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COMPACT PRINTED SLOT ANTENNAS FOR WIRELESS DUAL- AND MULTI-BAND OPERATIONS

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Abstract—This paper presents a printed slot antenna using the printed structure in order to improve its dual-band and compact size performances. The printed slot structure is used as additional resonators to produce dual-band operation for covering the worldwide interoperability for microwave access (WiMAX) and the 5.2-GHz wireless local area network (WLAN) bands. In order to achieve wideband and multi-band operation, the slot antennas with a slotted structure and an inverted-L slot structure for covering the wireless communication operations are developed. Finally, we propose a novel and compact printed slot antenna with mixing slot structures to obtain and cover for the 2.4-GHz WLAN (2.4–2.484 GHz), the WiMAX (IEEE 802.16e in the Taiwan: 2.5–2.69/3.5–3.65 GHz), and the 5-GHz WLAN (5.15–5.35/5.725–5.825 GHz). Several properties of the proposed antennas for dual- and multi-band characterize radiation performances such as impedance bandwidth and radiation pattern. Measured gain has been confirmed experimentally for the multi-band wireless communication systems.

1. INTRODUCTION

Compact design and multi-band operations for the wireless communication strong design advantages in low-profile, easy fabrication, low manufacturing cost, and easy integrating circuit boards. Many compact antennas with broadband and multi-band performances including dipole antenna, monopole antenna, and planar antenna configurations have been reported [1–6]. These are printed antennas with moderate radiating characteristics and can be operative at dual- and multiple-frequency bands. Moreover, for the antenna fabrication designs, the slot structures require to provide a broadband and multi-band systems including 2.4- and 5-GHz wireless local area network (WLAN) bands, but without the worldwide interoperability for microwave access (WiMAX). Recently several interesting designs of the slot antennas with diverse geometric configurations for the bandwidth enhancement and the size reduction functions have been widely studied [7–12]. These antennas based on the slot design configurations and the tunable antenna fabrications have been developed to obtain wide impedance bandwidth and small size, but they have complex designed structure. The designed slot antennas improve multi- and dual-band for the wireless communication operations [13–24]. The feed point structure of the slot antennas using coplanar waveguide (CPW) fed and microstrip line fed has been developed to integrate the circuit boards over wide- and multi-bandwidth of the operating bands.

In this paper, first a new compact antenna with the printed slot structure is proposed to achieve the dual-band operation. The slot structure on the printed antenna that satisfies the requirements of the mobile-WiMAX and 5.2-GHz WLAN applications such as the impedance bandwidth, radiation pattern and gain is presented. Second, printed slot antennas are introduced by using a slotted structure and an inverted-L slot structure, respectively. The investigation numerically and experimentally demonstrates that a tunable multi-operating band and an enhancement of the antenna bandwidth owing to the proposed antenna with the slot-shaped radiators. Finally, the proposed compact printed slot antenna with the mixing slot structures is presented and experimented by the way of arranging with simple configuration and slot configurations that we could applied to the printed antenna, and a multi-band characteristic with the proposed antenna improves the narrow band of the compact antenna with a single metal plane for wireless systems applications of the 2.4-GHz WLAN (2.4–2.484 GHz), the WiMAX (IEEE 802.16e in the Taiwan: 2.5–2.69/3.5–3.65 GHz) and the 5-GHz WLAN (5.15–5.35/5.725–5.825 GHz).

The paper is organized as follows. As a starting point, Section 2 presents the printed slot antenna for dual-band operation and its radiation performances. After that, design and parameter study of the printed slot antennas with a slotted structure and an inverted-L slot structure are described in Section 3 and the printed slot antenna using mixing slot structure is also created and tested. Finally, the complete study is summarized in Section 4.

2. DUAL-BAND ANTENNA

2.1. Antenna Design

The geometry and configuration of the printed slot antenna for dual-band operation is illustrated in Fig. 1. The compact design of proposed antenna has a slot structure, a rectangular-shaped ground plane and the fed by a 50 coaxial line that is applied to interface the antenna to the test equipment on the selfsame plane. The inner fed conductor and the outer metal sheath of the coaxial line connect to the feed point and the ground plane, both with a distance of 1.5 mm between two points, respectively. The microstrip line with feed point has a matching connector of $1.1 \times 11.5\,\mathrm{mm}^2$. The proposed antenna prints on the FR4 substrate with a thickness of 0.8 mm, dielectric constant of 4.3, and loss tangent of 0.0245 and has a compact dimension of $34 \times 15\,\mathrm{mm}^2$ in this study. In this design, the printed slot structure of the proposed antenna can produce two different surface current patches and obtain a dual- frequency band. The printed slot structure provides a wide upper resonance mode to cover 5.2-GHz WLAN band, while the right copper patch and the left rectangular-shaped ground plane obtain the lower resonance mode including the mobile-WiMAX band. This antenna structure is easy to design and to achieve a stable bandwidth for dual-band wireless operations.

