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Dual-band Slot Microstrip Patch Antenna with Dual Radiation Modes for Wireless Communication

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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-shape feed probe and an H-shape 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 the 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 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 dBi and 5.5 dBi realized gain in the xoz-plane and -48˚and 48˚with 2.9 dBi and 3.0 dBi realized gain in the yoz-plane. Therefore, the proposed antenna is a good candidate for wireless communication system.

Keywords: Dual-band, symmetrical radiation pattern, low-profile, microstrip antenna, monopole-like pattern

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I. INTRODUCTION

In recent years, wireless communication systems such as mobile phone, World 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. In order 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 the communication system which requires multiple-coverage. The number of the antennas in the system is reduced by using the dual radiation modes 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 lots of aspects of communication systems especially in wireless communication systems due to their excellent characteristic 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 the fundamental TM_{01} mode [4]. However, microstrip antennas can radiate two symmetrical beams by the operating at the TM_{02} mode [5]-[11]. Therefore, the dual-beam microstrip antenna is studied in recent years. For instance, the bandwidth of a microstrip antenna is broadened by a U-slot and operated at 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 the miniaturizing wireless communication system. 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 2dB and the size of the antenna is larger than one of other literatures [8] [9] [11]. A dual-band U-slot antenna with single- and dual-beam is presented for indoor and outdoor communication system [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 antennas is radiated in one plane, but couldn't cover omni-direction. Hence, the low-profile microstrip

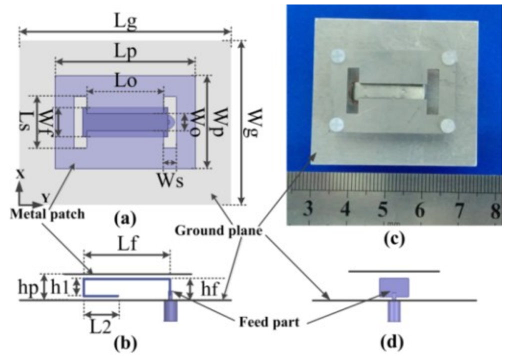

Fig. 1. Geometry of the dual-band microstrip antenna: (a) Top view; (b) Side view; (c) prototype of the antenna, (d) side view

antennas with monopole-like radiation patterns have been investigated [12]-[15]. The antenna [12] with two layer patches can radiate monopole-like radiation patterns in two operating frequency band for WLAN applications. The dual-band microstrip monopole patch antenna with high gain is realized in [13]. The operation principle of the microstrip monopole 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]-[15] can only realize monopole-like radiation patterns in all operating frequency bands. Based on the authors' 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 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 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 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 parts.

The rest of this paper is organized as follows. The antenna configuration and operation principle of the proposed antenna is introduced in Section 2. The details of the antenna performance and measured results are presented in Section 3. The comparison and discussion are presented in Section 4, followed by conclusions in Section 4.

II. ANTENNA CONFIGURATION AND OPERATION PRINCIPLE

A. *Antenna configuration*

The geometry of the 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 I . From Table I, 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. And it is a low cost antenna because it does not require the substrate.

TABLE I
OPTIMIZED DIMENSIONS OF THE PROPOSED ANTENNA

Parameter	Lg	Wg	Lp	Wp	Lo	Wo	Ls
Units (mm)	45	40	33	22	18	4	12
Parameter	Ws	Wf	Lf	L2	hp	h1	hf
Units (mm)	3	7	20	8	7	4	5.5

B. *Operation Principle*

As a well-known fact, a traditional rectangle patch antenna can produce TM_{01} and TM_{02} modes in the low and high operating frequency bands [8, 9, 11]. The antennas can operate 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 operate 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.

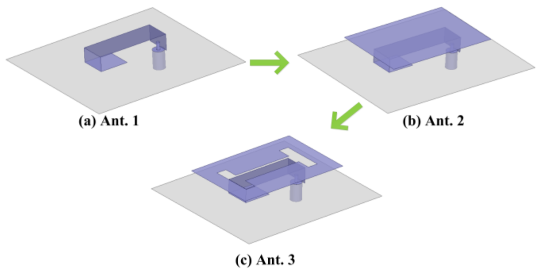

Fig. 2. Step to realize the proposed antenna (Ant. 1 - 3).

