

Research Paper

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Dual-band slot microstrip patch antennas with dual-radiation modes for wireless communication

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Abstract

In this paper, a novel compact dual-band microstrip patch antenna with dual-radiation modes is investigated. The proposed antenna consists of a rectangular ground plane, a U-shaped feed probe, and an H-shaped slot radiating patch. By adjusting the size of these structures, a dual-band antenna can be obtained. In the low-frequency band, the antenna can radiate one radiation beam with high gain. In the high-frequency band, the antenna can achieve monopole-like radiation pattern. Therefore, an antenna prototype is fabricated and measured for validation. Good agreement between the simulated and measured results is observed in this paper. The antenna's operating frequency ranges are 3.6–3.85 GHz in the low-frequency band and 5.1–6.1 GHz in the high-frequency band with the reflection coefficient less than -10 dB. At 3.7 GHz, the antenna radiate one beam with 8.8 dBi realized gain. At 5.5 GHz, it exhibits dual-radiation beams directed to -48 and 48° with 5.6 and 5.5 dBi realized gain in the xoz -plane and -48 and 48° with 2.9 and 3.0 dBi realized gain in the yo z -plane. Therefore, the proposed antenna is a good candidate for wireless communication systems.

Introduction

In recent years, wireless communication systems such as mobile phones, Worldwide Interoperability for Microwave Access (WiMax), Global Positioning System (GPS), wireless local area networks (WLANs), and satellite communication systems have been more and more popularly applied in public internet hotspots, home, and business where large buildings and spaces need wireless coverage. To meet the application requirements of the above systems, antennas with dual-radiation modes have been proposed in [1–3]. These antennas are applied for communication systems which require multiple-coverage. The number of antennas in a system is reduced by using dual-radiation mode antennas; meanwhile, the link quality is improved and the network deployment becomes easier.

With the rapid development of radio technology, patch antennas have been widely applied in a number of aspects of communication systems especially in wireless communication systems due to their excellent characteristics such as robustness, miniaturization, low profile, and low cost. As a well-known fact, most of microstrip patch antennas radiate the broadside beam by working in the fundamental TM_{01} mode [4]. However, microstrip antennas can radiate two symmetrical beams by operating in the TM_{02} mode [5–11]. Therefore, dual-beam microstrip antennas have been studied in recent years. For instance, the bandwidth of a microstrip antenna is broadened by a U-slot and operated in the TM_{02} mode to radiate dual beams [8]. However, the dual beams are little symmetric because of the asymmetry structure. The discrepancy between the beams' peak gains is 1.98 dB, and there is a little difference between the directions of the beams. In [9], a microstrip antenna is fed by a cross-shaped probe at the center of the patch. The proposed method can broaden the bandwidth of the antenna and achieve two symmetrical beams. However, the size of the antenna is quite large and the structure is complex, which is not suitable for miniaturizing wireless communication systems. A frequency selective surface is used to improve the radiation performance of the U-slot patch antenna in [10]. However, the difference in gain between two beams exceeds 2 dB and the size of the antenna is larger than one of other literature studies [8, 9, 11]. A dual-band U-slot antenna with single- and dual-beams is presented for indoor and outdoor communication systems [11]. The antenna can radiate a broadside beam in the lower bandwidth and a dual-beam in the higher bandwidth. However, the dual-beam of the above antenna is radiated in one plane, but couldn't cover the omni-direction. Hence, low-profile microstrip antennas with monopole-like radiation patterns have been investigated [12, 13, 14, 15]. The antenna [12] with two layer patches can radiate monopole-like radiation patterns in two operating frequency bands for WLAN applications. The dual-band microstrip monopole patch antenna with high gain is realized in [13]. The operation principle of the microstrip monopole

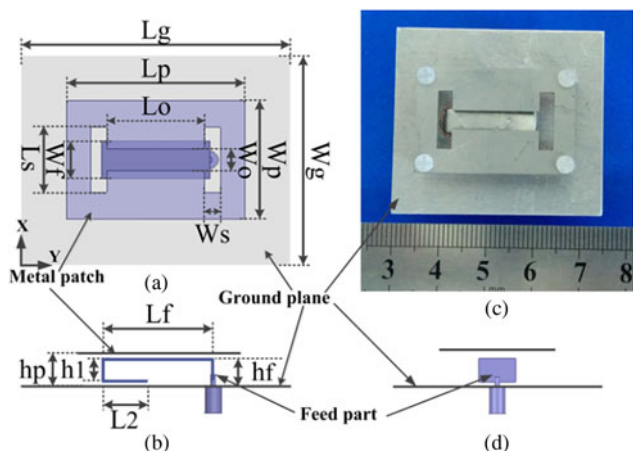


Fig. 1. Geometry of the dual-band microstrip antenna: (a) top view; (b) side view; (c) prototype of the antenna, and (d) side view.