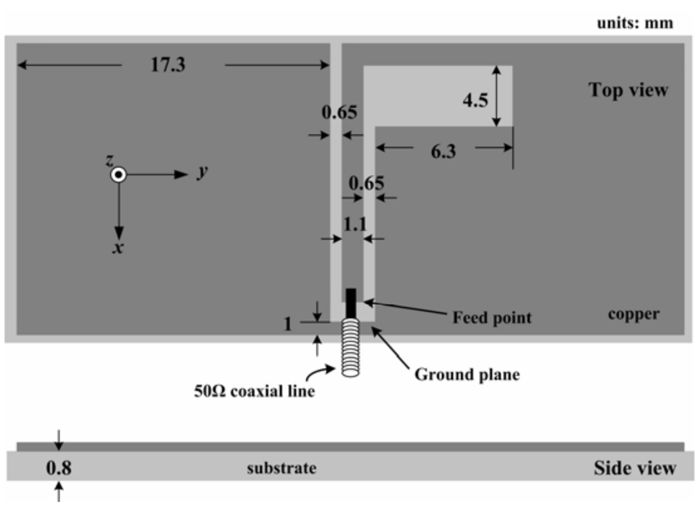

Figure 1. The geometry of the slot antenna.

2.2. Results

Fig. 2 shows the simulated and measured return loss of the proposed antenna with compact and low profile structures for dual-operating wireless application. Fig. 2 shows the measured return loss and it is noted that there are two main resonant modes at 2.7 and 5.1 GHz, which excite less than 10 dB return loss. The measured return loss of operating bandwidth portion has a 540 MHz between 2.48 and 3.02 GHz at the lower resonance mode. Nevertheless, this resonance bandwidth has the signification operation on the Mobile-WiMAX system in the Taiwan between 2.5 and 2.69 GHz. The printed slot structure shows the signification factor on the variation of the upper resonance mode of 1840 MHz within 3.81–5.65 GHz, which cover the 5.2-GHz for WLAN operation (5.15–5.35 GHz). The measured bandwidth of the proposed antenna covers two impedance bandwidths, 19.6% on the lower bandwidth for the Mobile-WiMAX system and 38.9% on the upper bandwidth for 5.2-GHz WLAN system, respectively. The results with the return loss and radiation performances of the proposed slot antennas are measured by an HP 8720C vector network analyzer and an NSI far-field chamber. We studied the new geometry of the proposed antennas by Ansoft HFSS electromagnetic simulation software.

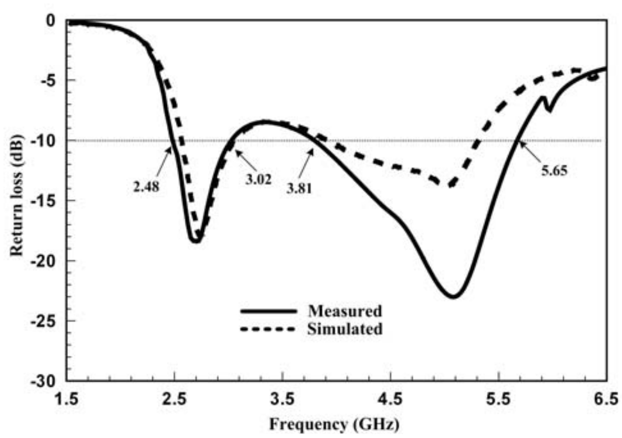

Figure 2. The measured and simulated return loss of the slot antenna.

The measured radiation patterns of the proposed slot antenna at 2.6 and 5.2 GHz are illustrated in Fig. 3. It is noticed that the radiation patterns with two main planes are conventional dipole antenna. The x-z plane radiation pattern is omni-directional pattern at two presented operation. So the radiation patterns are generally omni-directional over the entire bandwidth, which is similar to a conventional antenna for wireless communication systems. The peak antenna gain for frequencies throughout the matching bands for proposed antenna was measured, as shown in Fig. 4. The maximum measured gains at all radiation planes obtain a 4.95 dBi at 2.6 GHz within the lower operation band and a steady gain from 4.42 dBi to 3.88 dBi within 5–5.5 GHz at the upper operation band.

