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Quad-Band Planar Inverted-F Antenna (PIFA) for Wireless Communication Systems

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Abstract—In this paper, a compact quad-band planar inverted-F antenna (PIFA) for wireless communication systems is presented. The proposed PIFA consists of a radiating patch with a hook-shaped slot and a modified ground plane with pair of square-ring and rotated I-shaped slots. The antenna is fabricated on an *FR4* substrate with dielectric constant of 4.4. By cutting a hook-shaped slit at radiating patch, good dual-band property can be achieved which covers 3.5 GHz worldwide interoperability for microwave access (WiMAX) and 5.2 GHz wireless local area network (WLAN) frequencies. In addition, by using a modified ground plane with a rotated I-shaped an the pair of square-ring slot, additional resonances at the higher frequencies are generated which suitable for 7.25–7.75 GHz downlink of X-band satellite communication systems and 8.02–8.4 GHz international telecommunication union (ITU) applications. Good return loss, antenna gain and radiation pattern characteristics are obtained in the frequency band of interest. The proposed antenna has a small dimension of $24 \times 3 \times 1.6\,\text{mm}^3$.

1. INTRODUCTION

Recently, the increasing use of microwave mobile communication systems demands antennas for different systems and standards with properties such as reduced size, broadband, multi-band operation, moderate gain [1]. Some of the important frequency bands for wireless communications are the WiMAX operating in 3.3–3.7 GHz, WLAN systems for IEEE 802.11a operating in 5.15–5.35 GHz, 7.25–7.75 GHz downlink of X-band satellite communication systems, and 8.02–8.4 GHz ITU bands [2].

The wireless communication device provides the ability to integrate multiband. Therefore, a dual or multiband antenna is attractive in many commercial applications as it is designed to have a single radiator with a capability to transmit and receive multiple frequencies. Nevertheless, a multiband antenna may not sufficiently cover the required operating bands. Therefore, an antenna which is able to operate with multiple independent frequency bands is required [3–7].

It is a well-known fact that PIFA presents really appealing physical features, such as simple structure, small size, and low cost. Because of all these interesting characteristics, PIFAs are extremely attractive to be used in multi-band applications, and growing research activity is being focused on them. In this paper, a novel design of a multi-band PIFA is proposed which have many advantages such as simple structure of a wide bandwidth and easy integration with active devices. The measured impedance bandwidth for l0 dB return loss is from 3.35 GHz to 3.64 GHz (8%), 5.14 GHz to 5.32 GHz (3%), 7.28 GHz to 7.73 GHz (5%), and 8.02 GHz to 8.38 GHz (4%).

2. ANTENNA DESIGN

Figure 1 shows the presented PIFA configuration. The antenna was fabricated on an $h = 1.6\,\text{mm}$ *FR4 epoxy* substrate with the dielectric constant $\varepsilon_r = 4.4$ and loss tangent $\delta = 0.02$.

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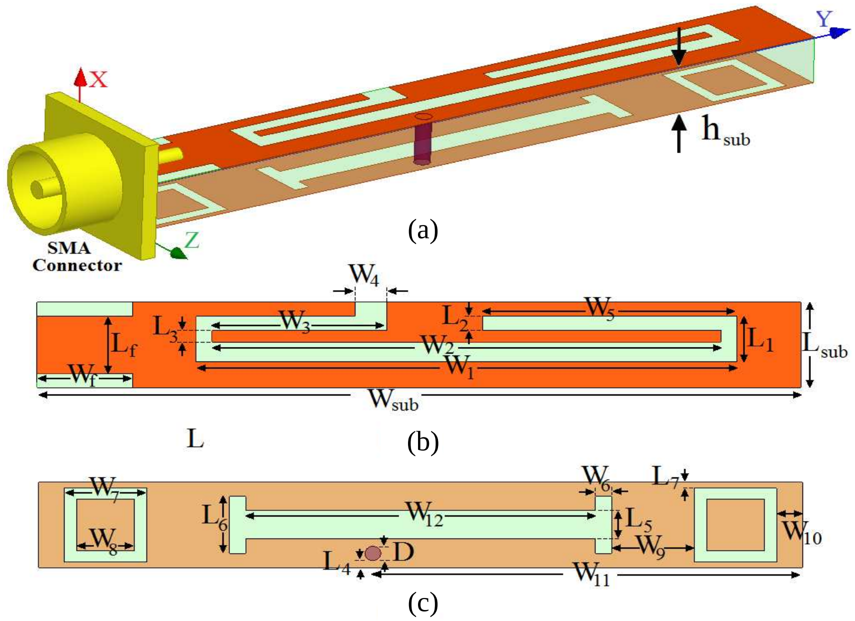