Table 1. Optimized dimensions of the proposed antenna

Parameter	L_g	W_g	L_p	W_p	L_o	W_o	L_s
Units (mm)	45	40	33	22	18	4	12
Parameter	W_s	W_f	L_f	L_2	h_p	h_1	h_f
Units (mm)	3	7	20	8	7	4	5.5

patch antenna is analyzed in [15]. The antenna can radiate a monopole-like radiation pattern in a wide bandwidth. However, the low-profile monopole antennas [12, 13, 14, 15] can only realize monopole-like radiation patterns in all operating frequency bands. According to our knowledge, there are few designs capable of the antenna with the broadside and monopole-like radiation patterns in dual operating frequency bands, respectively. A coplanar waveguide-fed dual-mode patch antenna with a patch-like radiation pattern in the low band and a monopole-like radiation pattern in the high band is proposed in [16]. However, the radiation performance of the antenna in higher band is not very good. In addition, a dual-band single/dual-beam slot patch antenna without the substrate is introduced in [17]. The antenna can realize a patch-like radiation pattern in the low band and a monopole-like radiation pattern in the high band, but the bandwidth in high band is not wide enough and not suitable for WLAN.

In this paper, a miniaturization, multifunction, low cost, dual-band H-shaped slot microstrip antenna with the broadside and monopole-like radiation patterns is presented. The working frequencies are applied in LTE-band (outdoor) band (3.60–3.80 GHz) and WLAN (indoor) band (5.15–5.85 GHz). The bandwidths of the proposed antenna are 3.60–3.85 GHz (6.7%) and 5.10–6.10 GHz (17.9%) in the low- and high-frequency bands, respectively. The size of the antenna with a simple structure is smaller than most of the previously designed antennas; the gain is higher in the low-frequency band than most of the previously designed antennas; and the beams are very symmetrical in the high-frequency band. The proposed antenna is simulated and measured to verify the excellent performance. The details of the proposed antenna and its performance are described in the following sections.

The rest of this paper is organized as follows. The antenna configuration and operation principle of the proposed antenna

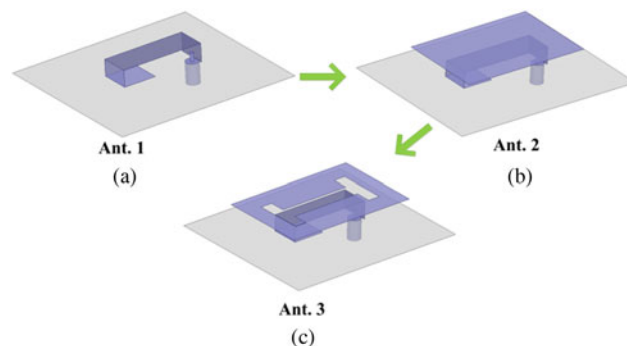


Fig. 2. Step to realize the proposed antenna (Ant. 1–3).

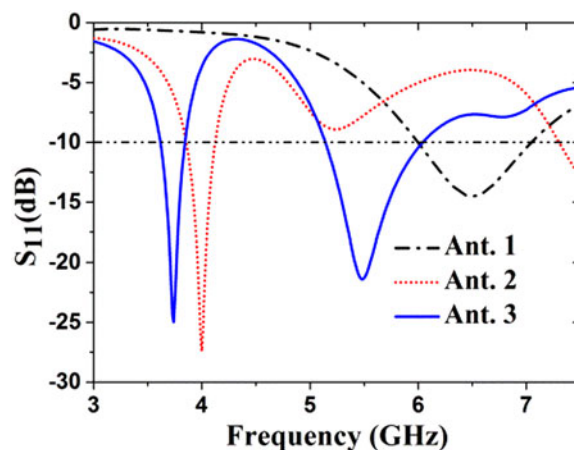


Fig. 3. Reflection coefficients ($S_{11} \leq -10$ dB) of the antennas (Ant. 1–3).

is introduced in the Section “Antenna configuration and operation principle”. The details of the antenna performance and measured results are presented in the Section “Antenna performance and measured results”. The comparison and discussion are presented in the Section “Comparison and discussion”, followed by conclusions in the last section.