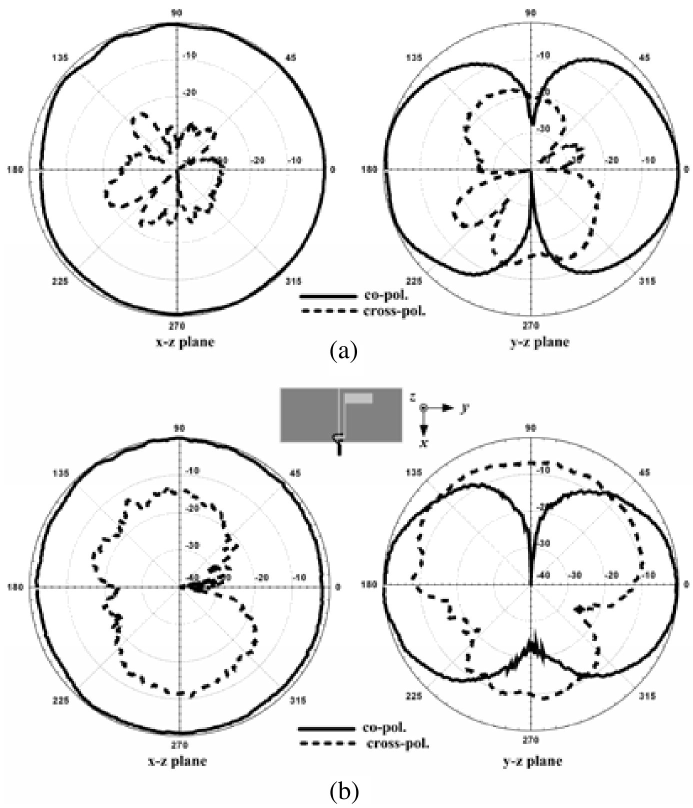

Figure 3. Measured radiation patterns of the slot antenna at x-z and y-z planes. (a) 2.6 GHz. (b) 5.2 GHz.

3. MULTI-BAND ANTENNAS

3.1. Antenna with Slotted Structure

In order to make the antenna achieve multi-band operation for wireless communication systems, we added a slotted and an inverted-L slot

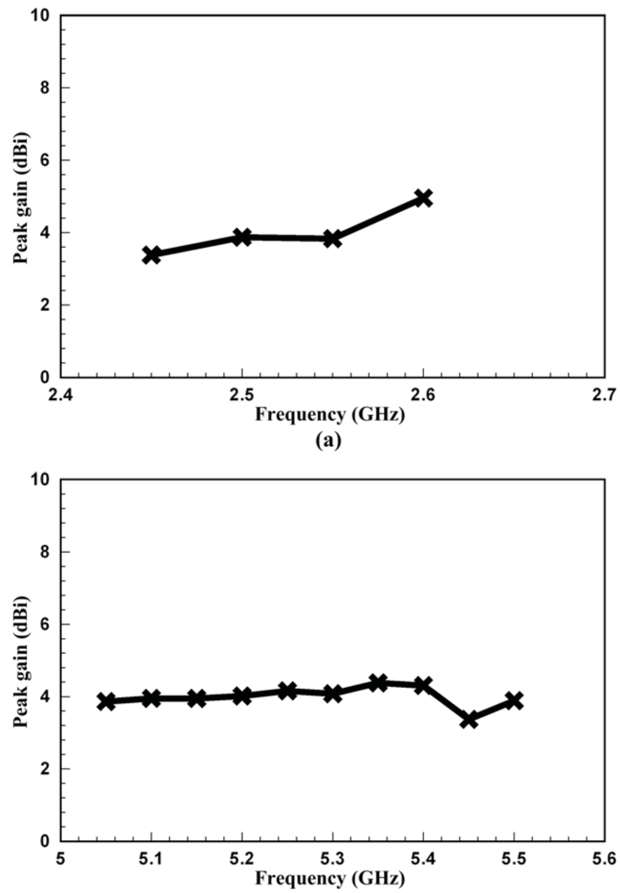

Figure 4. The measured gain of the slot antenna. (a) lower band. (b) upper band.