Figure 1. Geometry of the proposed PIFA, (a) side view, (b) top layer, and (c) bottom layer.

Table 1. Final dimensions of the proposed antenna.

Parameter	W_{sub}	L_{sub}	h_{sub}	W_f	L_f	W_1	L_1	W_2
(mm)	24	3	1.6	3	2	17	1.6	16
Parameter	L_2	W_3	L_3	W_4	L_4	W_5	L_5	W_6
(mm)	0.5	5.5	0.4	1	0.25	8	1	0.5
Parameter	L_6	W_7	D	W_8	W_9	W_{10}	W_{11}	W_{12}
(mm)	2	2.6	0.2	1.8	2.6	0.4	13.5	11

Basic antenna structure consists of a rectangular patch, a feed-line, and a ground plane. The radiating patch is connected to a feed line. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission. Final values of the antenna design parameters are specified in Table 1.

3. RESULTS AND DISCUSSIONS

The proposed antenna with various design parameters was constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement results is obtained [8].

3.1. PIFA with Dual Band Property

The configuration of the presented monopole antenna was shown in Figure 1. Figure 2 shows the structure of the various antennas used for dual-band performance simulation studies. Simulated return loss characteristics for the ordinary PIFA (Figure 2(a)), the antenna with a sickle-shaped slit at radiating patch (Figure 2(b)) and the antenna with a hook-shaped slit (Figure 2(c)) structures are compared in Figure 3.

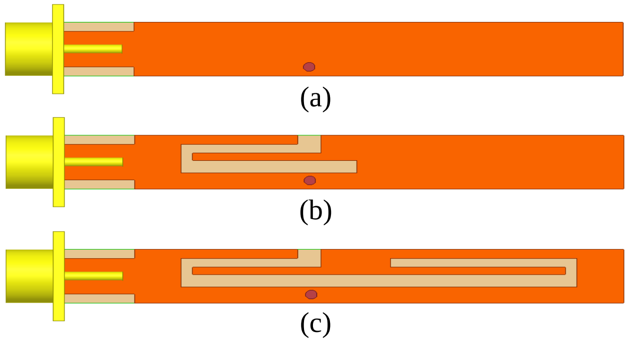

Figure 2. (a) Ordinary PIFA, (b) antenna with a sickle-shaped slit, and (c) the antenna with a hook-shaped slit.

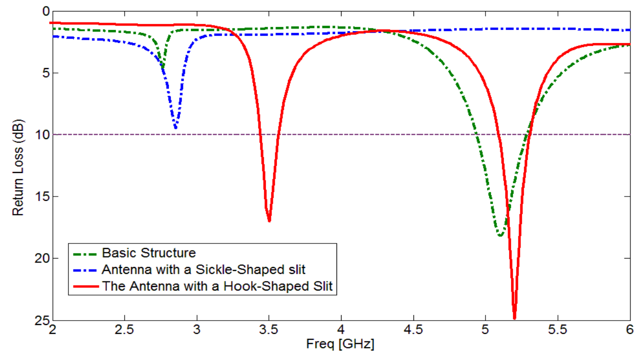

Figure 3. Simulated return loss characteristics for the various structures shown in Figure 2.

