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COMPACT TRIPLE-FREQUENCY SLOT ANTENNA FOR WLAN/WIMAX OPERATIONS

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Abstract—A novel microstrip-fed slot antenna with triple-band operation in compact size is proposed. The proposed antenna structure consists of a L-shaped microstrip feed line and open-ended slot on the ground plane, having small overall size of $14 \times 34\,\text{mm}^2$. The open-ended slot constructed of crossed double T-shaped slots is aimed to obtain resonant modes at 2.4/3.5 GHz. Meanwhile, with the use of a via-loaded metal patch connected to the edge of ground, the upper resonant frequency point at 5.8 GHz is achieved. The numerical and experimental results exhibit the designed antenna operates over triple frequency ranges, fulfilling the standards of 3.5-GHz WiMAX and 2.4/5.8-GHz WLAN. In addition, acceptable radiation characteristic is obtained over the operating bands.

1. INTRODUCTION

Recently, various service bands have been introduced due to rapid development of wireless communication technology, such as wireless local area network (WLAN) operating in the frequency band of 2.4–2.484 GHz, 5.15–5.35 GHz and 5.725–5.825 GHz, worldwide interpretability for microwave access (WiMAX) system covering 3.4–3.69 GHz. Thus, integrating more than one communication standards into a single compact system is development tendency for the portability of terminal device. Accordingly, the design of an antenna with multiband operation has presented considerable challenge and attracted increasing attention. As good candidates for multiband operations, planar printed antennas have the advantage of low profile, easy fabrication, and compatibility with microwave integrated circuits. In [1–3], some monopole antennas with multiple branches, such as

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G-shaped, double T-shaped, C-shaped and S-shaped, are reported, providing dual or triple current paths and resonating at different frequency points. Some hybrid antennas composed of a simple monopole and parasitic element are reported in [4–6], the parasitic element introduces another resonant mode and realizes multiband performance. Furthermore, the technology of defected ground plane is used for multiband antenna design in [7–9], which is a simple and effective method to excite additional resonance mode. The band-rejected designs of the printed wideband antenna are also reported in [10–12], the dispensable bands are suppressed and multiple narrow frequency bands are desirably separated from broad band. The printed slot antenna used in multiband operation design is relatively less in the open literature. Merely in [13, 14], the dual-band operation is achieved by carving annular-ring slots in ground or introducing U-shaped strips to wide slot. Although these antenna designs mentioned above can achieve dual or multiple band property, they are somewhat large in size, which are not perfectly practical for small communication terminals.

In this paper, a novel compact microstrip-fed slot antenna design with triple-band operation is proposed for WLAN and WiMAX applications. In the proposed design, the antenna is constructed by etching open-ended crossed double T-shaped slots in the ground plane that is excited by L-shaped microstrip feedline protrudent with a stub. Meanwhile, a via-loaded metal patch is connected with the ground on the edge of substrate board. These design skills are introduced to approach excitation of triple resonant modes accompanied with good impedance bandwidths at 2.4/3.5/5.8 GHz.

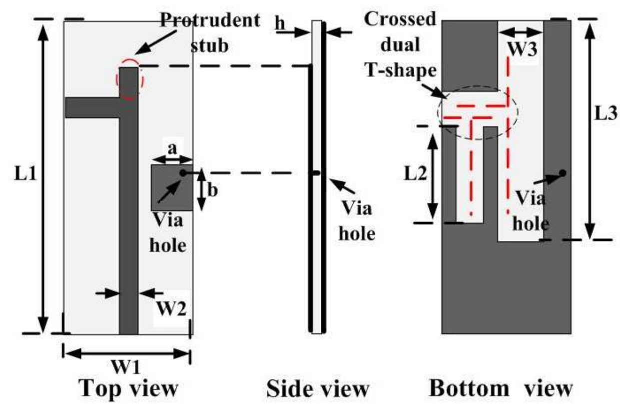


Figure 1. Geometry of the proposed triple-frequency slot antenna.

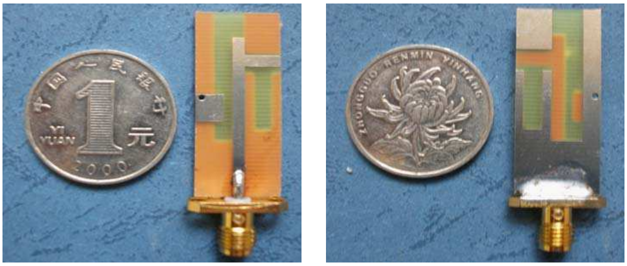
Furthermore, stable radiation characteristics can be obtained over the operating bands. The process of antenna design and results in simulation and measurement are discussed as follows.