structures on ground plane, respectively. The structure of the proposed antenna with a slotted structure on ground plane is illustrated in Fig. 5(a). This new designed antenna consists of a printed slot antenna element and a slotted structure on ground plane. The proposed antenna is printed the same as the printed slot antenna on the FR4 substrate. Fig. 6 shows the simulated and measured return loss of the proposed antenna with a slotted structure for dual-operating band application. It is noted that there are four main resonant modes at 2.4, 4.1, 5.1 and 5.6 GHz, which excite less than 10 dB return loss. The measured return loss of operating bandwidth portion is

160 MHz (6.6%) between 2.35 and 2.51 GHz at the lower resonance mode for 2.4-GHz WLAN band. The upper impedance bandwidth includes three resonance modes of 2300 MHz (45.1%) between 3.95 and 6.25 GHz, which covers the 5-GHz for WLAN operation (5.15–5.35/5.725–5.825 GHz).

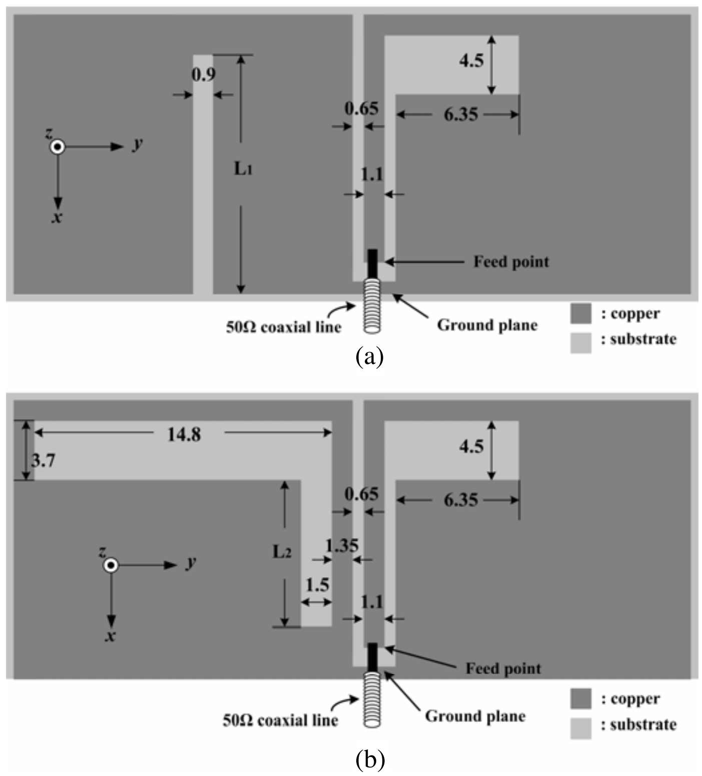

Figure 5. The geometry of the proposed slot antennas. (a) The slot antenna with a slotted structure. (b) The slot antenna with an inverted-L slot structure.

The parametric studies of the slot antennas can obtain the optimal design dimensions of proposed antenna performance for the wireless operating frequency bands. However, the effect of design parameter has been shown in the simulation that the impedance bandwidth and the operating resonance modes of proposed antenna (printed slot antenna with a slotted structure) are critically dependent on the length of the slotted on the ground plane (L_1). We modified the length of slotted structure. The results are shown in Fig. 7. Other parameters are fixed at the optimized state. If the tuning of the length of the

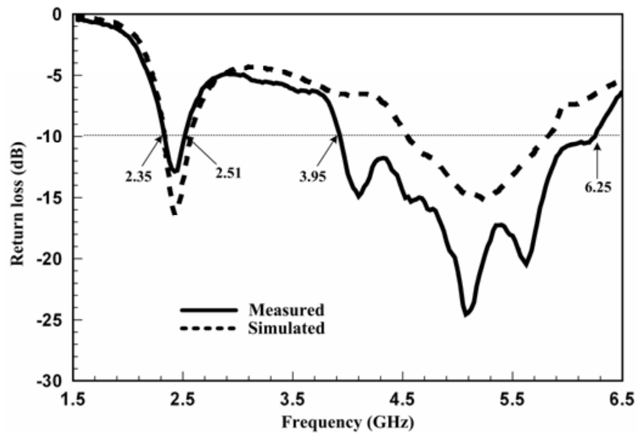

Figure 6. Measured and simulated return loss of the slot antenna with a slotted structure.

slotted structure has been finished, the impedance bandwidth will be broadband situation in the upper operation. By modifying the designed parametric of slotted structure, the lower band operation is also changed slightly.