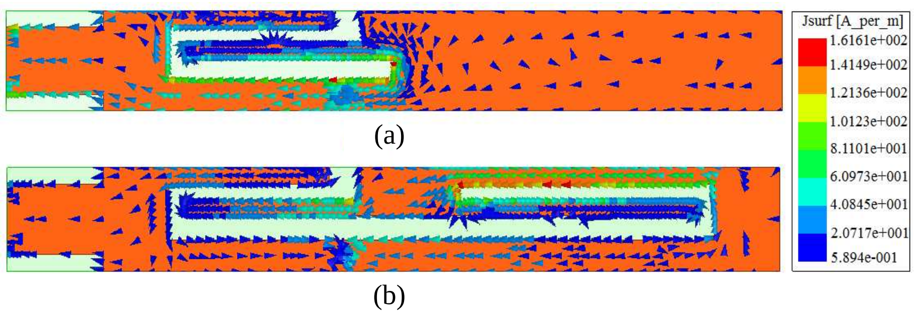

Figure 4. Simulated surface current distributions at radiating patch, (a) 5.2 GHz and (b) 3.5 GHz.

As shown in Figure 3, by cutting a sickle-shaped slit at radiating patch, a new resonance in 5.2 GHz for WLAN applications can be obtained, and also by converting the sickle-shaped slit to the hook-shaped structure another resonance at 3.5 GHz which is suitable for WiMAX systems is generated. Finally, it is observed that the generation of dual-band performance is sensitive to the cutting a hook-shaped slit at the top layer of antenna configuration [9–11].

In order to understand the phenomenon behind this dual-band performance, the simulated current distributions for the proposed antenna on the radiating stub at 3.5 and 5.2 GHz are presented in Figure 4. It can be observed in Figure 4(a), at the 5.2 GHz, the current concentrated on the edges of the interior and exterior of the sickle-shaped slit. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the pair of sickle-shaped structure [8, 9]. Figure 4(b) presents the simulated current distributions of the proposed antenna at 3.5 GHz. As shown in Figure 4(b), at the second resonance frequency the current flows are more dominant around of the top side of hook-shaped slit embedded at radiating patch [12].

3.2. Multi-Band PIFA with a Modified Ground Plane

In the proposed antenna structure, by using a modified ground plane consisting of rotated I-shaped and a pair of square-ring slots, we can give multi-band function. The structures of various antennas used for achieve quad-band property are shown in Figure 5. The simulated return loss characteristics for PIFA with a hook-shaped slit (Figure 5(a)), the antenna with a hook-shaped slit at radiating patch (Figure 5(b)), and the proposed antenna (Figure 5(c)) structures are compared in Figure 6. In the antenna, by cutting a rotated I-shaped slot and also by embedding a pair of square-ring slots in the ground plane, additional third and fourth resonances in 7.5 GHz and 8.2 GHz are generated, respectively.

In the proposed antenna, the upper resonance frequencies are significantly affected by using the modified ground plane with pair of square-ring and rotated I-shaped slots. This behavior is mainly due

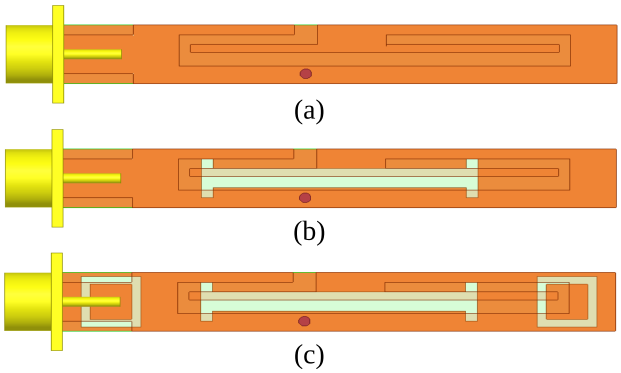

Figure 5. (a) antenna with a hook-shaped slit, (b) the antenna with a hook-shaped slit and I-shaped slot, and (c) the proposed antenna.

