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A COMPACT MICROSTRIP SLOT ANTENNA WITH A PAIR OF INVERTED L-STRIPS AND ELLIPTICAL-ARC-SHAPED STUB FOR WLAN/WIMAX APPLICATIONS

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Abstract—A novel compact microstrip slot antenna applied to WLAN/WiMAX applications is presented. The proposed antenna consists of a trapezoid and ellipse slot, a pair of symmetrical inverted L-strips, an elliptical-arc-shaped stub and a monopole radiator. By adjusting the dimensions and positions of these structures, the antenna can effectively generate three different resonances to cover the WLAN/WiMAX bands while maintaining small size and simple structure. Based on this concept, a prototype of the proposed antenna has been successfully fabricated and measured. The experimental and numerical results show that the antenna has impedance bandwidth with 10 dB return loss of 360 MHz (2.33–2.69 GHz) and 2630 MHz (3.24–5.87 GHz), which can cover both the WLAN 2.4/5.2/5.8 GHz bands and the WiMAX 2.5/3.5/5.5 GHz bands. In addition, good monopole-like radiation characteristics with sufficient antenna gains are obtained over the operating bands.

1. INTRODUCTION

With the rapid development of wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) in modern wireless communication systems, much attention has been attracted to the multi-band printed antenna due to their advantages of compact size, low cost, easy fabrication and wide bandwidth over traditional multiband antennas for portable wireless terminal devices.

Owning to these merits, several promising types of dual-band and multiband antennas have been reported in the recent literature [1–15]. For example, many printed monopole antennas with different

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shapes have been presented, including a printed symmetrical G-shaped antenna [1], a printed double-T-shaped antenna [2], an L-shaped and E-shaped antenna [3], and a planar antenna with a shorted parasitic inverted-L wire [4]. However, none of the above available designs can achieve a dual-band response with sufficiently large bandwidth to cover the whole WLAN/WiMAX bands. To enhance the bandwidth, there are many other triple-band antennas for both WLAN/WiMAX applications, such as a CPW-fed antenna with two thin bent slots [5], a slot antenna with a triangular split-ring resonator [6], a printed rectangular ring antenna with a straight strip and a meandered strip [7], and a rhombic slot antenna with a pair of straight strips [8]. Unfortunately, although these antennas exhibit the advantages of simple structure and wide bandwidth, they have a large overall size for the limited space of a portable device which possibly degrades their availabilities for practical engineering applications. In addition, several other designs of antennas are also proposed for WLAN/WiMAX applications by employing three L-shaped slots and a rectangular slot [9], combining a C-shaped strip and two L-shaped strips [10], and using one branch strip and two hook-shaped strips [11]. But the radiation performances of these antennas are not so good especially in the upper band because of the asymmetric structures. In [12–15], although the antennas have good radiation characteristics and reasonable compact size for both WLAN and WiMAX systems, they are somewhat complicated in structures.

In this paper, a compact microstrip slot monopole antenna is proposed for WLAN/WiMAX applications. The trapezoid and ellipse slot is introduced to achieve a lower resonant frequency, whereas the symmetrical inverted L-strips and the elliptical-arc-shaped stub embedded from the slot are introduced to yield another two resonant frequencies, so as to cover the whole WLAN/WiMAX bands. An experimental prototype of the proposed antenna design was then fabricated and measured, verifying the design concept. Details of the antenna design and parameter study are presented, with both simulated and measured results given and discussed. Good agreement between the simulated and measured results manifests the suitability of the designed antenna for the WLAN/WiMAX application.

2. ANTENNA DESIGN AND DISCUSSIONS

The geometry of the proposed antenna along with its design parameters is shown in Figure 1. The antenna is designed and fabricated on an FR4 substrate with a relative dielectric constant (ε_r) of 4.4, thickness (h) of 1.6 mm, and loss tangent of 0.02. The entire size of the antenna