2. ANTENNA DESIGN

Figure 1 shows the configuration of the proposed triple-band slot antenna, which is printed on FR4 substrate with relative dielectric constant of 4.6, thickness of 1.0 mm and small size of $14 \times 34\,\text{mm}^2$. In the antenna design, the open-ended slot etched in ground is composed of one horizontal shared slot and two vertical individual slots, called it crossed double T-shaped slot. The length of two vertical slots are L_3 and L_2, controlling the resonant mode at 2.4 GHz and 3.5 GHz, respectively. In order to introduce the excitation of another resonant mode at 5.8 GHz-WLAN, the via-loaded metal patch with the size of $a \times b\,\text{mm}^2$ is printed on the opposite side of ground, which is connecting with ground plane through metallic hole on the edge of board and providing an additional current path. On the other hand, the slots are electromagnetically fed by 50 Ω-microstrip feed line, which is placed over the junction of crossed slots at the other side of the board. The L-shaped microstrip feedline is protruded with a stub from the line's upper side, improving the impedance matching condition and broadening the impedance bandwidth of the proposed antenna.

Table 1. The optimal antenna parameters (Unit: mm).

W_1	W_2	W_3	a	b	L_1	L_2	L_3
14	2	5	4.1	5	34	10.5	24



(a) (b)

Figure 2. Photograph of the fabricated prototype. (a) Top view. (b) Bottom view.

The electromagnetic simulator HFSS based on the finite element method is applied for numerical investigation in the proposed antenna design. By fine-tuning, the final optimal dimension values are obtained and listed in Table 1.

3. RESULTS AND DISCUSSIONS

As a practical example, a prototype of the proposed antenna was experimentally fabricated and measured for validating feasibility of the proposed design. Figure 2 presents the photograph of the fabricated antenna, and a 50 Ω-SMA connector is used to feed the antenna.

The simulated and measured reflection coefficients (S_{11}) of the proposed tri-band slot antenna are illustrated in Figure 3. Reasonable agreements between the simulation and measurement results are attained. Some slight discrepancies between them may be attributed to measurement errors, inaccuracies in the fabrication process, and the impact of the SMA connector. As observed, the proposed antenna achieves three resonant modes around the frequencies of 2.4 GHz, 3.5 GHz and 5.8 GHz for $S_{11} \leq -10$ dB, simultaneously covering the 2.4/5.8 GHz-WLAN and 3.5 GHz-WiMAX operation bands.

To further examine the appropriate impedance matching condition caused from the open-ended slot or via-loaded metal patch, the S_{11} curves for proposed antenna with and without open-ended slot, via-

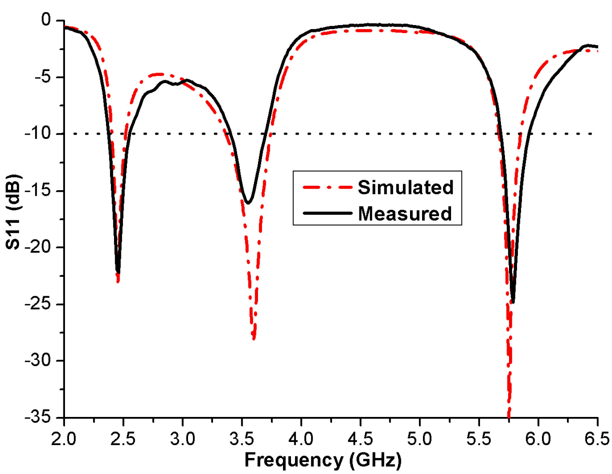


Figure 3. Simulated and measured S_{11} variations of the proposed antenna.

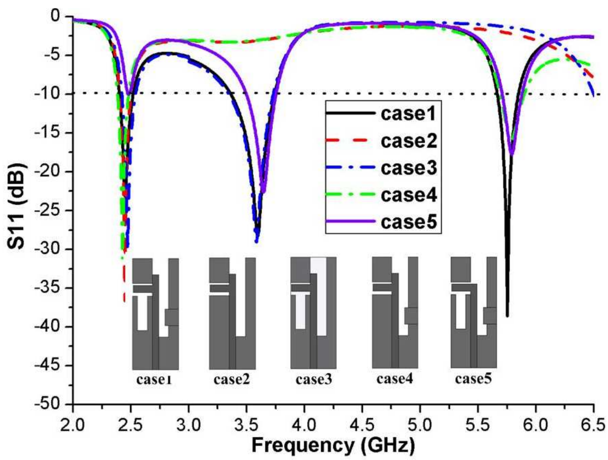


Figure 4. S_{11} variations of the proposed antenna in the different cases.