Antenna configuration and operation principle

Antenna configuration

The geometry of a dual-band and dual-radiation modes slot microstrip antenna is shown in Fig. 1. The proposed antenna consists of a ground plane, a metal patch with an H-shaped slot which is the radiating part of the antenna, and a U-shaped probe which is the feed part of the antenna. The U-shaped probe is directly connected to a coaxial probe of the SMA-connector and set between the ground plane and the metal patch. The structure of the antenna is very simple. The detailed dimensions of the antenna are reported in Table 1. From Table 1, the size of the antenna is $0.73\lambda_0 \times 0.83\lambda_0 \times 0.13\lambda_0$, where λ_0 is the wavelength in free space at 5.5 GHz. Hence, the antenna has a simple structure and is compact. It is a low-cost antenna because it does not require the substrate.

Operation principle

As a well-known fact that a traditional rectangle patch antenna can produce TM_{01} and TM_{02} modes in the low- and high-

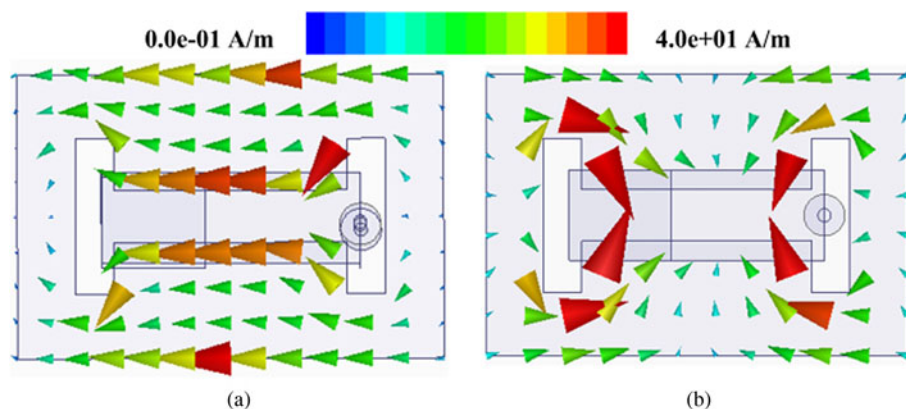


Fig. 4. Current distribution of the antenna: (a) 3.70 and (b) 5.50 GHz.

