A Novel Single-Feed Tri-Band PIFA Antenna for WLAN and WiMAX Applications

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***Abstract*—This paper presents a novel single-feed tri-band planar inverted-F antenna (PIFA). The antenna is comprised of cascading two metallic PIFAs vertically, which are fed by a common coaxial cable. Adding a slot to the ground plane of the lower PIFA allows the antenna to operate in two frequency bands, while the upper PIFA introduces the third working band. Moreover, good impedance matching is accomplished by etching a U-shaped slot on the ground plane of the upper PIFA. Simulation results show that the antenna operates in the frequency range of 2.36-2.59 GHz, 3.29-3.60 GHz, and 5.14-5.88 GHz, which can cover WLAN and WiMAX bands simultaneously. Besides, the overall dimension of the antenna is only $0.31\times0.20\times0.05\lambda^3$, and it can be easily manufactured by a single metallic sheet. With the advantages of low cost, compact size, tri-band operation, and high efficiency, the proposed antenna can be used for WLAN and WiMAX applications.**

***Index Terms*—Metallic antenna, PIFA, tri-band antenna**

I. Introduction

In recent decades, a succession of wireless communication technologies has undergone constant evolutions. Wireless local area networks (WLAN) and worldwide interoperability for microwave access (WiMAX) are two typical wireless systems that improve the wireless connectivity of the world. The development of WLAN and WiMAX technologies has led to an increasing demand for multi-band, cost-effective antennas, which have been investigated extensively. For instance, in [1], a tri-band antenna designed with a coplanar waveguide (CPW) operates at frequencies of 2.45 GHz, 3.5 GHz, and 5.2 GHz. A multi-band antenna based on asymmetric coplanar strips (ACS) was presented in [2], which achieved tri-band characteristic by adding parasitic elements to a monopole. In [3], by etching hexagonal complementary split ring resonators (CSRR) beneath the substrate, a multiband antenna was achieved. In [4], a transparent multi-band glass antenna with a frequency range covering 0.88-1.03 GHz, 1.47-2.74 GHz, and 3.32-5.97 GHz was developed.

The planar inverted-F antenna (PIFA) exhibits an ideal low specific absorption rate (SAR), and thus is widely deployed. Introducing slots or adding parasitic branches to the radiation patch facilitates the straightforward realization of multi-band operation. In [5], a low-profile PIFA was presented for dual-frequency operation. The introduction of slots on the antenna enables a dual-frequency characteristic, making it particularly suitable for WLAN and WiMAX applications. A compact dual-frequency PIFA capable of simultaneous operation in the 2.4 and 5.8 GHz frequency bands was proposed in [6]. However, these antennas are limited to dual-band operation and suffer from the drawbacks of complex manufacturing processes and high cost.

This paper introduces a novel low-cost single-feed PIFA with tri-band functionality for WLAN and WiMAX applications. The proposed antenna can be manufactured by folding a single piece of metallic plate, providing a cost-effective way of antenna fabrication. Simulation results indicate that the antenna exhibits tri-band operation at 2.5/5.5 GHz for WLAN and 3.5 GHz for WiMAX.

II. Antenna Design

The proposed antenna structure is illustrated in Fig.1. Fabricated by folding a 0.5mm-thick steel sheet, the overall structure forms a stacked bilayer PIFA. It consists of a lower PIFA along the X-direction and an upper PIFA along the Y-direction. The radiator of the lower PIFA serves as the ground plane for the upper PIFA, contributing to the overall miniaturization of the structure. To effectively excite both layers, a hole is introduced in the steel sheet, allowing the probe to pass through the lower PIFA and connect to the upper PIFA. During antenna operation, the lower PIFA is fed through probe coupling, while the upper PIFA is directly fed by the probe. As the upper and lower PIFAs are mutually orthogonal, determining the optimal probe positions is relatively straightforward. Specifically, the optimal fx is mainly determined by the lower PIFA's optimal feeding point, while the optimal fy is primarily determined by the upper PIFA's optimal feeding point.

The evolutionary design process of the proposed tri-band antenna is depicted in Fig.2. Antenna 1 represents