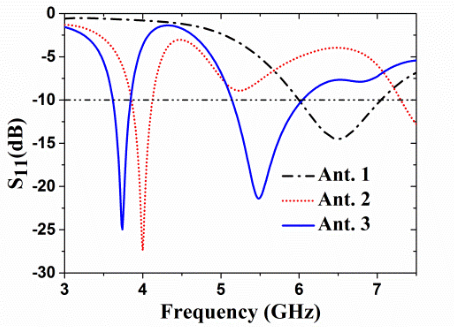

Fig. 3. The reflection coefficients ($S_{11} \leq -10$ dB) of the antennas (Ant.1-3)

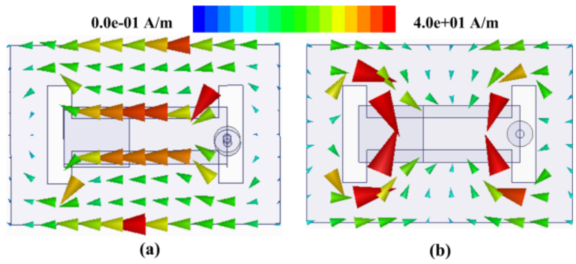

Fig. 4. The current distribution of the antenna: (a) 3.70 and (b) 5.50 GHz.

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 GHz to 7.0 GHz and radiate a monopole-like radiation pattern with high cross polarization. And this antenna only has one operating frequency band. In order to realize a broadside pattern, the radiating patch is set above the Ant. 1. The Ant. 2 consists of the U-shape probe (Ant. 1) and the radiating patch. The broadside pattern can be radiated by the Ant. 2 in the operating band from 3.85 GHz to 4.20 GHz. However, the high frequency band is not well as shown in Fig. 3. In order to improve the high operating frequency band and adjust the low frequency band, the H-shape 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 maxim 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 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 in order to acquire an excellent radiation performance.

C. Parametric Study

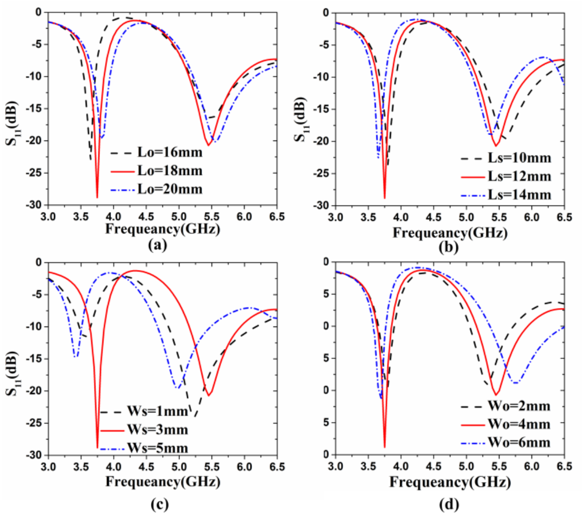

Fig. 5. The simulated reflection coefficients at different parameters (a)*Lo*; (b)*Ls*; (c)*Ws*; (d)*Wo*

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 decided by 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 part. From Fig. 5 (a), the low resonant frequency is controlled by *Lo*. However, the high resonant frequency is little affected by *Lo*. As shown in Fig. 5 (b), the low and high resonant frequencies are controlled by *Ls*. The low and high frequency bands can changes to higher frequency when the value of *Ls* decreases. However, the low and high resonant frequencies are controlled by *Ws* 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 are critical influence on the antenna performance. Besides, it is found the above critical influence by comparing the reflection coefficients of the Ant. 2 and 3 with and without the two slots in Fig. 3. The performance of the antenna at high frequency band is influenced by *Wo* mainly. The bandwidth of the high frequency band is increased when *Wo* is increased.

