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A Novel Face-Like Triple-Band Antenna for WLAN/WiMAX Applications

Neng-Wu Liu*, Long Yang, Zhi-Ya Zhang, Guang Fu, and Qiong-Qiong Liu

Abstract—A novel microstrip antenna for triple-band WLAN/WiMAX applications is presented. Based on a face-shaped slot, the antenna consists of a pair of symmetrical eye-like patches, a smiling-mouth-shaped feeding line and a rectangular stub that looks like the fringe. The resonant mode at 3.5 GHz is excited by the basic radiation patch with the face-shaped slot. By adding a rectangular fringe-shaped stub on the top of the radiation patch and a pair of symmetrical eye-like patches without increasing the size of the antenna, the antenna can effectively generate three different resonances to cover the WLAN/WiMAX bands. The measured results show that the antenna has three separated impedance bandwidths for $S_{11} < -10\,\mathrm{dB}$ of 550 MHz (2.36 GHz–2.91 GHz), 790 MHz (3.27 GHz–4.06 GHz) and 810 MHz (5.07 GHz–5.88 GHz), and the measured gain is above 2.8 dB over the operating band, which can be well applied for both 2.4/5.2/5.8 GHz WLAN bands and 2.5/3.5/5.5 GHz WiMAX bands.

1. INTRODUCTION

In modern wireless communication systems, such as the wireless local area network (WLAN: 2.4–2.48, 5.15–5.35, and 5.72–5.85 GHz) and the worldwide interoperability for microwave access (WiMAX: 2.5–2.69, 3.40–3.69, and 5.25–5.85 GHz), the demand for printed antennas with multiband operations has increased due to their low profit, compact size, simple structure and easy integration with monolithic microwave integrated circuits.

For these applications, several wideband or multiband planar antennas have already been proposed in [1–13]. Broadband antennas covering WLAN/WiMAX band is designed in [1–3]. However, it is a cost-effective solution by removing filters in the system to suppress dispensable bands. Many types of multiband antennas have also been proposed recently, including a printed symmetrical G-shaped antenna [4], an L-shaped and E-shaped antenna [5], a coplanar waveguide (CPW) antenna with rectangular notch [6] and a uniplanar antenna with C-shaped parasitic strip [7]. Although the antennas above have many advantages, only two bands are involved in the designs, which can not cover the whole WLAN/WiMAX bands. In [8], the design of a triple-band antenna has been proposed by introducing a triangular split-ring resonator. A trapezoidal ground is also used in the design of the antenna for the WLAN/WiMAX applications [9]. A triple-band unidirectional coplanar antenna with wide bandwidth is proposed [10]. Unfortunately, all of them have a relatively large size over $38 \times 30\,\mathrm{mm}^2$ for a portable device with limited space, which possibly degrades their availabilities for practical engineering applications. In addition, several other designs are also proposed for WLAN/WiMAX applications by utilizing radiating elements together with a dual U-shaped slot [11], combining a miniascape-like strip [12], and using a rectangular ring with open-end [13]. But the radiation performance of these antennas is not so good especially in the upper band because of the asymmetric structures. In [14–16], the antennas have good radiation patterns in wireless systems, but they are complex in configuration.

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* Corresponding author: Neng-Wu Liu (nengwuliu@126.com).
The authors are with the Science and Technology on Antenna and Microwave Laboratory, Xidian University, Xi'an 710071, People's Republic of China.

In this letter, for WLAN/WiMax applications, a novel compact triple-band monopole antenna is proposed. Based on a face-shaped slot, the antenna consists of a smiling-mouth-shaped patch fed by a 50-Ω microstrip line, a pair of symmetrical eye-like patches and a rectangular fringe-shaped stub. The smiling-mouth-shaped patch enhances the impedance matching in the operating band. By adding a fringe-shaped stub and embedding two symmetrical eye-like patches without increasing the size of the structure, the antenna covers the 2.4/5.2/5.8 GHz WLAN bands and 2.5/3.5/5.5 GHz WiMAX bands. The measured results match well with the simulated ones. Moreover, the monopole-like radiation pattern in E-plane, omnidirectional radiation pattern in H-plane and constant gain above 2.8 dB are obtained in the operating band. Thus, the novel antenna is well applied in wireless system.

