          | -12.3                           | 26.2                    |
| Hannan et al. (2021)         | $0.054 \lambda_0$          | 10.0                         | -8.0                            | 14.5                    |
| Tewary et al. (2021)         | $0.036 \lambda_0$          | 10.8                         | -9.2                            | 33.3                    |
| Khan et al. (2022)           | $0.032 \lambda_0$          | 6.8                          | -18.0                           | 15.2                    |
| Chinnagurusamy et al. (2021) | $0.036 \lambda_0$          | 5.0                          | 0                               | 15.3                    |
| Yang et al. (2020b)          | $0.037 \lambda_0$          | 5.9                          | -16.0                           | 18.0                    |
| Proposed                     | $0.029 \lambda_0$ (3-mode) | 8.0                          | <-20.0                          | 18.0                    |
|                              | $0.03 \lambda_0$ (4-mode)  | 8.0                          | <-20.0                          | 21.7                    |

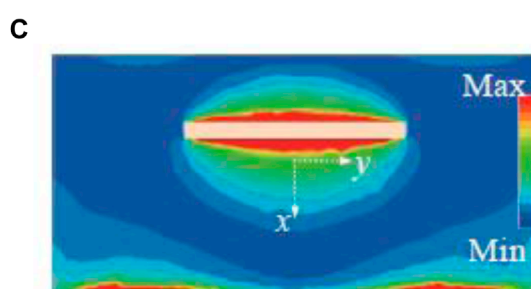




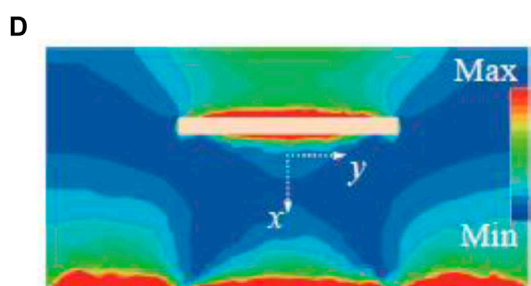
$TM_{1/2,0}$  (2.68 GHz)



$TM_{3/2,0}$  (2.9 GHz)



$TM_{RS}$  (3.05 GHz)



$TM_{1/2,2}$  (3.3 GHz)

**FIGURE 8**  
Comparison of E-field distribution in different modes and frequencies. **(A)**  $TM_{1/2,0}$  (2.68 GHz). **(B)**  $TM_{3/2,0}$  (2.9 GHz). **(C)**  $TM_{RS}$  (3.05 GHz). **(D)**  $TM_{1/2,2}$  (3.3 GHz).