3.2. Antenna with Inverted-L Slot Structure

The configuration of the printed slot antenna with an inverted-L slot structure is illustrated in Fig. 5(b). The new designed antenna consists of a printed slot antenna element and the inverted-L slot structure on ground plane. This proposed antenna is printed the same as the printed slot antenna on the FR4 substrate. Fig. 8 shows the simulated and measured return loss of the proposed antenna with an inverted-L slot structure for the triple-operating bands. It is noted that there are four main resonant modes at 2.62, 3.97, 5.42 and 5.8 GHz, which excite less than 10 dB return loss. The measured return loss of the operating bandwidth portion is 330 MHz (12.4%) between 2.49 and 2.82 GHz at the lower resonance mode for the mobile-WiMAX band. The inverted-L slot structure on ground plane shows the signification factor on the variation of the middle impedance bandwidth of 740 MHz (19.3%) within 3.47–4.21 GHz, which cover WiMAX (3.5–3.65 GHz) bands. The upper impedance bandwidth includes two resonance modes of 1580 MHz (28%) within 4.85–6.43 GHz, which covers the 5-GHz for WLAN operation (5.15–5.35/5.725–5.825 GHz).

The effect of the design parameter has been shown in the

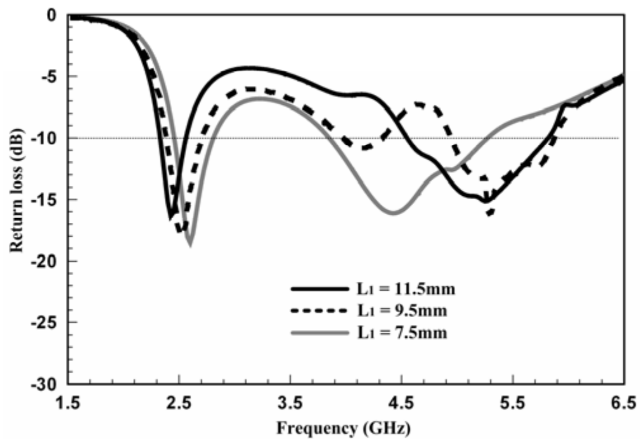

Figure 7. Simulated return losses with different slotted length (L_1) of the slot antenna with a slotted structure.

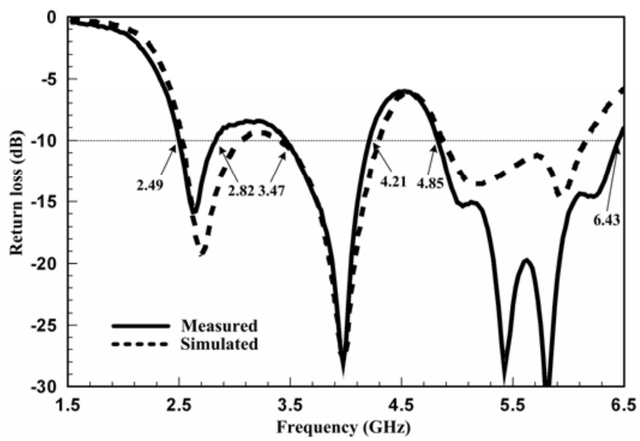

Figure 8. Measured and simulated return loss of the slot antenna with an inverted-L slot structure.

simulation dependent on the length of the inverted-L slot structure on ground plane (L_2). We modified the length of the inverted-L slot structure. The results are shown in Fig. 9. Other parameters are fixed at the optimized state. If the antenna has confirmed the length of proposed slot configuration, the performance of resonant mode will add impedance bandwidth in the middle band. By modifying the lengths of the slot form, the middle and the upper bands have been changed also dependent on surface current patches.