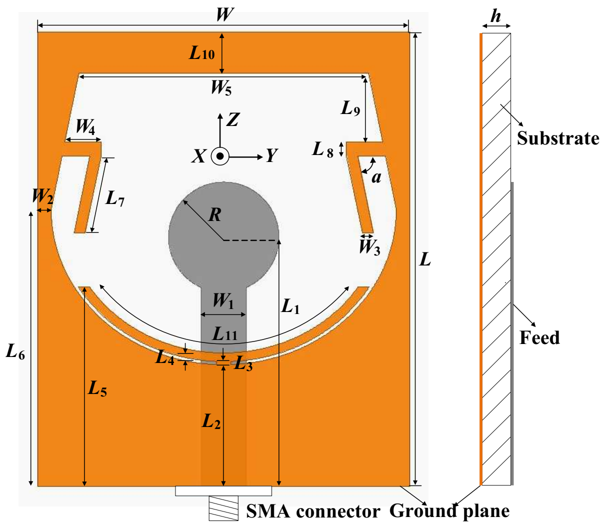


Figure 1. Geometry of proposed microstrip slot antenna.

is only $L \times W\,\mathrm{mm}^2$, which is less than the antennas presented in [5–8]. The antenna is fed centrally at one side of the substrate by a 50-Ω microstrip feed line which has a width of W_1 and is joined to a circular patch having a radius of R. As mentioned earlier, in order to achieve a multiband antenna, a pair of symmetrical inverted L-strips is embedded in the trapezoid and ellipse slot. By tuning the length of inverted L-strips, the upper resonant mode at 5.5 GHz is produced. Moreover, an elliptical-arc-shaped stub with appropriate width can also be added to the slot of the antenna, which generates the middle resonant mode at 3.5 GHz and ensures good impedance match over the operating bands. It is worth noticing that the length of the inverted L-strip is $W_4 + L_7 = 8.3\,\mathrm{mm}$, which is close to the quarter wavelength at the upper resonant frequency 5.5 GHz and can be empirically calculated by the following equations:

$$f_{upper} = \frac{c}{\sqrt{\varepsilon}_{eff} \cdot \lambda_g} \approx \frac{c}{4\sqrt{\varepsilon}_{eff} \cdot (W_4 + L_7)} \tag{1}$$

$$\varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

where c and ε_{eff} are the speed of light at free space and the approximated effective dielectric constant, respectively. The numerical analysis and geometry refinement of the proposed structure are performed by using the electromagnetic simulation software Ansoft

HFSS 13 [16], which is based on the finite element method. The optimal parameters for the antenna are listed in Table 1.

Table 1. Optimal parameters of the proposed antenna.

Parameter	L	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
Unit (mm)	33	18.1	8.85	0.25	0.8	13	20.1	5.9	1	5	3
Parameter	W	W_1	W_2	W_3	W_4	W_5	h	R	ε_r	L_{11}	a
Unit (mm)	27	3.3	1	0.83	2.6	21	1.6	4	4.4	18.4	78°

To validate the mechanism of the proposed antenna, the simulated return loss of various antenna structures involved in the antenna design evolution process is also shown in Figure 2. As seen from Figure 2, the design of Ant 1 without both the inverted L-strips and elliptical-arc-shaped stub can achieve the lowest resonant frequency at 2.5 GHz. Then, in order to yield another resonance, a pair of symmetrical inverted-L strips is embedded in the trapezoid and ellipse slot to form another current flow path in Ant 2. By tuning the length of the inverted-L strips, the upper resonance at 5.5 GHz is produced. At the last step to generate the middle resonant frequency at 3.5 GHz, an elliptical-arc-shaped stub is added to the slot in Ant 3. By fine-tuning the geometry parameters of these parts independently, a microstrip slot antenna suitable for WLAN/WiMAX operation is achieved.

In order to explain in more detail the excited resonant modes, the simulated surface current distributions of the proposed antenna at different resonant frequencies of 2.5 GHz, 3.5 GHz, and 5.5 GHz

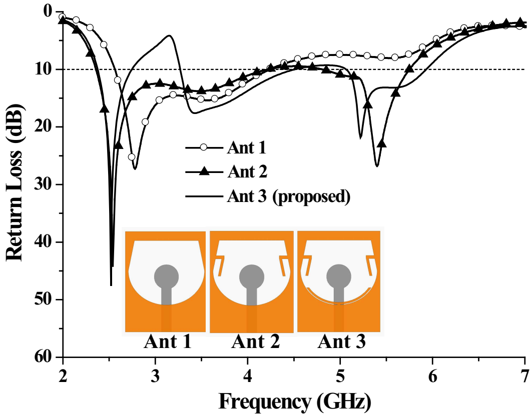
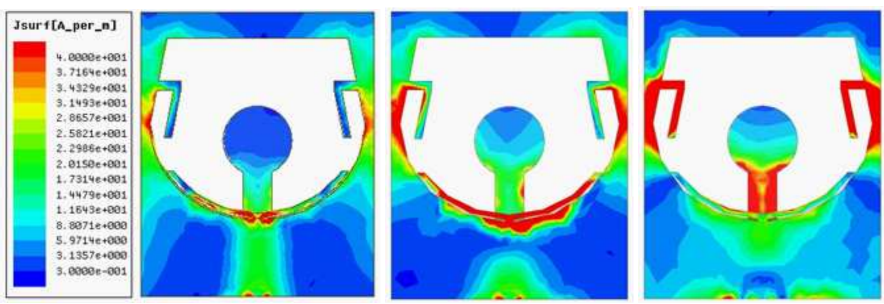


