Progress In Electromagnetics Research Letters, Vol. 31, 89–96, 2012

COMPACT TRIPLE-BAND SLOT ANTENNA FOR WIRELESS COMMUNICATIONS

F.-C. Ren*, **F.-S. Zhang, B. Chen, Y.-T. Wan, and Y.-C. Jiao**

National Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, China

Abstract—This paper presents a compact microstrip-fed slot antenna with triple-frequency operation. The proposed antenna structure consists of a cross-shaped microstrip feed line and multiple open-ended slots on the ground plane. By properly selecting shapes and dimensions of these embedded slots, the triple-resonance situations at 2.4/3.5/5.8 GHz are obtained. Meanwhile, the cross-shaped feedline with shorting pin makes a joint benefit to adjust the matching condition and impedance bandwidth. The numerical and experimental results exhibit the designed antenna operates over triple frequency ranges and covers numbers of useful frequency bands for present wireless communication systems. In addition, acceptable radiation characteristics are obtained over the operating bands.

1. INTRODUCTION

Due to the rapid development of wireless communication systems, various services have been integrated to collaborate with each other, such as wireless local area network (WLAN) operating in 2.4-, 5.2-, 5.8-GHz bands; industrial science medical (ISM) assigned at 2.4–2.5 GHz; Bluetooth operating at 2.4–2.484 GHz; worldwide interoperability for microwave access (WiMAX) system covering at 3.4–3.69 GHz and intelligent transport systems (ITS) working in the 5.8-GHz frequency band. Accordingly, the design of an antenna with multiband operation is the development tendency for improving the utility efficiency of the limited spatial resource in compact terminal device. As a good candidate, planar printed antennas have the attractive features of low profile, easy fabrication, and compatibility with microwave integrated

Received 29 February 2012, Accepted 6 April 2012, Scheduled 12 April 2012
* Corresponding author: Feng-Chao Ren (fchren@163.com).

circuits. Some monopole antennas with multiple branches, such as dual U-shape [1], G-shape [2], trident-shape [3], rectangular ring with strips [4] and adding parasitic element [5], are reported, providing dual or triple current paths and resonant modes. The band-rejected designs of the printed wideband antenna are also reported in [6, 7], the dispensable bands are suppressed and multiple narrow frequency bands are desirably separated from a broad band. The printed slot antenna used in multiband operation design is relatively less in the open literature. In [8], the wide slot antenna broadens the bandwidth of a single resonance band. The dual-band and triple-frequency performances are obtained in [9, 10], however, only one resonant frequency band is introduced by slot embedment, the other resonance modes are excited by traditional monopole antenna all the same. A slotted patch antenna is proposed in [11], the embedded slots into the patch form the antenna as a conventional monopole with four protruded strips and excite multiresonant modes.

In this paper, a compact microstrip-fed slot antenna with triple-band operation is presented for wireless communication systems. The antenna is constructed by etching multiple open-ended slots in the ground plane, including inverted U-slot, inverted L-slot and reversed F-slot, which is excited by a cross-shaped microstrip feed line shorted to the ground on the other side of substrate. These design skills are introduced to approach excitation of triple resonant modes accompanied with stable radiation characteristics over the operating bands. The design method and result discussions are provided in the following.

2. ANTENNA DESIGN

Figure 1 illustrates the geometry of the proposed slot antenna for triple-frequency operation. The antenna is etched on double sides of FR4 substrate with relative dielectric constant of 4.6, thickness of 1.0 mm and small size of $18 \times 28\,\mathrm{mm}^2$. In the antenna design, the open-ended slot etched in ground is composed of multiple individual slots. The inverted U-slot occupied area of $a_1 \times b_1$ introduces the excitation of fundamental resonant mode at 2.4 GHz, while the inverted L-slot combined with rectangle slot at the right side of feed line has the lengths of the horizontal part a_2 and vertical part b_2, controlling the resonant mode at 3.5 GHz. In order to introduce the excitation of upper resonant mode at 5.8 GHz, the reversed-F-shaped slot, comprised of two horizontal arms of length a_3 and one vertical arm of length b_3, is etched on the ground at the left side of feed line. On the other hand, the slots are electromagnetically fed by a $50\,\Omega$-microstrip feed line on the

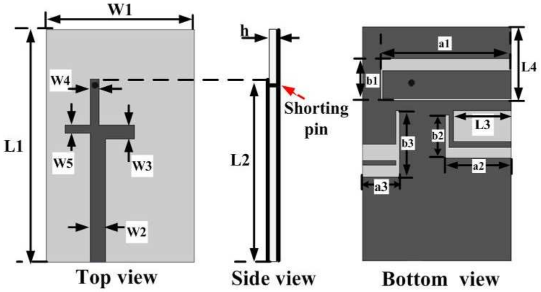

Figure 1. Geometry of the proposed triple-frequency slot antenna.