loaded metal patch or protrudent stub are presented in Figure 4. For the case of only having one open-ended T-shaped slot in ground, the fundamental mode is excited at 2.4 GHz. As the case of inserting another T-shaped slot on the ground plane, which shares horizontal section with prior one slot in the other side of microstrip feedline, the second resonant mode at 3.5 GHz is also emerged. A via-loaded metal patch is connected to the ground edge in another case, the additional resonance at 5.8 GHz can be excited. Finally, if we remove the protrudent stub from the upper side of L-shaped microstrip feedline, though the triple-resonance situation is still existed, the matching condition of the lowest resonance and the bandwidth of medium resonance become worse.

For better understanding the excitation behavior of the proposed antenna, surface current distributions at 2.44, 3.5, and 5.8 GHz, are studied and displayed in Figure 5. For the lower band at 2.4 GHz and medium band at 3.5 GHz, the large surface current density can be observed along the two vertical slots, respectively. Meanwhile, the obviously increased current distribution on the via-loaded metal patch occurs at the upper resonant frequency point 5.8 GHz. Thus, both from the S_{11} characteristic curves and surface current distributions, we can clearly comprehend the function of the related geometrical mechanism on the impedance matching condition of the three resonant modes.

Now, the vital parameters are analyzed for further investigation on resonant frequency bands. Simulated S_{11} curves for different values of

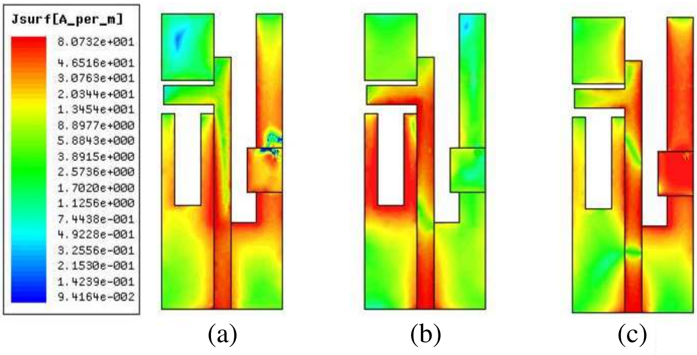


Figure 5. Surface current distribution at different frequencies. (a) 2.44 GHz. (b) 3.5 GHz. (c) 5.8 GHz.

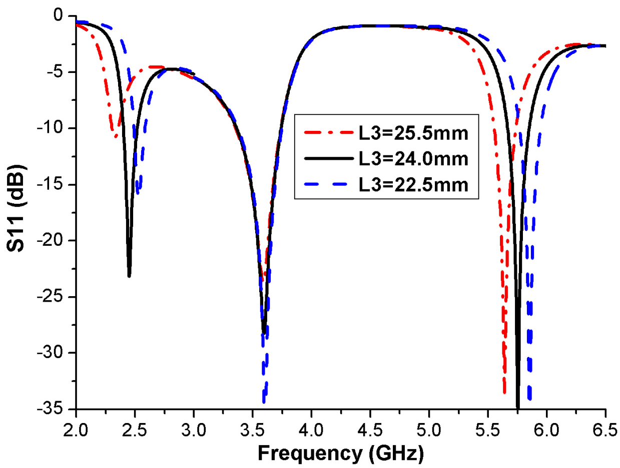


Figure 6. S_{11} variations for different values of slot's length L_3.

L_3 are illustrated in Figure 6, it is seen from the figure that increasing the slot length L_3 leads to the shift towards the lower frequencies of resonant mode at 2.4 GHz, simultaneously has a little impact on highest one at 5.8 GHz. Figure 7 shows the effect of the various slot length L_2 on the S_{11} curves, implying that the changing of the length L_2 has great impact on the resonant mode for 3.5 GHz. Figure 8 shows the effect of the various patch width a on the S_{11} curves, suggesting that the upper resonant mode for 5.8 GHz can be tuned by adjusting the width of the patch.