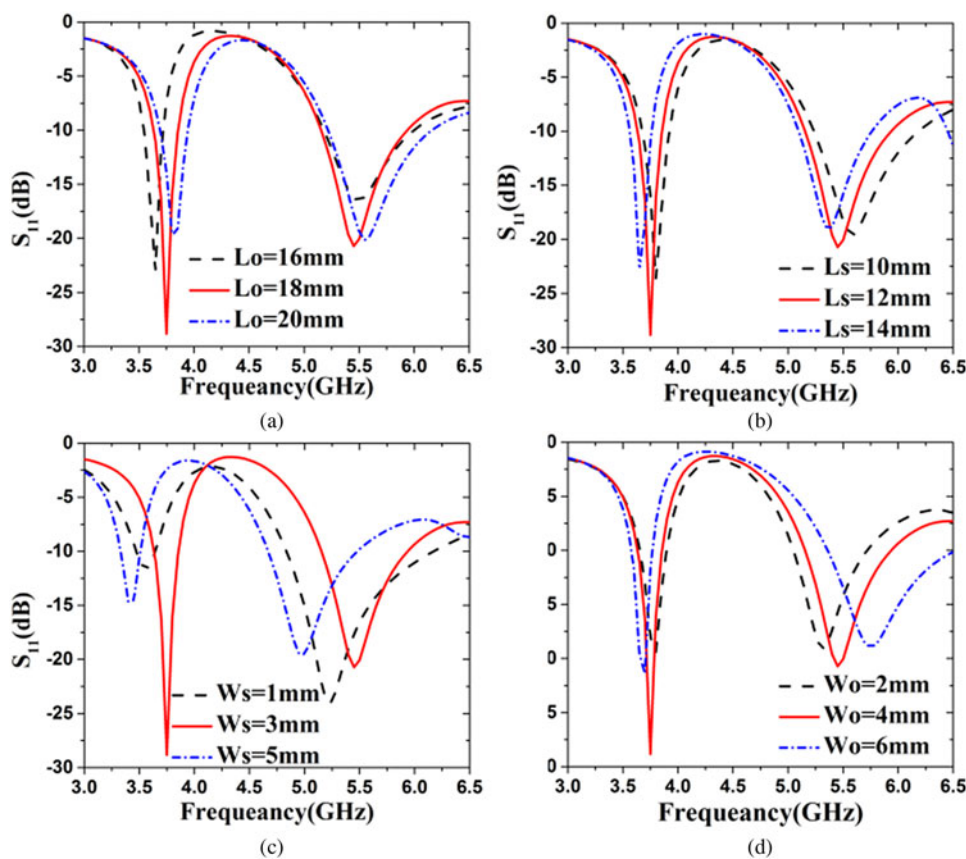


Fig. 5. Simulated reflection coefficients at different parameters: (a) L_o ; (b) L_s ; (c) W_s ; and (d) W_o .

operating frequency bands [8, 9, 11]. The antennas can radiate one broadside pattern in the low-frequency band and dual-beam pattern in the high-frequency band. However, in this paper, a rectangular patch antenna is fed by the U-shaped microstrip probe to radiate a broadside pattern with high gain in the low-frequency band and a monopole-like radiation pattern in the high-frequency band. The design principle of the proposed antenna is shown in Fig. 2.

The operating frequency bands of the three antennas are shown in Fig. 3. The U-shaped monopole antenna (Ant. 1) can operate in the frequency band from 6.0 to 7.0 GHz and radiate a monopole-like radiation pattern with high cross polarization. And this antenna only has one operating frequency band. To realize a broadside pattern, the radiating patch is set above

Ant. 1. Ant. 2 consists of the U-shaped probe (Ant. 1) and the radiating patch. The broadside pattern can be radiated by Ant. 2 in the operating band from 3.85 to 4.20 GHz. However, the high-frequency band is not good as shown in Fig. 3. To improve the high-operating frequency band and adjust the low-frequency band, the H-shaped slot is opened on the radiating patch. Hence, the proposed antenna is designed to realize a dual-band for radiating a broadside pattern in the low-frequency band and a monopole-like pattern in the high-frequency band. In addition, the cavity model of a microstrip patch antenna points out that the current on the rectangular patch's surface has one maxima when the TM_{01} mode is excited in the low-frequency band as shown in Fig. 4(a) [4]. The current on the rectangular patch's surface has two maxima when the TM_{11} mode is excited in the high-

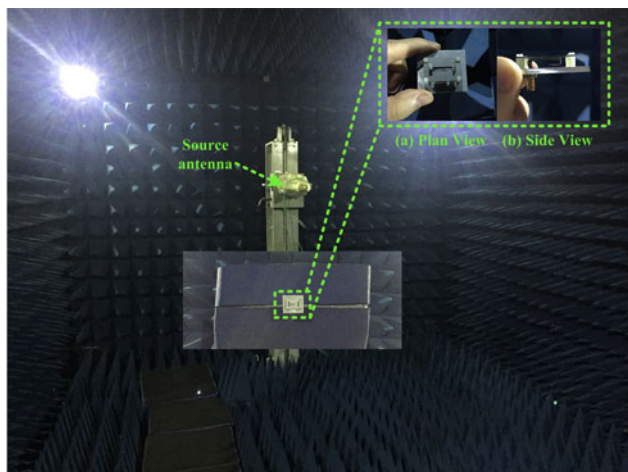


Fig. 6. Fabricated antenna and testing in the microwave anechoic chamber.

frequency band as shown in Fig. 4(b). It is obvious that the current distribution is effected by the H-shaped slot. It should be mentioned that the H-shaped slot parameters need to be optimized and studied to acquire an excellent radiation performance.