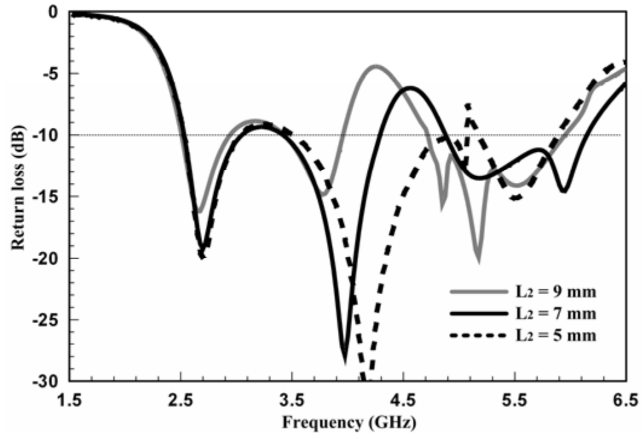

Figure 9. Simulated return losses with different slot length (L_2) of the slot antenna with an inverted-L slot structure.

3.3. Antenna with Mixing Slot Structure

In the foregoing paragraphs slotted and inverted-L slot forms can achieve the dual-band and the multi-band operations at the compact configuration for the wireless communication systems. Fig. 10 shows the geometry of the proposed antenna with mixing slot structure for the wireless multi-band applications. It is printed on a 0.8 mm FR4 substrate and has a compact dimension of $34 \times 15\,\text{mm}^2$ in this study. The compact design of the proposed antenna has a small slotted form, an inverted-L slot on ground plane and fed by a 50Ω coaxial cable line on the selfsame plane. Moreover, in order to achieve a compact structure for the proposed antenna, the slot structures on metal plane are designed exactly as shown in Fig. 10.

Fig. 11 shows the simulated and measured return loss of the proposed antenna with compact and mixing slot structures for the multi-band wireless communication applications. The measured return loss of operation bandwidth portion is 340 MHz between 2.38–2.72 GHz at the first resonance mode. Nevertheless, this resonance bandwidth has the signification operation on the 2.4-GHz WLAN system between 2.4 and 2.484 GHz and the Mobile-WiMAX system in Taiwan between 2.5 and 2.69 GHz. However, it shows the signification factor on the variation of the second resonance mode of 540 MHz between 3.48–4.02 GHz, which cover the WiMAX (3.5–3.65 GHz) bands. The two higher resonance modes exhibit bandwidth of 1460 MHz from 4.85 GHz to 6.31 GHz, covering the 5-GHz for WLAN operation (5.15–5.35 GHz and 5.725–5.825 GHz). The measured bandwidth of proposed antenna covers three impedance bandwidths, 13.4% on the first bandwidth for the 2.4-GHz WLAN system and Mobile-WiMAX system, 14.4% on the second bandwidth for the WiMAX system, and 26.2% on the third bandwidth for 5-GHz WLAN system, respectively.

The effects of design parameter have been shown in the simulation that the impedance bandwidth and impedance matching of the

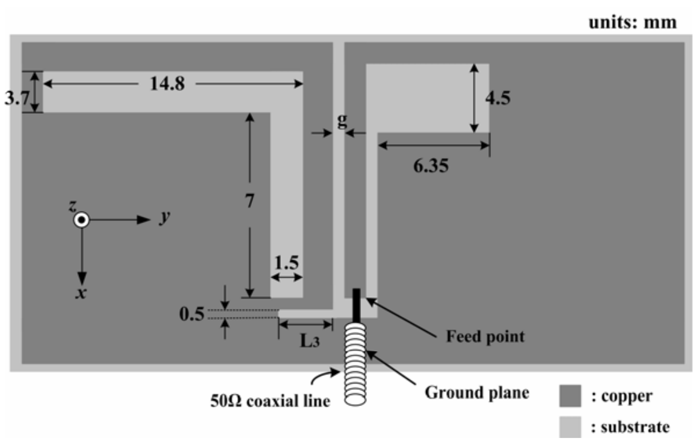

Figure 10. The geometry of the slot antenna with the mixing slot structure.

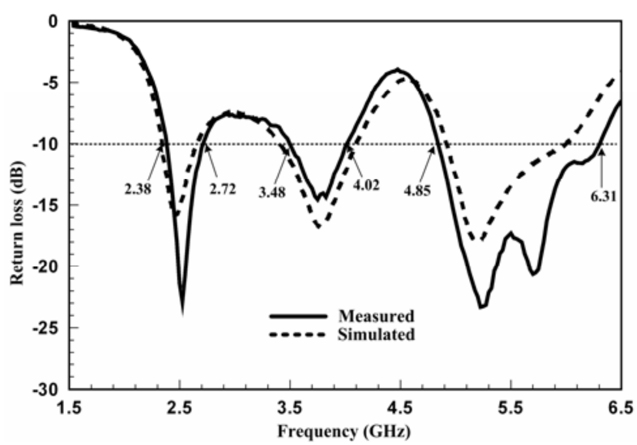

Figure 11. Measured and simulated return loss of the slot antenna with the mixing slot structure.

proposed antenna are critically dependent on the length of a slotted structure (L_3). We modified the length of slot form. The results are shown in Fig. 12. Other parameters are fixed at the optimized state. Its main effect is to match all the operating frequency bandwidth. If the antenna has completed the length of slotted form, the performance of impedance bandwidth will be broadband situation in all operating bands.