Figure 2. Geometry and simulated return loss of various antennas.

are illustrated in Figure 3. It can be clearly seen that as frequency increases, the current has different distribution along the antenna. When the antenna operates at 2.5 GHz, the current density flows mainly along the trapezoid and ellipse slot, as shown in Figure 3(a). This indicates that the trapezoid and ellipse slot acts as a resonator to generate the lowest resonance. At frequency of 3.5 GHz, strong surface current distribution around the elliptical-arc-shaped stub is observed in Figure 3(b) as expected, which demonstrates that the elliptical-arc-shaped stub is the major radiating element for the proposed antenna at the middle resonant mode. Figure 3(c) demonstrates the current distributions at 5.5 GHz. It can be clearly observed that most of the surface currents are concentrated along the symmetrical inverted-L strips with nearly no current on the elliptical-arc-shaped stub. Therefore, we can conclude that the inverted-L strip is of great significance for creating the upper resonance mode. This clearly validates the design mechanism and explanation of the proposed antenna.



(a) (b) (c)

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

The effects of the elliptical-arc-shaped stub's length L_5 and the inverted-L strip's length L_7 on impedance matching for the proposed antenna are shown in Figures 4 and 5, respectively. As indicated in Figure 4, the length of the elliptical-arc-shaped stub has a great effect on the middle resonant band. As L_5 increases from 13.5 to 14.5 mm, the middle resonance frequency of this antenna shifts down obviously as the result of the increasing of the electric current path generated by the elliptical-arc-shaped stub, whereas lowest and upper resonances change slightly. Therefore, we can conclude that the 3.5 GHz resonant mode is achieved by the elliptical-arc-shaped stub. Similarly in Figure 5, the upper resonant mode is quickly shifted to the lower resonant frequencies with an increase in L_7 apparently. The result clearly indicates that the upper resonance of the antenna can be effectively controlled by adjusting the length of the inverted-L strip. For this case, the antenna characteristic is similar to that of the traditional monopole antenna. By selecting L_5 14.5 mm and L_7 5.7 mm, better impendence bandwidth which can meet the requirement for WLAN/WiMAX standards is obtained.

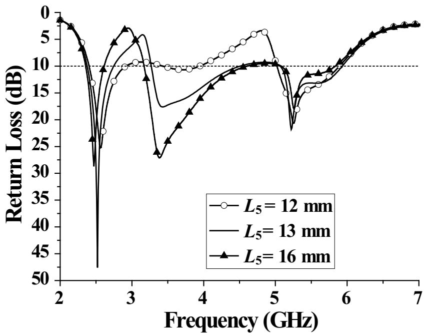


Figure 4. Simulated return loss with varying the elliptical-arc-shaped stub's length L_5.

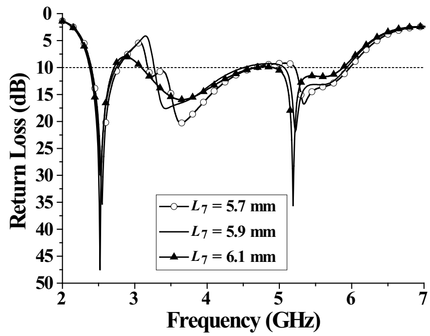


Figure 5. Simulated return loss with varying the inverted-L strip's length L_7.