Parametric study

The antenna is simulated and optimized in the full-wave simulator Ansoft HFSS [18]. The radiation performance of the proposed antenna in the low- and high-operating frequency bands is based on the H-shaped slot from the evolution (Fig. 3) and current distribution of the antenna (Fig. 4). Hence, the parameters of the H-shaped slot are studied in this section. From Fig. 5(a), the low-resonant frequency is controlled by L_o . However, the high-resonant frequency is little affected by L_o . As shown in Fig. 5(b), the low- and high-resonant frequencies are controlled by L_s . The low- and high-frequency bands can change to higher frequency when the value of L_s decreases. However, the low- and high-resonant frequencies are controlled by W_s significantly, as shown in Fig. 5(c). The above three parameters are responsible for the rectangle slots. Therefore, it is found that two symmetry rectangle slots have critical influence on the antenna performance. Besides, it is also verified by comparing the reflection coefficients of Ant. 2 and 3 with and without the two slots as shown in Fig. 3. The performance of the antenna in the high-frequency band is influenced by W_o mainly. The bandwidth of the high-frequency band increases when W_o is increased.

Antenna performance and measured results

We carried out antenna simulations using HFSS to serve as a reference for the fabricated antenna prototype. The size of the antenna prototype is consistent with the antenna shown in Fig. 1. The antenna is made of 1 mm aluminum sheet and the ground plane is made of 2.5 mm aluminum sheet. The antenna is fixed through the four nylon columns. A dual-band slot microstrip antenna with dual-radiation modes is verified in the microwave anechoic chamber as shown in Fig. 6.

The simulated and measured reflection coefficients ($S_{11} \leq -10$ dB) of the proposed antenna are shown in Fig. 7. The measured results are in agreement with the simulated results because of some fabrication errors; however, they have slight discrepancies. The simulated

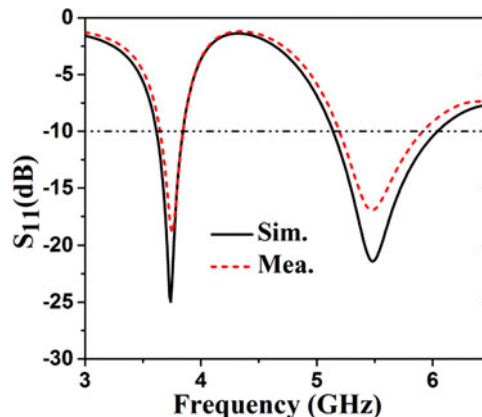


Fig. 7. Reflection coefficients ($S_{11} \leq -10$ dB) of the antenna.

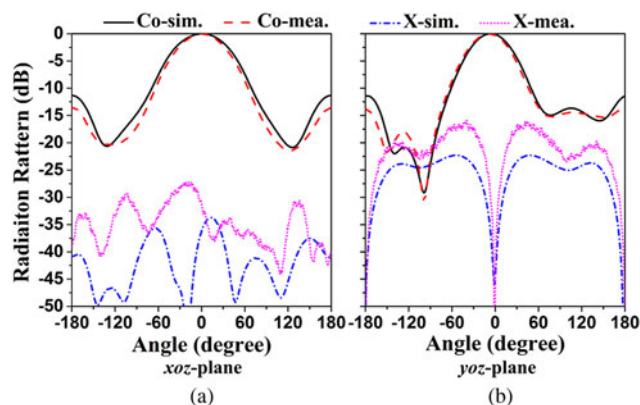


Fig. 8. Simulated and measured normalized radiation patterns of the proposed antenna at 3.7 GHz.

impedance bandwidth of the proposed antenna is about 3.60–3.85 GHz (6.7%) in the low band, and 5.10–6.10 GHz (17.9%) in the high band, respectively. The measured impedance bandwidth of the proposed antenna is about 3.62–3.85 GHz (6.2%) in the low band, and 5.15–5.95 GHz (14.4%) in the high band, respectively. The proposed antenna utilizes the 3.8 GHz TD-LTE 43 band (3.6–3.8 GHz), an IEEE 802.11a which employs the 5 GHz U-NII band and ISM band (5.15–5.825 GHz).