III. ANTENNA PERFORMANCE AND MEASURED RESULTS

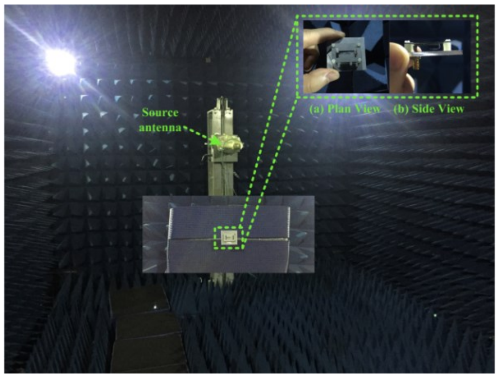

Fig. 6. The fabricated antenna and testing picture in the microwave anechoic chamber

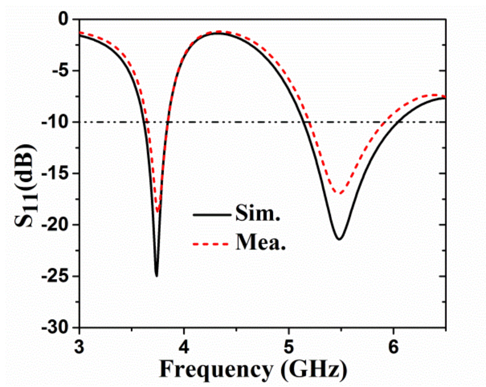

Fig. 7. The reflection coefficients ($S_{11} \leq -10$ dB) of the antenna

We carried out the antenna simulations using HFSS to serve as reference for the fabricated antenna prototype. The size of the antenna prototype is consistent with the antenna in Fig. 1. The antenna is made of 1mm aluminum sheet and the ground plane is made of 2.5mm aluminum sheet. The antenna is fixed through the four nylon columns. Hence, all the quality of the antenna is lighter. 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 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 ~ 3.85GHz

(6.2 %) in low band, and 5.15 ~ 5.95 GHz (14.4 %) in 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).

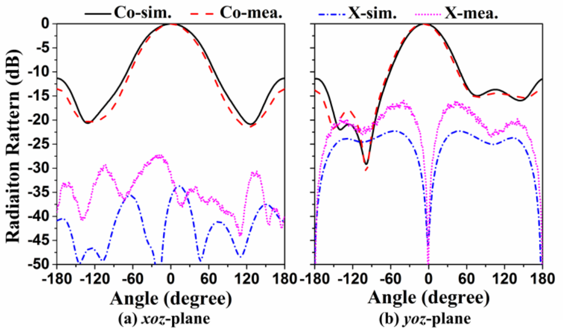

Fig. 8. The simulated and measured normalized radiation patterns of the proposed antenna at 3.7GHz

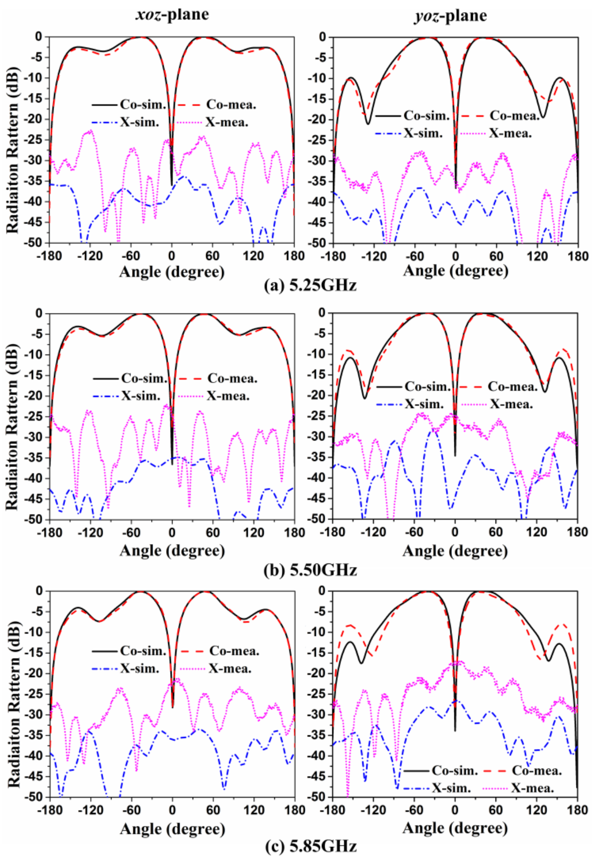

Fig. 9. Simulated and measured normalized radiation patterns of the proposed antenna at 5.25, 5.50 and 5.85GHz