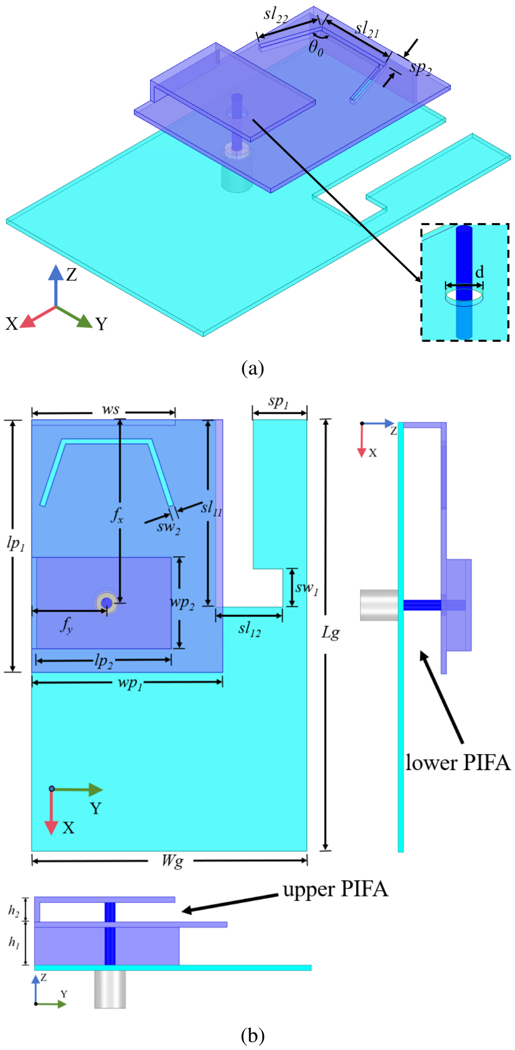

Fig. 1. Geometry of the proposed antenna (a) Perspective view. (b) Composite views

a traditional PIFA. By widening its ground plane and etching an L-shaped slot on the ground plane to introduce a new resonance mode — specifically, a current mode along the slot. Meanwhile, adjusting ws to achieve impedance matching and results in Antenna 2. As shown in Fig.3, Antenna 2 exhibits dual-band characteristics, introducing an additional resonant point compared to Antenna 1. To achieve the third impedance band without occupying additional space, another PIFA is stacked on top of Antenna 2, and a U-shaped slot is introduced on Antenna 2 to Realize impedance matching, resulting in Antenna 3, which means the proposed antenna. Antenna 3 is a compactly stacked bilayer planar inverted-F antenna. Simulation results demonstrate its tri-band characteristics, with operating frequency bands at 2.36-2.59 GHz, 3.29-3.60 GHz, and 5.14-5.88 GHz, as illustrated in Fig.3.

The optimized dimensions of the antenna are presented in Table I. It is worth noting that the antenna can be obtained by precisely folding a single piece of steel twice, as depicted in Fig.4. Therefore, the antenna offers the key benefits of being lightweight, low cost, and high radiation efficiency.

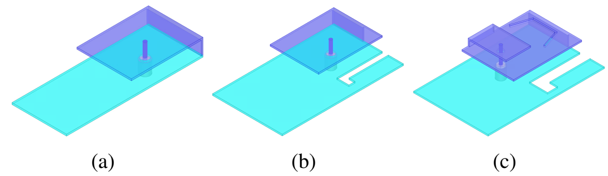

Fig. 2. Design evolution of the proposed antenna (a) Antenna 1 (b)Antenna 2 (c)Antenna 3

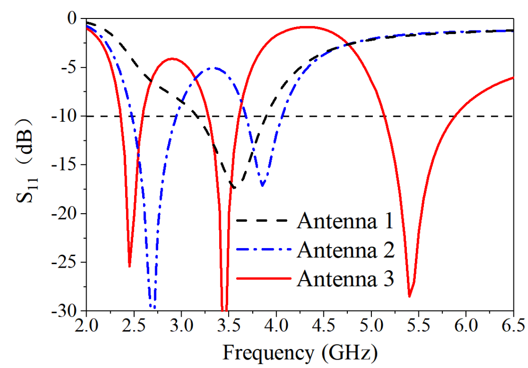

Fig. 3. Simulated $|S_{11}|$ of various antennas involved in Fig. 2

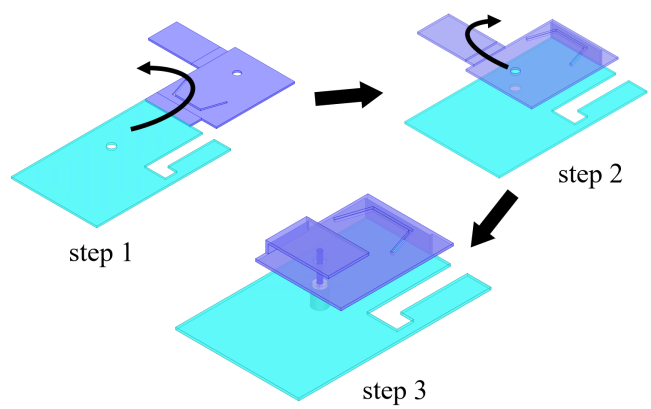

Fig. 4. Manufacturing steps of the proposed antenna

TABLE I
DIMENSIONS OF THE PROPOSED ANTENNA (UNIT: MM/DEG)