The simulated and measured normalized radiation patterns at 3.7 GHz in two planes are shown in Fig. 8. It can be seen that the measured co-polarization results are in agreement with the simulated results in two planes. However, the measured cross-polarization patterns have a discrepancy with the simulated results. There are two main reasons for the difference. First, some fabrication errors of the antenna went beyond the tolerance limit. Second, the measured results are affected by the testing system of the microwave anechoic chamber. Hence, the measured results are not better than the simulated results. The measured and simulated radiation pattern results at 5.25, 5.50, and 5.85 GHz are shown in Fig. 9. As with the above problems, the measured cross-polarization results are basically similar to the simulated results. The measured co-polarization results are in good agreement with the simulated ones, except for the difference between the back-direction patterns. The difference is mainly because the measured results are affected by equipment which fixes the antenna on the test system. The beam-width in the xoz -plane of the radiation

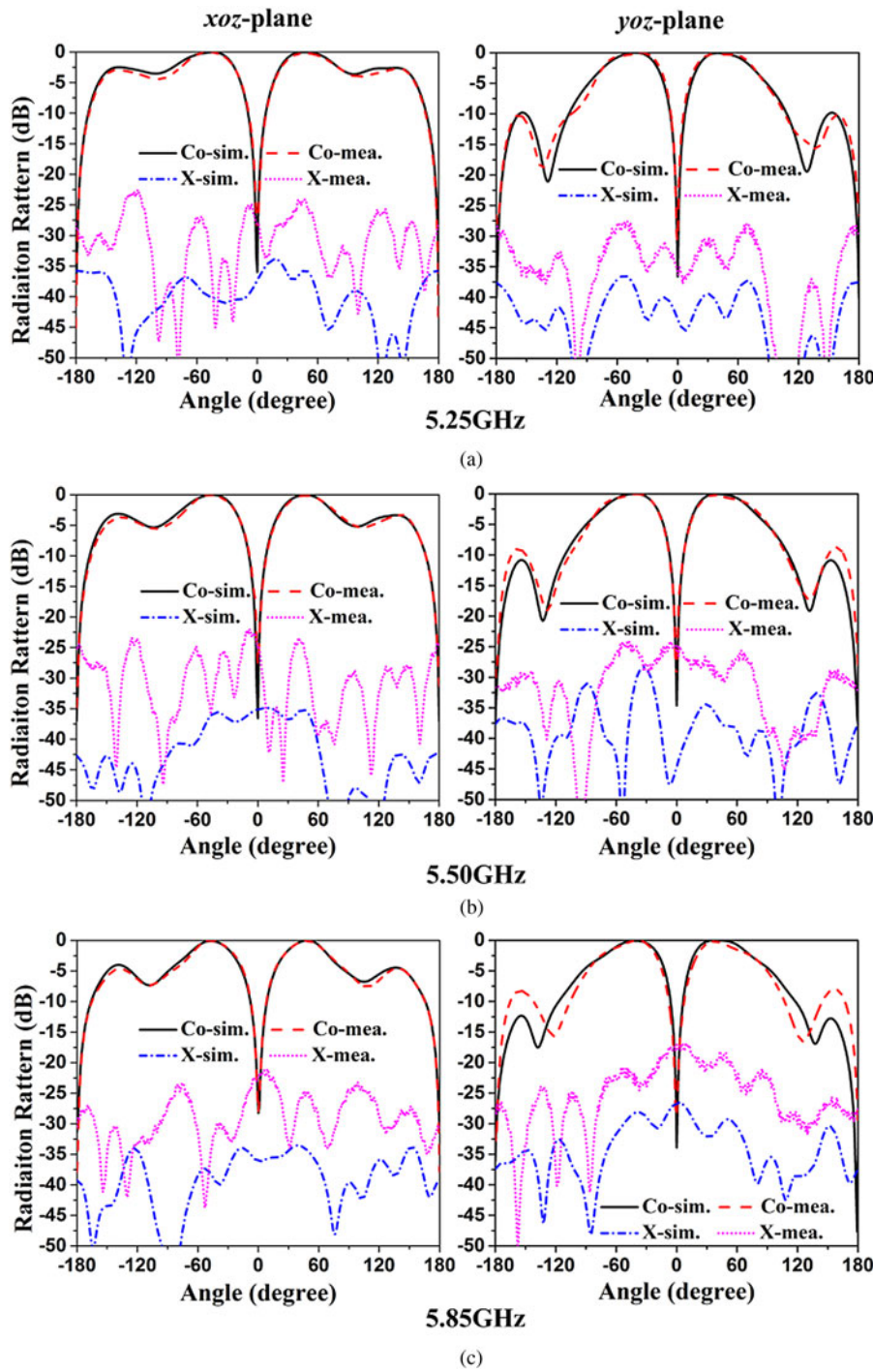


Fig. 9. Simulated and measured normalized radiation patterns of the proposed antenna at 5.25, 5.50, and 5.85 GHz.

Table 2. Simulated and measured gains of the proposed antenna at 5.25, 5.50, and 5.85 GHz in the xoz-plane

Frequency (GHz)	Left beam				Right beam			
	Direction (°)		Gain (dBi)		Direction (°)		Gain (dBi)	
	Sim.	Mea.	Sim.	Mea.	Sim.	Mea.	Sim.	Mea.
5.25	-41	-48	5.9	5.0	41	48	5.9	4.9
5.50	-42	-48	6.5	5.6	40	48	6.5	5.5
5.85	-41	-47	7.1	6.1	40	48	7.2	6.0

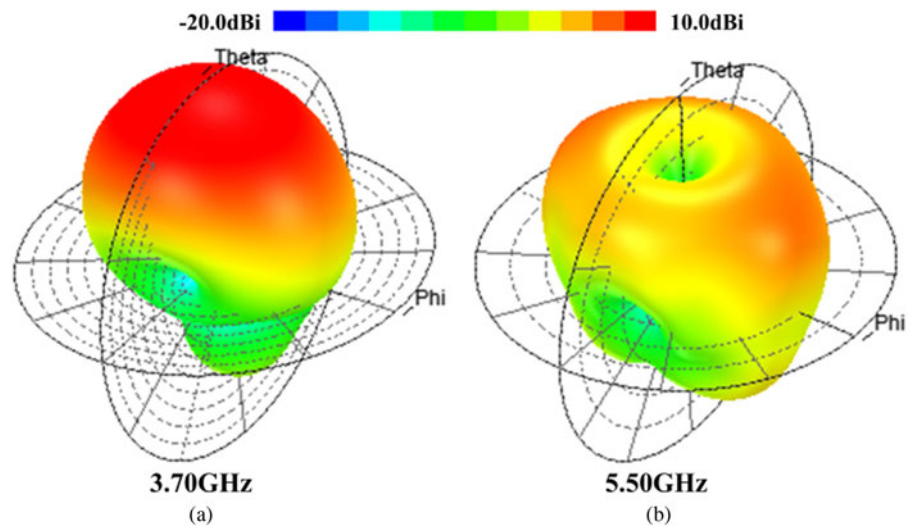


Fig. 10. Simulated three-dimensional radiation patterns of the proposed antenna at 3.70 and 5.50 GHz.

Table 3. Simulated and measured gains of the proposed antenna at 5.25, 5.50, and 5.85 GHz in the yo -plane

Frequency (GHz)	Left beam				Right beam			
	Direction (°)		Gain (dBi)		Direction (°)		Gain (dBi)	
	Sim.	Mea.	Sim.	Mea.	Sim.	Mea.	Sim.	Mea.
5.25	-44	-49	3.2	2.4	44	47	3.2	2.4
5.50	-45	-48	3.8	2.9	48	48	3.8	3.0
5.85	-47	-47	4.5	3.6	49	48	4.5	3.6