2. ANTENNA DESIGN AND DISCUSSIONS

As shown in Figure 1, the proposed antenna is printed on a FR4 epoxy substrate with a relative permittivity of 4.4, a thickness of 1.6 mm, and a loss tangent of 0.02. It is fed by a 50-Ω microstrip line of a width 3.3 mm. The 50-Ω feeding line with a smiling-mouth-shaped patch is located on the backside of the dielectric substrate. The radiation patch with the face-shaped slot, which is printed on the front of the substrate, consists of a pair of symmetrical eye-like patches and a fringe-shaped stub. The dimensions of the antenna are $34 \times 28\,\text{mm}^2$, which is smaller than the antennas in [8–10]. The design evolution of the proposed triple-band antenna and its corresponding simulated return losses are presented in Figure 2. As shown in Ant I, there is just an operating band from 2.6 GHz to 5 GHz based on the radiation patch with face-shaped slot, it consists of a rectangular ($W_7 \times L_3$) and two semi-elliptical slots, which have the same major axis (W_7), and the semi-minor axis of the semi-ellipse slots are L_4 and L_2 at the up and low part of the antenna, respectively. By adding a fringe-shaped stub (Ant II) on the top of the patch to lengthen the effective current paths, the impedance bandwidth for $S_{11} < -10\,\text{dB}$ moves toward the lower frequency, and impedance matching condition around 2.5 GHz and 3.5 GHz is significant improved. Finally, to obtain the higher frequency band (around 5.5 GHz), a pair of symmetrical eye-like patches are placed inside the slot of the antenna in Ant III, the proposed antenna covers two impedance bandwidths with $S_{11} < -10\,\text{dB}$ about 610 MHz (2.37–3.98 GHz) and 990 MHz (4.95–5.94 GHz). For detailed design, all parameters of the proposed antenna are optimized using the Ansoft HFSS 14. The optimal parameters for the antenna are listed in Table 1.

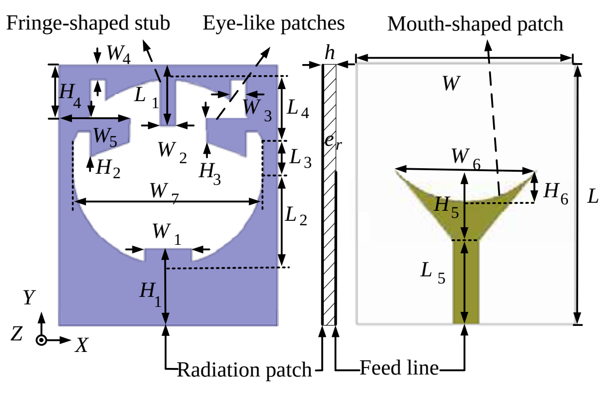

Figure 1. Geometry of the antenna.

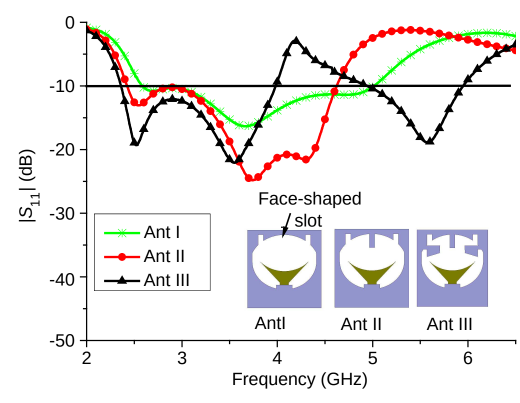

Figure 2. Simulated return loss of various antennas.

Table 1. Dimensions of proposed antenna.

Parameters	L	L_1	L_2	L_3	L_4	L_5	W	W_1	W_2	W_3
Values/mm	34	8	12	4	8	11	28	6	2	2
Parameters	W_4	W_5	W_6	W_7	H_1	H_2	H_3	H_4	H_5	H_6
Values/mm	2	9	18	24.4	10	5	3.2	6	7	4

In order to investigate the mechanism of the proposed antenna, the current distributions at different resonant frequencies of 2.5 GHz, 3.5 GHz, and 5.5 GHz are displayed in Figure 3. It is worth noticing that the current paths along the eye-like patch is $L_3 + H_2 = 9$ mm, which is close to the quarter wavelength at the resonant frequency 5.5 GHz and can be calculated by the following equations:

$$L = \frac{c}{4f\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where c, ε_r is the speed of light at free space and the dielectric constant, respectively. More exactly,