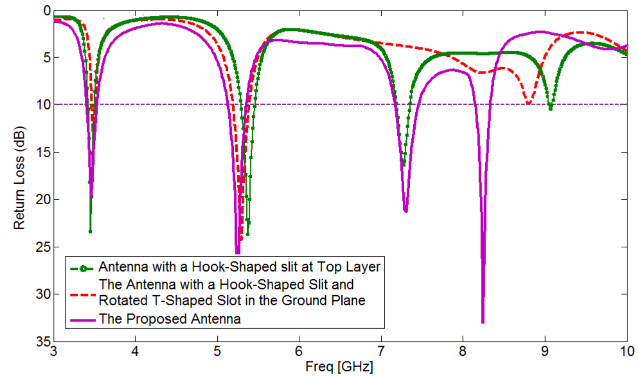

Figure 6. Simulated return loss characteristics for the various structures shown in Figure 5.

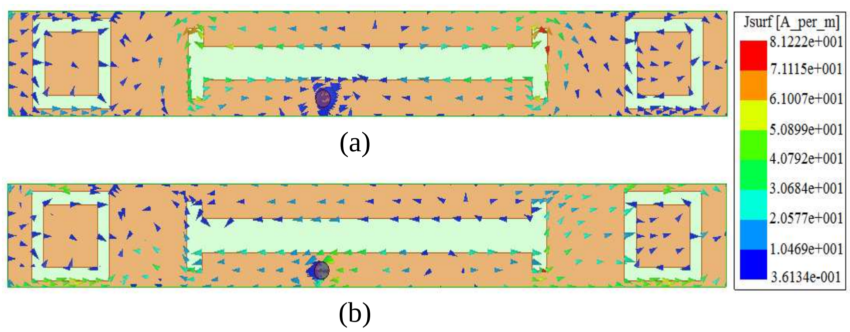

Figure 7. Simulated surface current distributions in the ground plane, (a) 7.5 GHz and (b) 8.2 GHz.

to the change of surface current path by the dimensions of embedded structures as shown in Figure 7. As illustrated in Figure 7(a), at the third resonance frequency (7.5 GHz), the currents concentrated on the edges of the interior and exterior of the I-shaped slots in the ground plane. Figure 7(b) presents the simulated current distributions in the ground plane at 8.2 GHz (fourth resonance frequency). As seen, at the upper resonance frequencies, the current flows are more dominant around of the square-ring slots.

3.3. Antenna Radiation Characteristics

The proposed antenna with final design was built and tested. The measured and simulated return loss characteristics for the proposed antenna are shown in Figure 8. The fabricated antenna has a frequency band from 3.35 GHz to 3.64 GHz, 5.14 GHz to 5.32 GHz, 7.28 GHz to 7.73 GHz, and 8.02 GHz to 8.38 GHz which covers 3.5 GHz WiMAX, 5.2 GHz WLAN, 7.5 GHz downlink of X-band satellite communication and 8.2 GHz ITU bands.

Figure 9 illustrates the measured radiation patterns, including the co-polarization and cross-polarization, in the H-plane (x-z plane) and E-plane (y-z plane). The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in X-Z plane are nearly omni-directional even at higher frequencies, and also the cross-polarization level is low for the fourth frequencies [13–15]. Figure 10 shows the measured maximum gain of the proposed antenna for the WiMAX, WLAN, downlink of X-band satellite communication, and ITU frequencies. As illustrated, the proposed antenna has sufficient and acceptable gain level in these bands [16, 17].

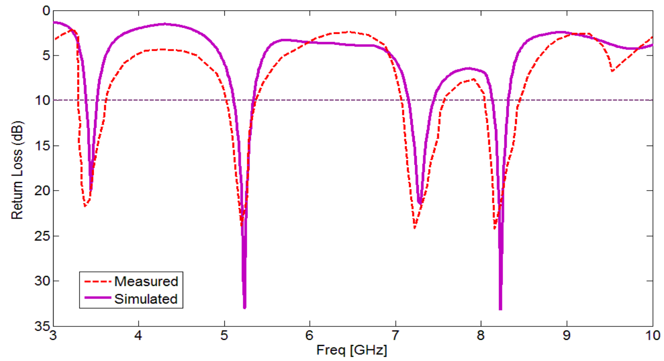

Figure 8. Simulated and measured return loss characteristics for the proposed antenna.