Table 4. Comparison of the proposed antenna and references

	Lower BW (GHz)	Higher BW (GHz)	Single-beam gain (dBi)	Dual beam gain (dBi)		Size (λ_0)
				Left	Right	
[8]	-	11.8% (5.18–5.8)	-	5.94	7.92	$1.23 \times 1.36 \times 0.06$
[9]	-	13.2% (5.10–5.82)	-	8.87	8.78	$1.28 \times 1.83 \times 0.1$
[10]	3.7% (2.4–2.49)	1.7% (5.73–5.83)	4.7	-	6.54	$0.51 \times 0.54 \times 0.04$
[11]	7.3% (2.4–2.55)	12.7% (4.7–5.4)	6.3	7.7	7.2	$0.32 \times 0.84 \times 0.08$
[17]	8.0% (3.6–3.9)	9.9% (4.8–5.3)	7.9	5.8	5.7	$0.6 \times 0.6 \times 0.08$
This work	6.7% (3.6–3.85)	17.9% (5.1–6.1)	8.8	5.6	5.5	$0.48 \times 0.54 \times 0.08$

λ_0 refers to the wavelength of the lower frequency of the respective antenna.

pattern is wider than that in the yo -plane. However, it is obvious that the antenna can radiate monopole-like radiation pattern. The simulated and measured peak gains of the proposed antenna at 3.7 GHz are 9.3 and 8.8 dBi. The simulated and measured gains of the proposed antenna for the monopole-like radiation pattern at 5.25, 5.50, and 5.85 GHz are shown in Table 2 in the xo -plane and in Table 3 in the yo -plane, respectively. The gain of the beam in the xo -plane is higher than that in the yo -plane. The current distribution in the x -axis direction is stronger than that in the

y -axis direction as shown in Fig. 4(b). The measured beam directions have little difference with the simulated ones. However, the monopole-like radiation pattern is very symmetric in the whole high-operating frequency band. The three-dimensional radiation patterns of the proposed antenna at 3.7 and 5.50 GHz are shown in Fig. 10. It is observed that the antenna can radiate a broadside radiation pattern in the low-operating frequency band, and a monopole-like radiation pattern in the high-operating frequency band, respectively.

Comparison and discussion

Table 4 lists the comparison of the proposed antenna with some similar antennas which have been published earlier. A low-profile antenna is achieved by a U-slot in [8], which is operated in the higher-order TM_{02} mode to produce dual-radiation beams. However, the two beams are not symmetric because of the asymmetry structure. In contrast, a microstrip antenna is fed by a cross-shaped probe at the center of the patch to broaden the bandwidth of the antenna and to achieve two symmetrical beams in [9]. However, the size of the antenna is quite large and the structure is complex. Compared to the above antennas in [8] and [9], the proposed antenna is operated at a lower band with a single beam with higher gain and a higher band with a dual symmetry beam, which has a simple structure and small size. In addition, the dual band antennas in [10] and [11] operated at a lower band with a single beam and a higher band with dual-radiation beams. The single-beam gain is low at the lower band and the dual beams are not symmetric at the higher band in [10]. Besides, the antenna has a complex structure and narrower bandwidth at the higher band. A U-slot antenna with a beam at lower band and two beams at higher band is presented in [11]. However, the gain in the lower band is low, the higher band is narrower, and the size of the antenna is larger. In [17], the antenna is similar to the proposed antenna and can realize a patch-like radiation pattern in the low band and a monopole-like radiation pattern in the high band, but the bandwidth in the high band is not wide and not suitable for WLAN. To broaden the bandwidth and improve the radiation performance, the proposed antenna is presented. Overall, it can be found that the proposed antenna has a relatively wide bandwidth, high gain in lower bandwidth, symmetrical dual beams, and small size. Particularly, the antenna operates at the dual band by the H-shaped slot not by the U-slot, which has a simple structure without the substrate.

Conclusion

A compact dual-band and dual-radiation mode H-shaped slot microstrip patch antenna with a simple structure is presented in this paper. The antenna with a low profile can realize the excellent performance of the antenna with the broadside and monopole-like radiation patterns in dual-operating frequency bands, respectively. The proposed antenna operates at an impedance bandwidth of 6.7 and 17.9% at low- and high-frequency bands with the peak gains of 8.8 and 5.6 dBi, respectively. The beams direct to around $\pm 48^\circ$ and achieve the gain of around 5.6 dBi in the xoz -plane and 3.0 dBi in the yoZ -plane at 5.5 GHz. The cross-polarization of the antenna is less than -15 dB in the E - and H -planes. The simulated results are in good agreement with the measured results. The proposed design is a desirable candidate for miniaturizing indoor wireless communication systems because of its small size, excellent radiation performance, and low cost.

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