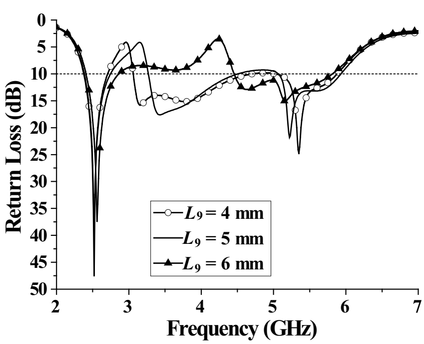


Figure 6. Simulated return loss with varying the position of inverted-L strip L_9.

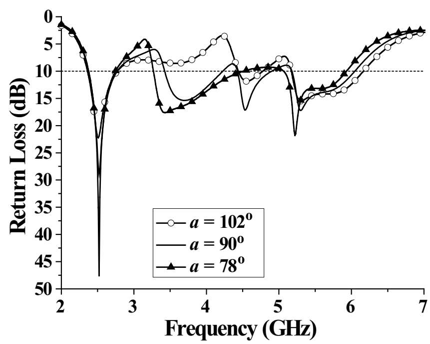


Figure 7. Simulated return loss with varying the angle of inverted-L strip a.

The important effects of the inverted-L strip's position L_9 and angle a on the impedance matching for the proposed antenna are also illustrated in Figures 6 and 7. The results show that the upper resonance is shifted toward the higher frequencies whereas the impedance bandwidth for the middle resonance is improved when L_9 decreases from 6 to 4 mm due to the mutual coupling between the inverted-L strip and the elliptical-arc-shaped stub. However, varying angel a from 102° to 78°, it is seen that the impedance matching condition for the middle resonant can be improved whereas the lowest and upper resonances are slightly affected by this parameter. Finally, an overall good bandwidth has been obtained in case of $L_9 = 5$ mm and $a = 78°$.

3. EXPERIMENTAL RESULTS

Based on the detailed design dimensions given in Figure 1 and Table 1, the proposed antenna prototype for WLAN/WiMAX operation has been designed, fabricated, and measured with Agilent E8363B vector

Figure 8. Photograph of the fabricated antenna. (a) Front view, (b) back view.

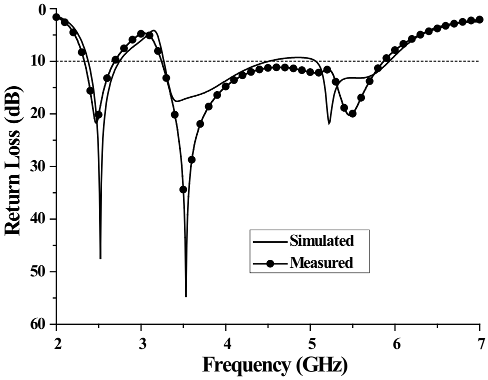


Figure 9. Measured and simulated return losses of the proposed antenna.