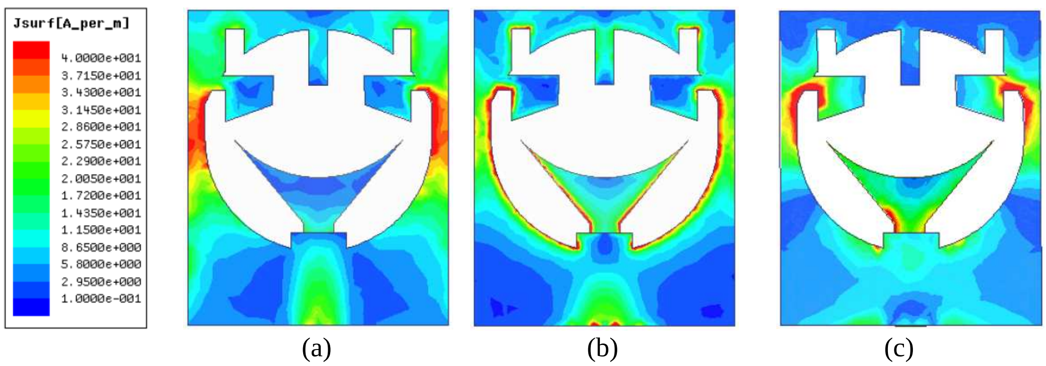

Figure 3. Simulated surface current distributions of the proposed antenna at (a) 2.5, (b) 3.5, and (c) 5.5 GHz.

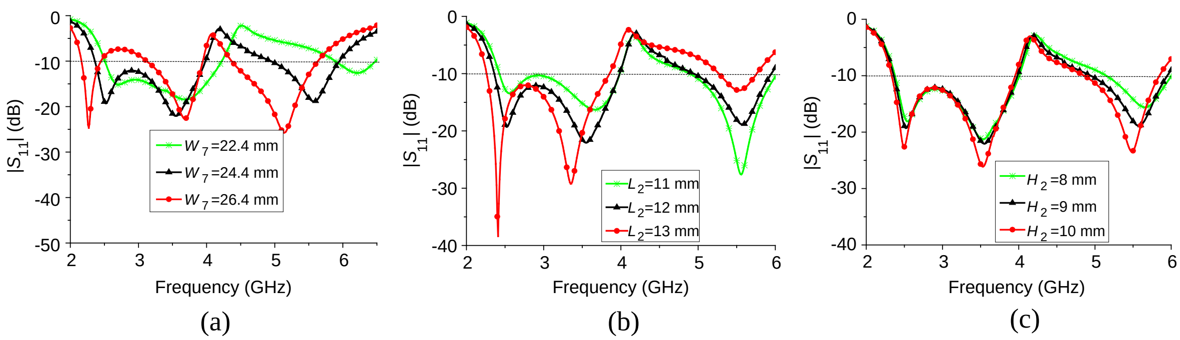

Figure 4. Reflection coefficient against frequency with different L_1, L_2 and W_5.

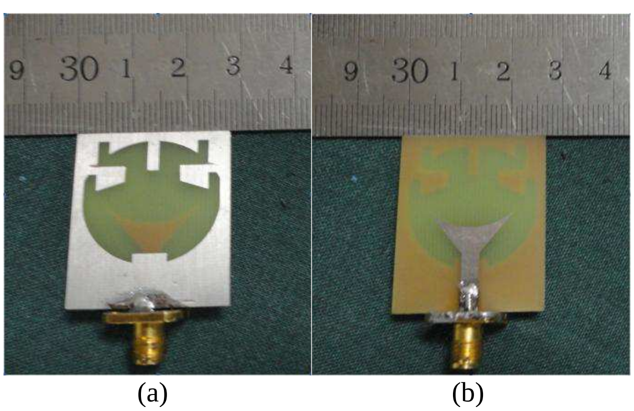

Figure 5. Photograph of the fabricated antenna: (a) front view, (b) back view.