Figure 2. Photograph of the fabricated prototype.

other side of board. The modified feed line, which is protruded with two perpendicularly cross stubs of width W_3 and W_5, is connected to the ground plane via a metallic shorting pin at line's upper end, with the consideration of the impedance matching improvement and bandwidth enhancement in the proposed antenna design.

An electromagnetic software package, HFSS 13.0 based on the finite element method, is used for required numerical analysis to examine the performance of the antenna. In the HFSS configuration, the solution frequencies are set as 2.4 GHz, 3.5 GHz and 5.8 GHz respectively, with radiation boundary and convergence of less than 0.02 as default. Via iterative trials, the final optimal dimension values are obtained and listed in Table 1.

3. RESULTS AND DISCUSSIONS

Figure 2 presents the photograph of the fabricated antenna prototype, and a 50 Ω-SMA connector is used to feed the antenna. The simulated and measured reflection coefficients magnitude ($|S_{11}|$) of the proposed slot antenna are plotted in Figure 3. Reasonable agreements between the simulation and measurement results are attained, some slight discrepancies may be attributed to inaccuracies in the fabrication, impact of the SMA connector and their soldering on the board. As observed, the proposed antenna achieves three resonant modes over the frequency ranges of 2.39–2.51 GHz, 3.4–3.7 GHz and 5.64–5.96 GHz for $|S_{11}| \leq -10$ dB, simultaneously covering numbers operation bands of the wireless communication systems (2.4 GHz-Bluetooth, 2.4 GHz-ISM, 2.4/5.8 GHz-WLAN, 3.5 GHz-WiMAX, 5.8 GHz-ITS).

To further examine the effect of each slot on the antenna's triple-

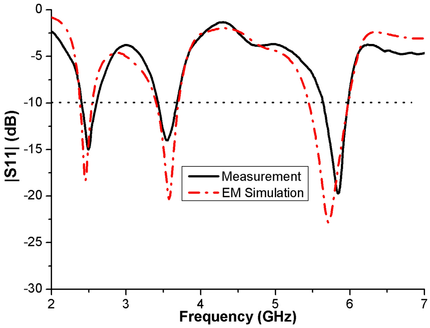

Figure 3. Simulated and measured $|S_{11}|$ variations of the proposed antenna.

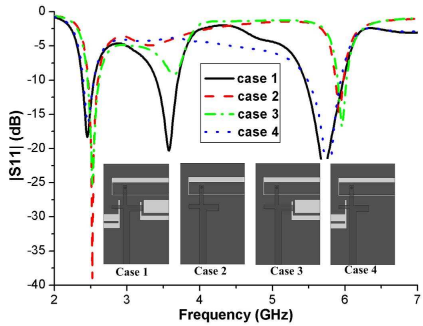

Figure 4. $|S_{11}|$ variations of the proposed antenna in the different embedded slots.

resonance situations, the frequency response of $|S_{11}|$ for proposed antennas with different slot embedments are analyzed and presented in Figure 4. For the case of only having U-shaped slot in the ground, the fundamental resonance mode at 2.4 GHz is effectively excited with spurious resonance in vicinity of undesired frequency 6 GHz. As for the case of inserting inverted L-slot on the ground plane at the right side of feed line, the second resonant situation at 3.5 GHz is also emerged though the matching condition is not very good. For the case with the reversed F-slot embedment, the upper resonance at 5.8 GHz is excited and the spurious resonance is interestingly eliminated. Figure 5 shows the frequency response of $|S_{11}|$ for different feed line modifications. Seen from the figure, the matching condition and impedance bandwidth become worse if we remove two perpendicularly crossed stubs, though the triple-resonance situation is still existed. In other case, the triple-resonance situation disappears when the shorting pin is removed and feed line becomes open-circuited stub.

For gain better understanding of the way each resonance is excited, surface current distributions for proposed antenna at 2.44, 3.5, and 5.8 GHz, are studied and displayed in Figure 6. For 2.4-GHz excitation, a large surface current density is observed along the inverted U-slot. Meanwhile, the obviously increased current distributions along the inverted L-slot and reversed F-slot occur at around 3.5 GHz and 5.8 GHz respectively. Thus, the related geometrical mechanism of proposed antenna on the resonance situation is clearly presented both from the frequency response of $|S_{11}|$ and surface current distributions.