Lg	Wg	lp_1	wp_1	lp_2	wp_2	fx	fy	ws
40	25.6	23.5	17.8	13	8.5	17	7	13.4
d	h_1	h_2	sp_1	sl_{11}	sl_{12}	sw_1	sp_2	sl_{21}
2	4	2.3	5	15.5	4.5	204	2	8
sl_{22}	sw_2	θ_0						
6.3	0.5	108.5						

III. Results And Discussion

To explore the mechanism behind the tri-band operation, Fig.5 presents simulated surface current distributions on the antenna at resonant frequencies of 2.5, 3.5, and 5.5 GHz. The black arrow represents the direction of the current. It is evident that at 2.5 GHz, the antenna operates in the slot mode, with the current primarily concentrated near the L-shaped slot. At 3.5 GHz, the current is mainly distributed in the lower PIFA, while at 5.5 GHz, the current noticeably concentrates in the upper PIFA. This observation indicates that the upper band and middle band originate from the upper and lower PIFAs, respectively.

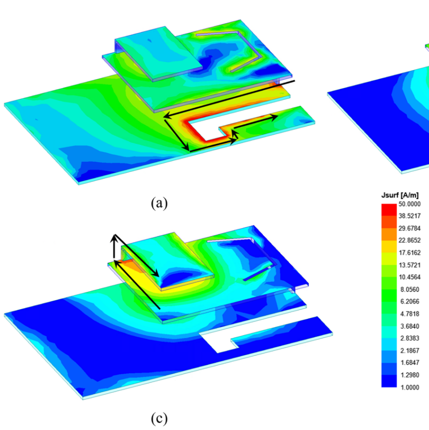

Fig. 5. Simulated surface current distributions of the proposed antenna at(a) 2.5, (b) 3.5, and (c) 5.5 GHz.

To validate this theory, Fig.6 illustrates the impact of key parameters on the three frequency bands of the antenna. In Fig.6a, it is evident that altering the length of the slot(sl_{11}) significantly affects the lower band, while having minimal impact on the middle and upper band. Fig.6b demonstrates that increasing the length of the lower PIFA (lp_1) leads to a decrease in the resonance frequency of the middle band without affecting the lower and upper bands. Additionally, adjusting the length of the upper PIFA (lp_2) only modifies the resonant characteristics in the upper band, as shown in Fig.6c. Finally, the radiation patterns at various resonant points of the antenna are illustrated in Fig.7.

IV. Conclusion

A compact single-feed tri-band PIFA suitable for WLAN/WiMAX is proposed. The antenna can operate at three working bands, covering 2.4 GHz and 5.5 GHz bands for WLAN, as well as 3.5 GHz band for WiMAX. The resonance modes at these three bands are nearly independent, allowing easy adjustment of each band by tuning relevant antenna parameters. The advantages of low cost, light weight, high efficiency, and tri-band operation capability make it a promising candidate for applications in WLAN and WiMAX systems.

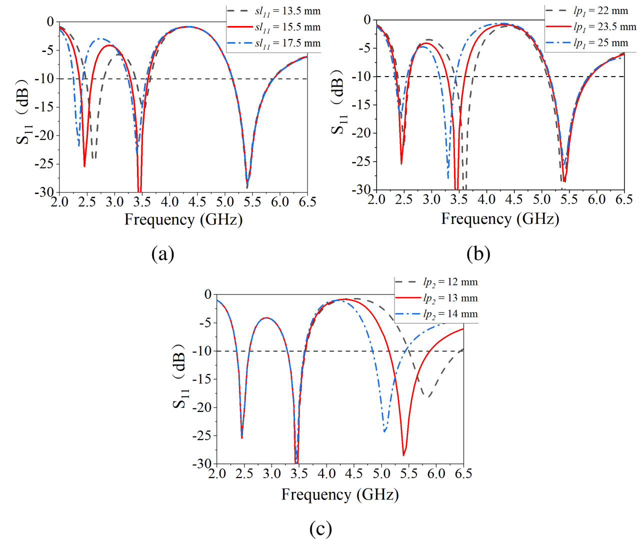

Fig. 6. Simulated $|S_{11}|$ of the proposed antenna for various (a)sl_{11} (b)lp_1 (c)lp_2

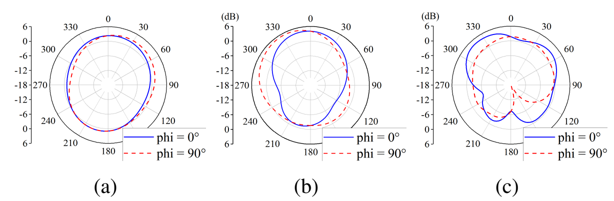

Fig. 7. Radiation patterns for the proposed antenna at (a)2.5, (b)3.5, and (c)5.5 GHz.

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