The radiation patterns in main cut planes at 2.44 GHz, 3.5 GHz

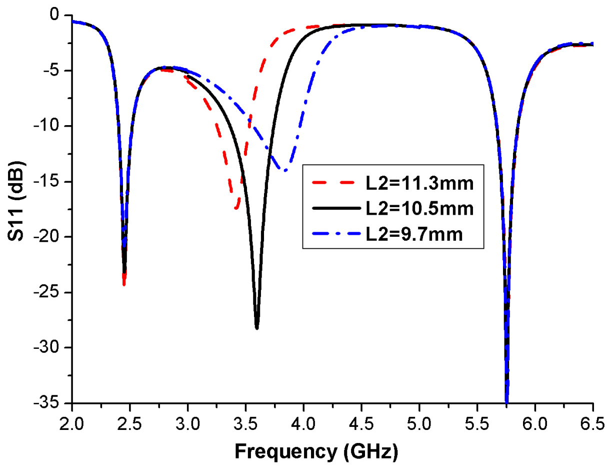


Figure 7. S_{11} variations for different values of slot's length L_2.

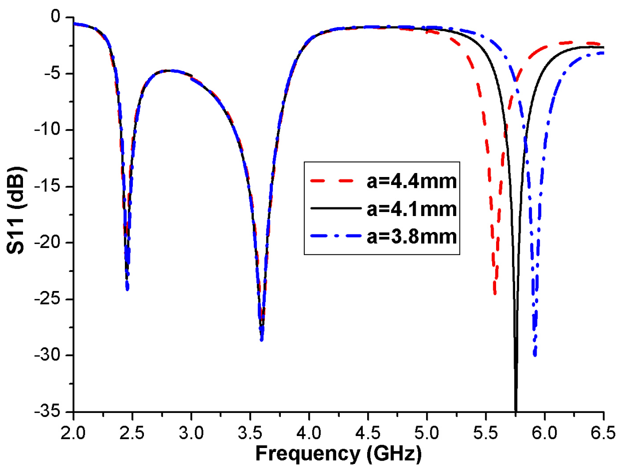


Figure 8. S_{11} variations for different values of square patch's width a.

and 5.8 GHz are shown in Figure 9. From an overall view, the antenna behaves nearly omnidirectional performance with some deterioration at highest resonant mode. The peak gain of the proposed antenna for frequencies across the triple operating bands is stable and acceptable, as illustrated in Figure 10.

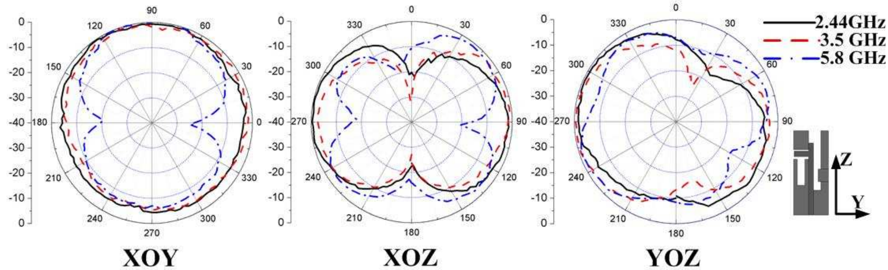


Figure 9. Radiation patterns in main cut planes.

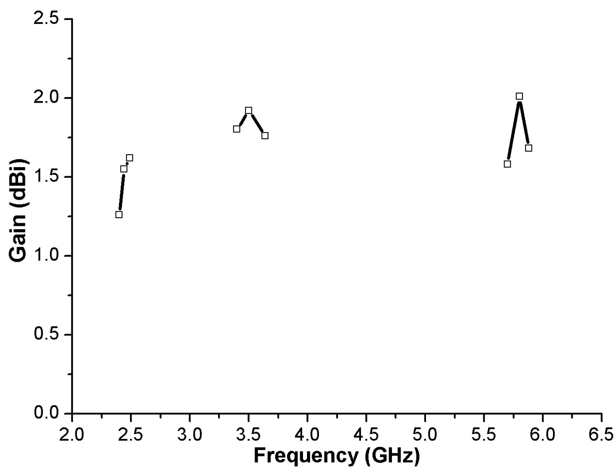


Figure 10. Variations of the peak gains with frequency.

4. CONCLUSION

A novel compact microstrip-fed slot antenna with triple-band operation is presented and investigated. With the skills of etching open-ended crossed double T-shaped slots in the ground plane and connecting via-loaded metal patch to the edge of ground, the proposed slot antenna shows the compactness in the size of $14 \times 34\,\text{mm}^2$ and exhibits triple-frequency resonant performance at 2.4/3.5/5.8 GHz. Furthermore, acceptable radiation patterns and stable gain are also obtained across the operation bands. Consequently, the proposed slot antenna design could be promising and suitable for 3.5-GHz WiMAX and 2.4/5.8-GHz WLAN applications.

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