Now, the vital parameters are studied for the designers to have

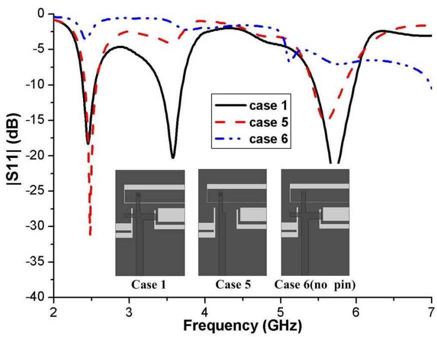

Figure 5. $|S_{11}|$ variations of the proposed antenna in the different feed lines.

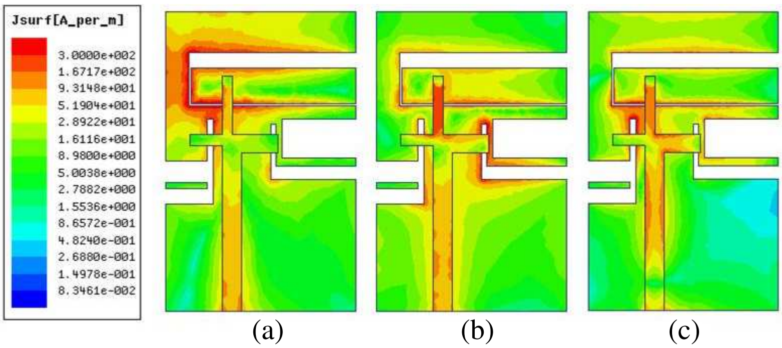

Figure 6. Surface current distributions at different frequencies: (a) 2.44 GHz, (b) 3.5 GHz, (c) 5.8 GHz.

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

W_1	W_2	W_3	W_4	W_5	L_1	L_2	L_3	L_4	a_1	b_1	a_2	b_2	a_3	b_3
18	1.8	1.7	1	1	28	22	7	8.8	15.8	5	8	5.2	4.5	8

more information in achieving the desired resonant band. Figure 7 presents simulated $|S_{11}|$ curves for different values of a_1, it is seen from the figure that this parameter has great effect on resonance band, and the 2.4-GHz resonant mode can be tuned by adjusting the slot length a_1. Figure 8 shows the effect of the various slot length b_2 on the $|S_{11}|$ curves, implying that increasing the slot length b_2 leads to the shift towards the lower frequencies of 3.5-GHz operation band. Figure 9 shows the effect of the various slot length b_3 on the $|S_{11}|$ responses,

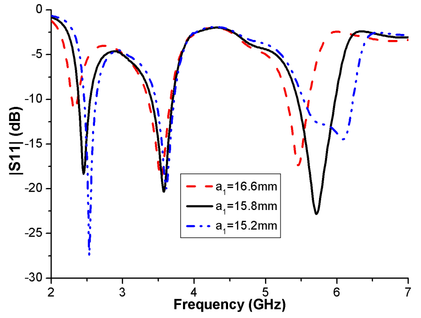

Figure 7. $|S_{11}|$ variations for different values of slot's length a_1.

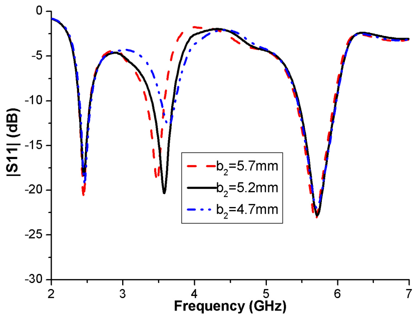

Figure 8. $|S_{11}|$ variations for different values of slot's length b_2.

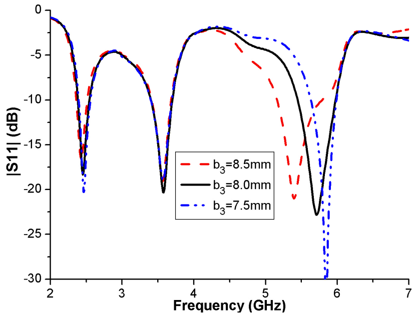

Figure 9. $|S_{11}|$ variations for different values of slot's length b_3.

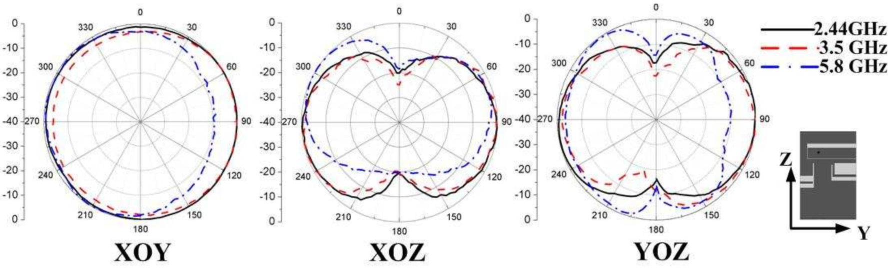

Figure 10. Radiation patterns in main cut planes.

suggesting that the changing of the length b_3 has great impact on the resonant mode for 5.8 GHz.