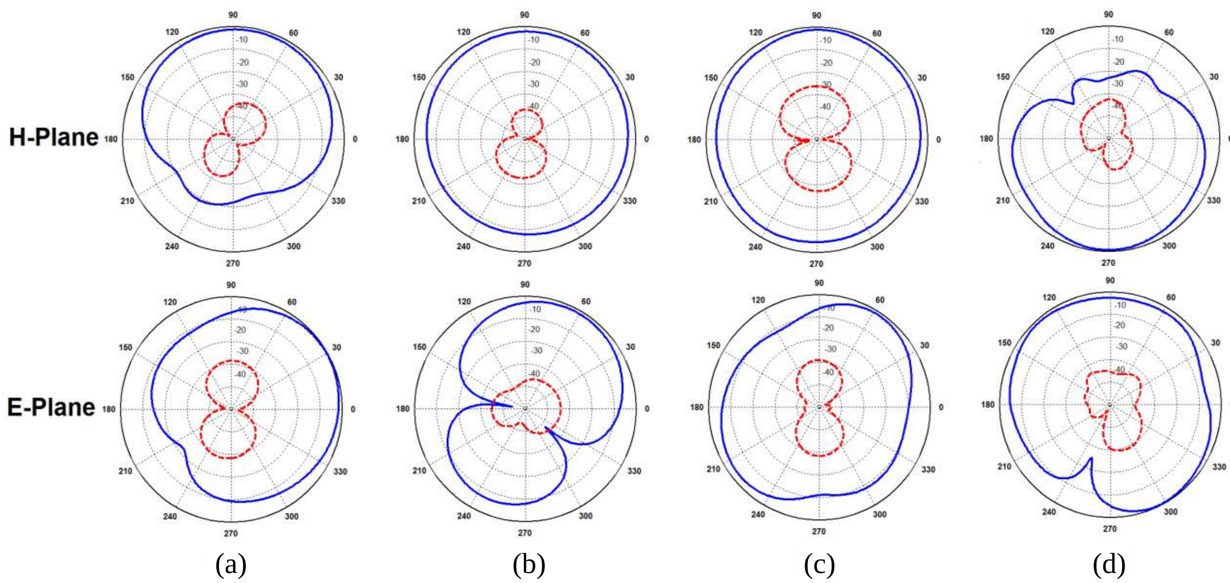

Figure 9. Measured radiation patterns of the proposed antenna at (a) 3.5 GHz, (b) 5.5 GHz, (c) 7.5 GHz and (d) 8.2 GHz.

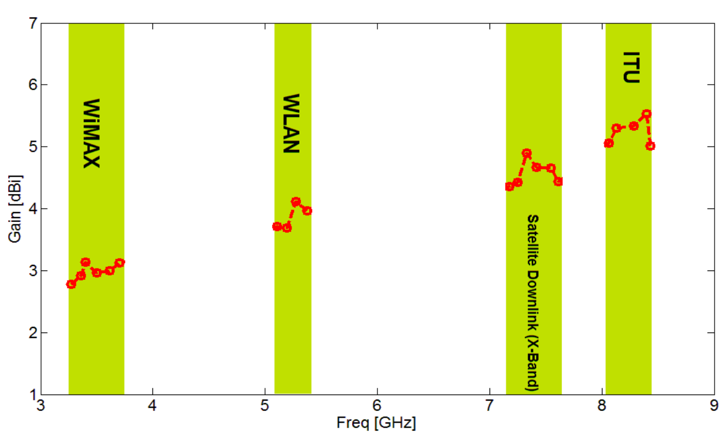

Figure 10. Measured maximum gain of the proposed antenna.

4. CONCLUSION

A novel multi-band PIFA for narrow-band wireless communication systems is presented. The antenna configuration consists of a hook-shaped slot at radiating patch and a modified ground plane with a pair of square-ring and rotated I-shaped slots. The proposed antenna can operate at 3.5 GHz WiMAX, 5.2 GHz WLAN, 7.5 GHz downlink of X-band satellite communication and 8.2 GHz ITU bands. Simulated and experimental results show that the proposed antenna can be a good candidate for multi-band wireless communication applications. The designed antenna has a small size.

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