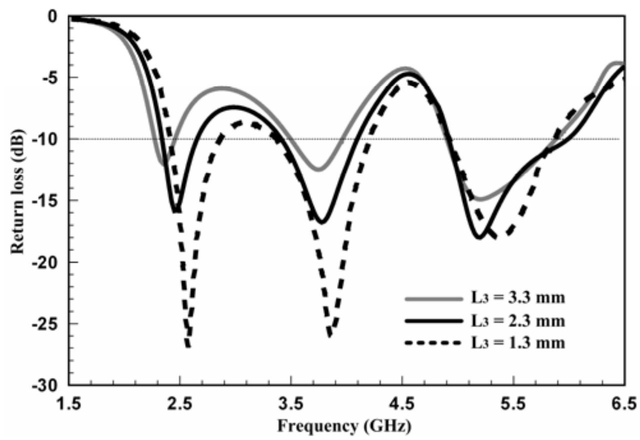

Figure 12. Simulated return losses with different slot length (L_3) of the slot antenna with the mixing slot structure.

The measured radiation patterns of the proposed antenna at 2.45 GHz, 3.6 GHz, and 5.8 GHz are illustrated in Fig. 13. It is noted that the radiation patterns in two main planes at the wireless communication operations are conventional dipole antenna of the same. The x-z plane radiation pattern is omni-directional pattern at three presented operations. So the radiation patterns are generally omni-directional over the entire bandwidth, similar to a conventional antenna for wireless communication systems. The peak antenna gain for frequencies throughout the matching bands for proposed antenna was measured, as shown in Fig. 14. The variation ranges of maximum measured gain at all radiation planes are varied from 3.9 dBi to 1.06 dBi within 2.4–2.7 GHz at the first operating frequency band, from 1.95 dBi to 0.97 dBi within 3.5–3.9 GHz at the second operating frequency band and from 4.48 dBi to 2.82 dBi within 5.1–5.9 GHz at the third operating frequency band, respectively. The measured results of proposed antenna not only have multi-band effect but also reach the operating applications of the wireless communication systems.