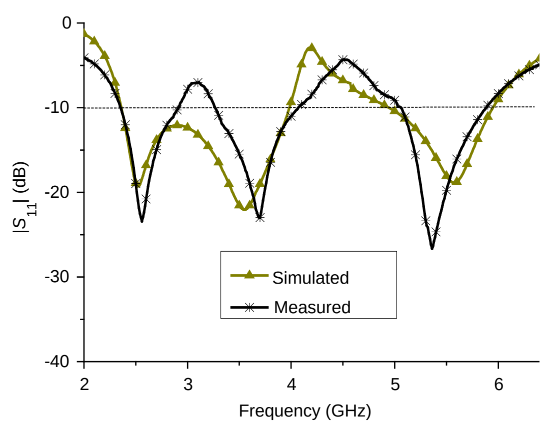

Figure 6. Measured and simulated return losses of the proposed antenna.

it can be clearly seen that when frequency increases, the current distribution is different along the antenna. In Figure 3(a), the surface current flows along the edge of the face-shaped slot. This indicates that the length of slot affects the lower resonant mode. Figure 3(b) shows the current distribution at 3.5 GHz, which presents that the strong current distribution is along the down-edge of the face-shaped slot, which demonstrates that the down-edge of the face-shaped slot is the major radiating element for the proposed antenna at the middle resonant mode. Result in Figure 3(c) shows the current distribution at 5.5 GHz, which is mainly distributed around the eye-like patches. Therefore, we can conclude that the eye-like patches create the upper resonance mode. This clearly validates the design mechanism and explanation of the proposed antenna.

Based on the above analysis, we investigate the influence of the related geometrical dimensions on the proposed antenna performance. In the process, except for the parameters of interest, other parameters keep constant. As indicated in Figure 4(a), the width of slot (W_7) has an effect on the lower resonant band. With an increment of W_7, the edge of the face-shaped slot and the the current path at lower frequency are increased as shown in Figure 3(a), thus the first resonant band moves to a

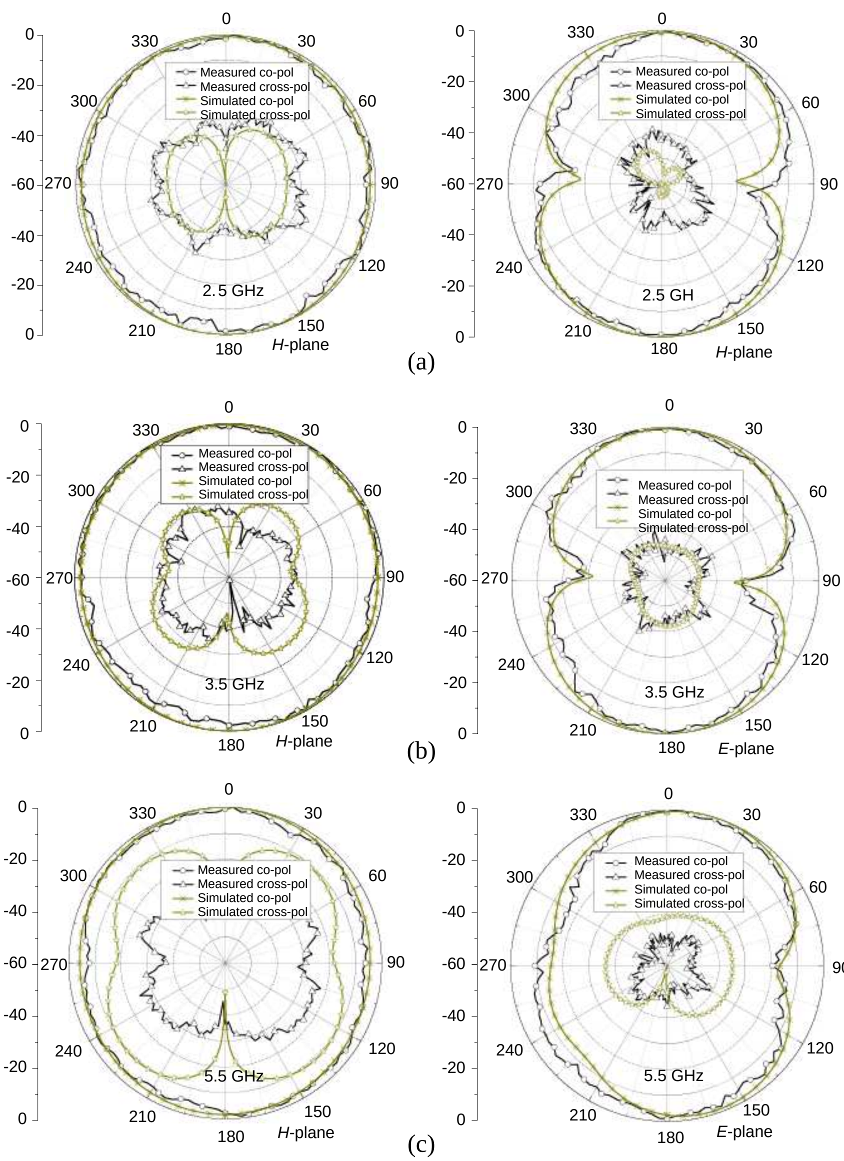

Figure 7. Radiation patterns of the proposed antenna at (a) 2.5, (b) 3.5, and (c) 5.5 GHz.