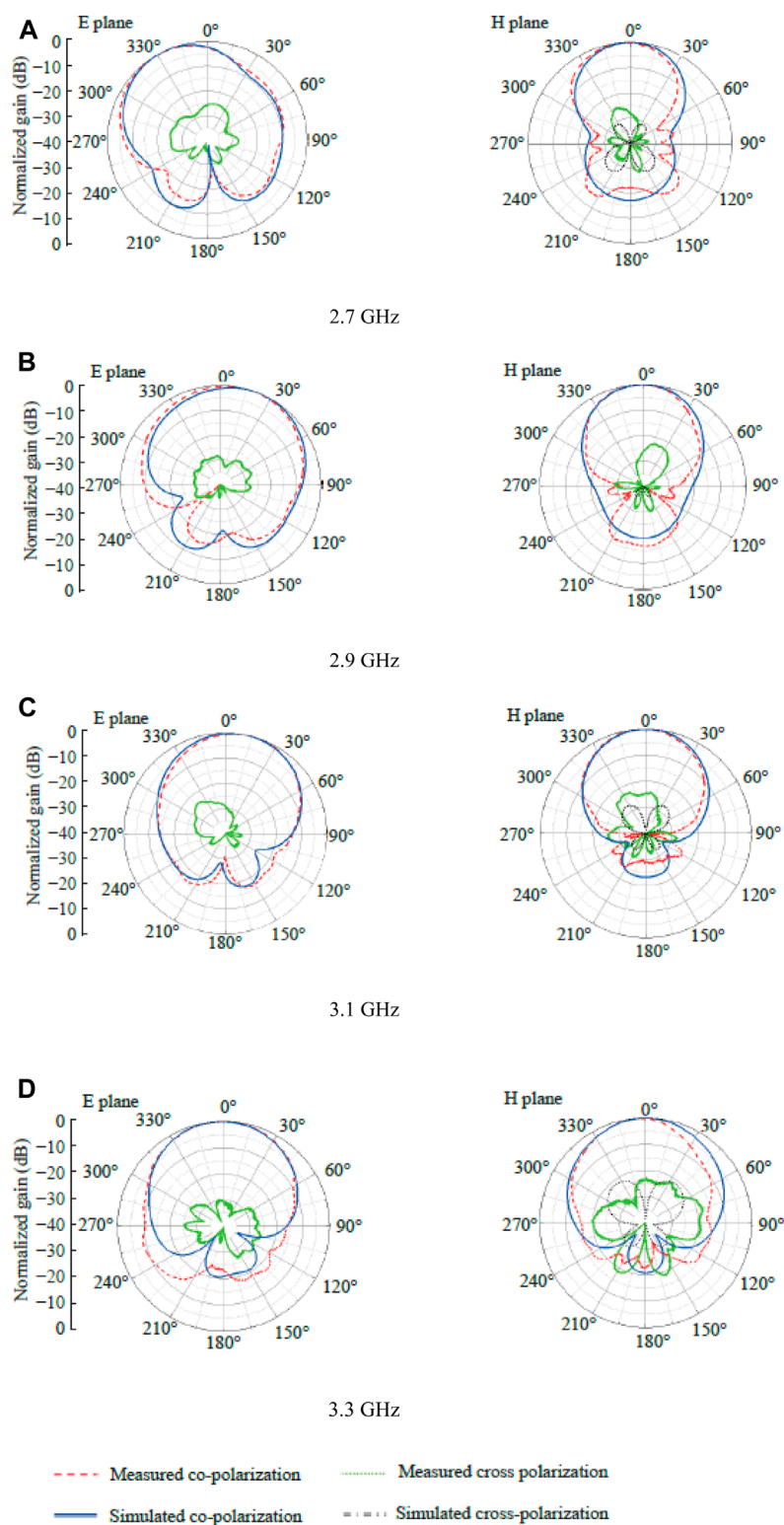


FIGURE 9 Comparison of radiation pattern and normalized gain of four-mode microstrip antenna. (A) 2.7 GHz. (B) 2.9 GHz. (C) 3.1 GHz. (D) 3.3 GHz.

## 4 Conclusion

This article designs a low-profile, multi-mode, broadband patch antenna that improves radiation performance. By loading a short-circuit wall on the non-radiating edge of the patch, the E-plane side lobes of the antenna radiation pattern are reduced, effectively reducing the H-plane cross-polarization. By adjusting the number and position of the pins, the size and position of the opening slit, and the width of the patch antenna, we further introduced the three-mode patch antenna based on  $TM_{1/2,0}$ ,  $TM_{3/2,0}$  and  $TM_{RS}$  made by predecessors. In  $TM_{1/2,2}$  mode, a four-mode low-profile broadband patch antenna is designed, which achieves an operating bandwidth of 21.7% with a thickness of only  $0.03\lambda_0$ .

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

## Author contributions

JT: Conceptualization, Formal Analysis, Resources, Writing—original draft. DA: Software, Validation, Methodology, Resources, Writing—review and editing. IK: Conceptualization, Project administration, Supervision, Visualization, Writing—original draft. P-CW: Investigation, Methodology, Validation, Resources, Writing—review and editing. DM: Funding acquisition,

Investigation, Methodology, Project administration, Resources, Supervision, Writing—review and editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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