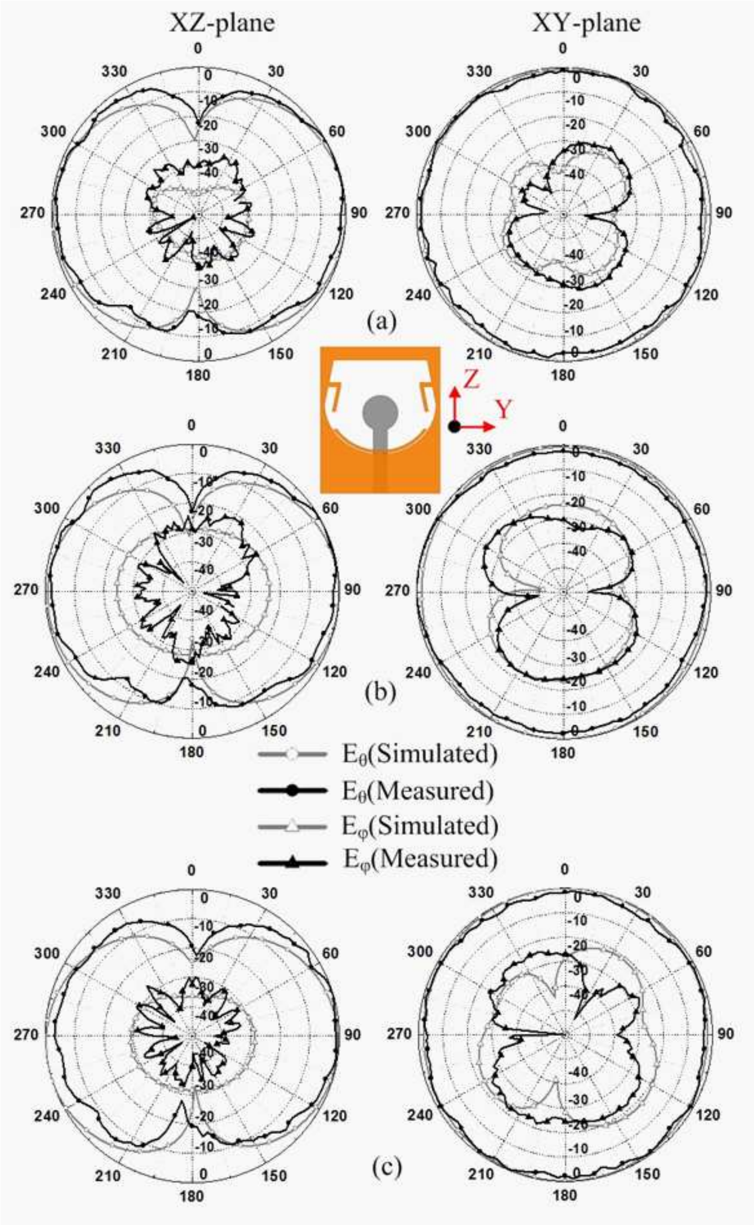


Figure 10. Radiation patterns of the proposed antenna at (a) 2.5, (b) 3.5, and (c) 5.5 GHz.

network analyzer. Figure 8 shows the photograph of the proposed antenna. The measured and simulated return loss against frequency is depicted in Figure 9, which as can be seen, shows reasonable agreement and three separate resonant modes at about 2.5, 3.5, and 5.5 GHz are excited with good impedance matching. The variation between the measured and simulated results is probably due to the effect of the SMA connector and fabrication tolerance. The measured impedance bandwidths for 10 dB return loss are about 360 MHz (2.33–2.69 GHz), and 2630 MHz (3.24–5.87 GHz), respectively, which are able to cover simultaneously the 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX bands.

Figure 10 exhibits the measured and simulated normalized far-field radiation patterns of the fabricated prototype in E-plane (x-z plane) and H-plane (x-y plane) for frequencies at 2.5, 3.5, and 5.5 GHz, respectively. Nearly omnidirectional H-plane patterns are obtained at these frequencies, which indicate that the proposed antenna is much preferable for the applications of portable devices.

The measured peak gains of the antenna at several discrete frequencies are shown in Figure 11. As can be seen, stable gain variation across the operation bands has been obtained. For the lower operating band of 2.3–2.7 GHz, the antenna gain varies from 2.34 to 2.99 dBi. The measured gain variation in the upper operating band of 3.1–5.9 GHz is from 2.05 to 3.95 dBi. Therefore, the proposed microstrip slot antenna with stable gain is competent to be mounted in the portable wireless terminals for WLAN/WiMAX operations.

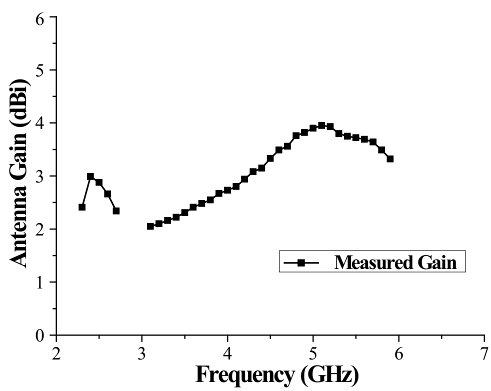


Figure 11. Measured antenna gain for the proposed antenna.

4. CONCLUSION

In this letter, a compact microstrip slot antenna for WLAN/WiMAX applications is presented. Compared to many antennas proposed in recent papers [1–15], this antenna is designed based on a rather simple structure and suitable for all the WLAN/WiMAX frequency bands. By introducing a pair of symmetrical inverted L-strips and an elliptical-arc-shaped stub, the proposed antenna can generate two separate resonances at 3.5 and 5.5 GHz, while the trapezoid and ellipse slot on the ground plane is to excite the lowest resonant mode. The antenna prototype is then designed, fabricated, and measured. The measured results show reasonable agreement with the simulated ones, validating our design concept. In addition, due to the good radiation characteristics and reasonable gains over the required bands, the proposed antenna can emerge as an excellent candidate in WLAN/WiMAX wireless communication systems.

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