lower frequency. Therefore, we can conclude that the 2.5 GHz resonant mode is achieved by the length of the edge of slot. Similarly, Figure 4(b) shows that the middle resonant mode quickly shifts to the lower resonant frequency with an increase in L_2 apparently, thus the length of the down-edge of the face-shaped slot affects the middle resonant mode. Finally, the length of the eye-like patches H_2 is studied. As shown in Figure 4(c), the third resonant mode is shifted to higher frequency with decrease in H_2 as the result of the decreasing of the effective current path generated by the symmetrical eye-like patches, whereas lowest and upper resonances change slightly. By selecting $W_7 = 24.4\,\text{mm}$, $L_2 = 12\,\text{mm}$ and $H_2 = 9\,\text{mm}$, better impendence bandwidth which can meet the requirement for WLAN/WiMAX standards is achieved.

3. RESULTS AND DISCUSSION

The prototype of the novel triple bands antenna depicted in Figure 1 is fabricated as shown in Figure 5. The S-parameter of the proposed antenna is measured by the Agilent E8363B vector network analyzer. To be convenient for comparison, the measured and simulated S-parameter curves of the triple-band antenna are given in Figure 6. It can be seen that the simulated result covers two impedance bandwidths with $S_{11} < -10\,\text{dB}$ about 610 MHz (2.37–3.98 GHz) and 990 MHz (4.95–5.94 GHz), and the measured impedance bandwidth for $S_{11} < -10\,\text{dB}$ is 2.36 GHz–2.91 GHz, 3.27 GHz–4.06 GHz and 5.07 GHz–5.88 GHz. The center frequencies of the bands are 2.55, 3.68 and 5.39 GHz, respectively. Some differences occur between the measured and simulated results are mostly due to the welded joint of the SMA connector, the machining error of the substrate.

The simulated and measured radiation patterns at 2.5 GHz, 3.5 GHz, 5.5 GHz in the YZ plane (E-plane) and XZ plane (H-plane) are plotted in Figure 7. The antenna has a monopole-like radiation pattern in E-plane and an omnidirectional radiation pattern in H-plane. In addition, the radiation characteristic of the antenna is stable in the operating bands.

The simulated and measured gain of the antenna over the frequency bands of interest are shown in Figure 8. The measured results matches well with the simulated ones. For the 2.4–2.7 GHz working band, the measured peak gain is about 3.06 dB. For the second band (3.4–3.7 GHz), the measured antenna gain is above 2.8 dB with a variation of 0.04 dB. The peak gain reaches about 4 dB ranging from 5.1 to 5.9 GHz, and the gain variation is about 0.77 dB. Thus, the constant gain is above 2.8 dB in the operating band. Additionally, the radiation efficiency is about 90% during the operating band. All in all, the antenna satisfies the requirement of the wireless communication systems.

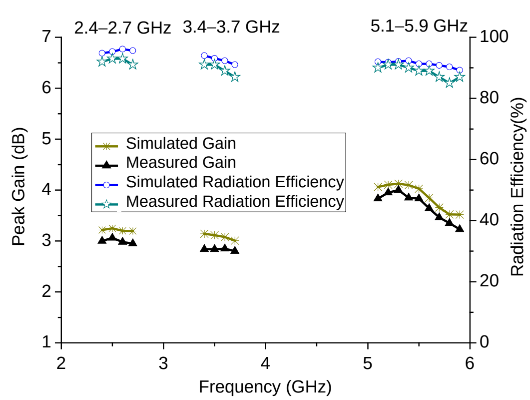

Figure 8. Measured and simulated results for the proposed antenna.

4. CONCLUSION

A novel face-like triple-band antenna suitable for WLAN/WiMAX applications is proposed. By embedding a fringe-shaped stub and a pair of symmetrical eye-like patches, which does not increase the dimensions of the structure, three resonant modes with excellent impedance match are achieved. Effects of vital parameters of the structure on the antenna are also studied. The measured results match well with the simulated ones. In addition, the antenna shows good dipole-like radiation pattern performance with relatively stable gains over the operating bands, which is attractive for wireless communication applications.

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