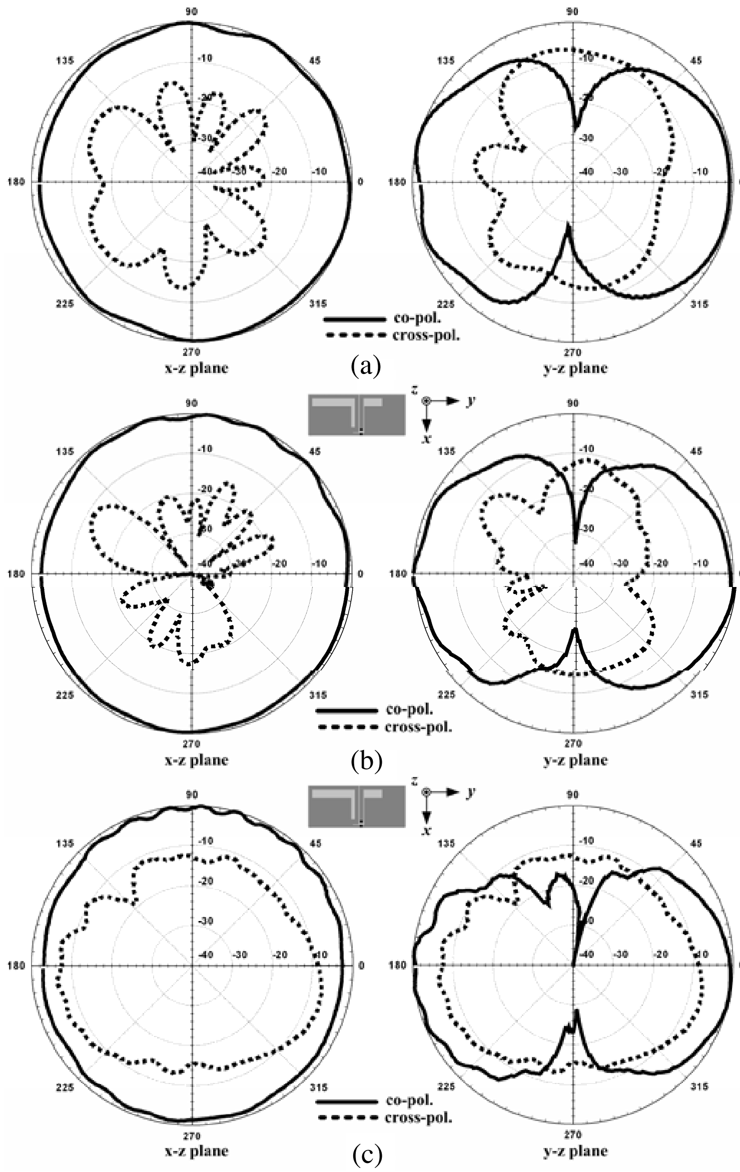

Figure 13. Measured radiation patterns of the slot antenna with the mixing slot structure at x-z and y-z planes. (a) 2.45 GHz. (b) 3.6 GHz. (c) 5.8 GHz.

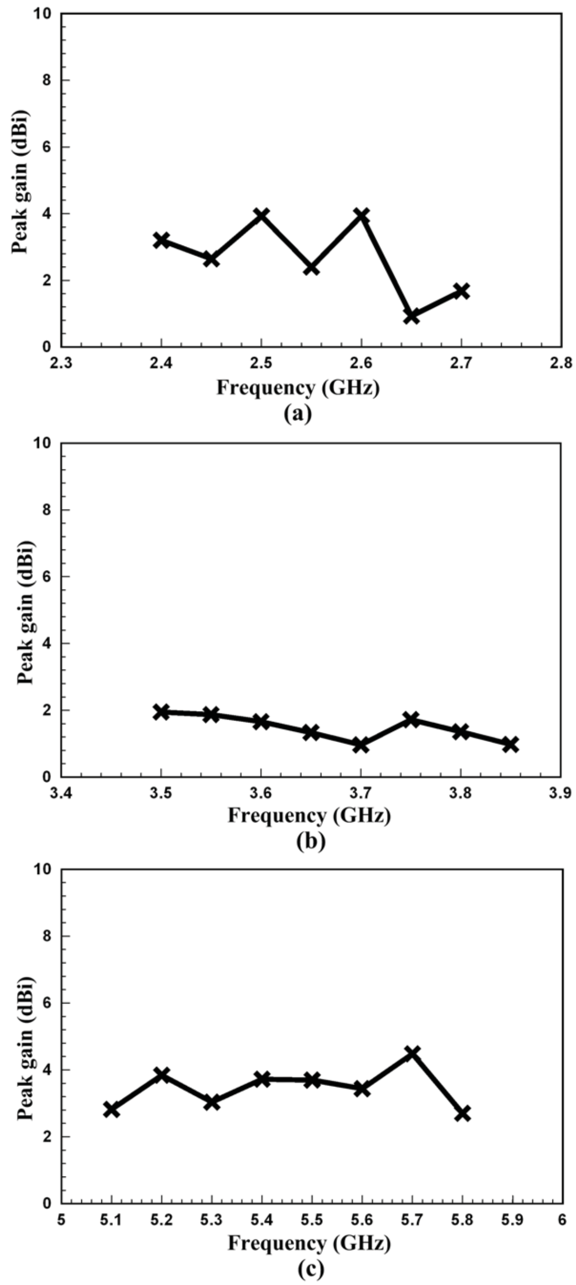

Figure 14. Measured gains of the slot antenna with the mixing slot structure. (a) lower band. (b) middle band. (c) upper band.

4. CONCLUSION

New printed compact slot antennas have been developed and can achieve the dual-band and the multi-band wireless communication operations by using the manifold slot structures including the printed slot, the slotted form and inverted-L slot. The experimental results of the slots on the metal plane in the printed compact antenna make a strong effect on the antenna's operating resonance modes and impedance bandwidth, so the characteristics of compact antennas with the slot configurations are improved and verified. Experimental results show that by using proposed designs and tuning their dimensions, operating bandwidth, measured gain and radiation patterns can be obtained for 2.4- and 5-GHz WLAN/WiMAX applications.

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