The radiation patterns in main cut planes at 2.44 GHz, 3.5 GHz and 5.8 GHz are shown in Figure 10. From an overall view, the

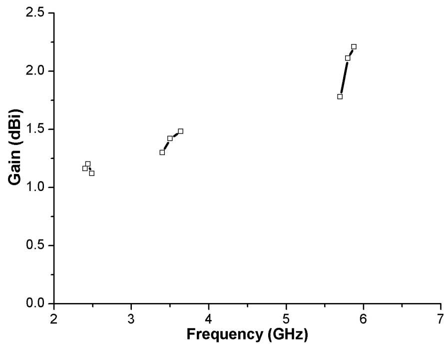

Figure 11. Variations of the peak gains with frequency.

antenna behaves nearly monopole-like radiation performance with conical patterns in the elevation planes and omnidirectional patterns in the azimuth plane. However, the monopole-like property is degraded at upper frequency may due to the difference of the current distributions. Moreover, the measured gains of the proposed antenna for frequencies across the triple operating bands are stable and acceptable, as illustrated in Figure 11.

4. CONCLUSION

A compact microstrip-fed slot antenna with triple-frequency operation is presented and investigated. With the technologies of etching multiple open-ended slots (U-slot, L-slot, F-slot) in the ground plane and feeding with cross-shaped microstrip line, the proposed slot antenna shows the compactness in the size of $18 \times 28\,\text{mm}^2$ and exhibits triple-frequency resonant performance at 2.4/3.5/5.8-GHz bands. Furthermore, acceptable radiation patterns and stable gains are obtained across the operation bands. Thus, the proposed slot antenna could be promising for numbers of modern wireless communication standards.

REFERENCES

1. Lu, J.-H. and W.-C. Chou, "Planar dual U-shaped monopole antenna with multiband operation for IEEE 802.16e," *IEEE Antennas Wireless Propagat. Lett.*, Vol. 9, 1006–1009, 2009.
2. Song, Y., Y.-C. Jiao, H. Zhao, Z. Zhang, Z.-B. Weng, and F.-S. Zhang, "Compact printed monopole antenna for multiband

applications," *Microwave Opt. Technol. Lett.*, Vol. 50, No. 2, 365–367, 2008.

3. Wang, C., Z.-H. Yan, P. Xu, J.-B. Jiang, and B. Li, "Trident-shaped dual-band CPW-fed monopole antenna for PCS/WLAN applications," *Electron. Lett.*, Vol. 47, No. 4, 231–232, 2011.
4. Ren, X.-S., Y.-Z. Yin, W. Hu, and Y.-Q. Wei, "Compact tri-band rectangular ring patch antenna with asymmetrical strips for WLAN/WIMAX applications," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 13, 1829–1838, 2010.
5. Li, Z.-Q., C.-L. Ruan, L. Peng, and X.-H. Wu, "Design of a simple multi-band antenna with a parasitic C-shaped strip," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 14–15, 1921–1929, 2010.
6. Chen, W.-S. and K.-Y. Ku, "Band-rejected design of the printed open slot antenna for WLAN/WiMAX operation," *IEEE Trans. Antennas Propag.*, Vol. 56, No. 4, 1163–1169, 2008.
7. Song, K., Y.-Z. Yin, and B. Chen, "Triple-band open L-slot antenna with a slit and a strip for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters,* Vol. 22, 139–146, 2011.
8. Zhu, L., R. Fu, and K.-L. Wu, "A novel broadband microstrip-fed wide slot antenna with double rejection zeros," *IEEE Antennas Wireless Propagat. Lett.*, Vol. 2, 194–196, 2003.
9. Huang, C.-Y. and E.-Z. Yu, "A slot-monopole antenna for dual-band WLAN applications," *IEEE Antennas Wireless Propagat. Lett.*, Vol. 10, 500–502, 2011.
10. Liu, W.-C., C.-M. Wu, and Y. Dai, "Design of triple-frequency microstrip-fed monopole antenna using defected ground structure," *IEEE Trans. Antennas Propag.,* Vol. 59, No. 7, 2457–2463, 2011.
11. Liu, W.-C., C.-M. Wu, and N.-C. Chu, "A compact CPW-fed slotted patch antenna for dual-band operation," *IEEE Antennas Wireless Propagat. Lett.*, Vol. 3, 110–113, 2010.