TABLE II
SIMULATED AND MEASURED GAINS OF THE PROPOSED ANTENNA AT 5.25, 5.50, AND 5.85 GHZ IN *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

TABLE III
SIMULATED AND MEASURED GAINS OF THE PROPOSED ANTENNA AT 5.25, 5.50, AND 5.85 GHZ IN *YOZ*-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

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. Firstly, some fabrication errors for the antenna went beyond the tolerance limit. Secondly, 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 with 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 the equipment which fixes the antenna on the test system. The beam-width in the *xoz*-plane of the radiation pattern is wider than one in the *yoz*-plane. However, it is obvious that the antenna can operate 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 monopole-like radiation pattern at 5.25, 5.50, and 5.85 GHz are shown in Table II with the *xoz*-plane and Table III with the *yoz*-plane, respectively. The gain of the beam in the *xoz*-plane is higher than the one in the *yoz*-plane. Since the current distribution in *x*-axis direction is stronger than the one in *y*-axis direction as shown in Fig. 4 (b). The measured beam directions have a little difference with the simulated ones. However, the monopole-like radiation pattern is very symmetric in the whole high operating frequency band. The 3-dimensional radiation patterns of the proposed antenna at 3.7 GHz 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.

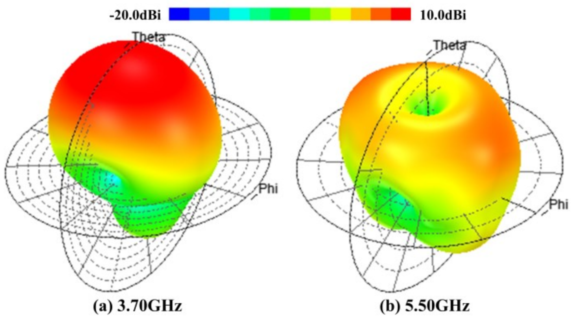

Fig. 10. The simulated three-dimensional radiation patterns of the proposed antenna at 3.70 GHz and 5.50 GHz

IV. COMPARISON AND DISCUSSION

Table IV lists the comparison with some similar antennas which have been published. A low profile antenna is achieved by a U-slot in [8], which is operated at 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 [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 beams, which has a simple structure and small size. In addition, the dual band antennas [10] and [11] are operated at a lower band with a single beam and a higher band with a 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 the 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 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 high band is not wide and suitable for WLAN. In order 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. Especially, the antenna operates at the dual band by the H-shaped slot not U-slot, which has a simple structure without the substrate.

TABLE IV
Comparison of 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	1.23×1.36×0.06
[9]	/	13.2% (5.10-5.82)	/	8.87	8.78	1.28×1.83×0.1
[10]	3.7% (2.4-2.49)	1.7% (5.73-5.83)	4.7	/	6.54	0.51×0.54×0.04
[11]	7.3% (2.4-2.55)	12.7% (4.7-5.4)	6.3	7.7	7.2	0.32×0.84×0.08
[17]	8.0% (3.6-3.9)	9.9% (4.8-5.3)	7.9	5.8	5.7	0.6×0.6×0.08
This work	6.7% (3.6-3.85)	17.9% (5.1-6.1)	8.8	5.6	5.5	0.48×0.54×0.08

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

V. CONCLUSION

A compact dual-band and dual radiation modes H-shape slot microstrip patch antenna with a simple structure is presented in this paper. The antenna with 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 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 ±48° and achieve the gain of around 5.6 dBi in *xoz*-plane and 3.0 dBi in *yoz*-plane at 5.5 GHz. The cross-polarization of the antenna is less than -15 dB in the E- and H-plane. The simulated results are in good agreement with the measured results. The proposed design is a desirable candidate for the miniaturizing indoor wireless communication system because of its small size, excellent radiation performance and low cost.

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