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A NOVEL QUAD-BAND (GSM850 TO IEEE 802.11A) PIFA FOR MOBILE HANDSET

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Abstract—In this paper, a novel planar inverted-F antenna (PIFA) with slotted ground structure is proposed for multiband mobile communication application. The multimode performance is applied for multiband operation in our design. The proposed antenna has good impedance matching characteristics for GSM850/900, DCS1800/1900, LTE2300/2500, IEEE 802.11a/b. The measured radiation efficiency of proposed antenna is all higher than 69% in GSM (824–960 MHz)/DCS (1710–1880 MHz)/PCS (1850–1990 MHz)/LTE (2300–2400 MHz, 2500–2690 MHz)/802.11b (2.4–2.48 GHz), and is up to 50% in IEEE 802.11a (5.15–5.825 GHz).

1. INTRODUCTION

With the rapid development of mobile communications, the demand for electronic small antennas with multiband is increasing. Recently, the long-term evolution (LTE) system was introduced to afford better mobile services. In addition to this, a web access through the wireless wide area network (WLAN) could be provided a guarantee for on-demand service [1–5]. Due to the overall size limited for placing a mobile terminal antenna, it becomes more difficult to achieve wide bandwidth. Usually, PIFA is used in mobile devices because of its easy fabrication, low profile, low implementation cost. However, PIFA is no longer suitable because of its narrow bandwidth.

In order to obtain a wide frequency band, the coupled-fed structure is usually applied [10–12]. However, the performance, especially in the high frequency band, is susceptible to the width of

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coupling gap. The fabrication is difficult, and hence, the cost increases significantly. Such structure is not suitable for WLAN 11a (5.15–5.825 GHz) operation either. In order to obtain a compact antenna with large and multiple frequency band, many other constructions for PIFA are applied with probe feedings [1–8]. Again, in these designs, it is difficult to realize multi-band and wide band operation at the same time [1–6]. What is worse, the micro-electromechanical systems (MEMS) element [8] involved makes the cost further increase.

In this paper, a compact and low profile antenna is presented. The proposed design has a wider bandwidth, reduced size and high efficiency. The presented PIFA occupies a small volume of $47 \times 20 \times 5.5\,\text{mm}^3$. In particular, low band frequency operation is achieved by two parallel open-end slots in the ground plane. Based on the joint disposition of the PIFA and a meandered monopole in the structure, the multiband operation is realized. Reflection coefficient less than -6 dB is obtained in 787–980 MHz (21.8% relative bandwidth, GSM850/900), 1550–2065 MHz (28.5% relative bandwidth, GSM1800/1900), 2250–2750 MHz (20% relative bandwidth, LTE2300/2500 and WLAN 11b) and 5.04–5.84 GHz (14.8% relative bandwidth, WLAN 11a) respectively.

Another issue of mobile terminal antenna is the radiation efficiency [11–22]. In our design, the efficiency is up to 69% at low frequency band, and is more than 50% in high frequency band. The structure of the rest of the paper is as follows: In Section 2, geometric structure and prototype of the PIFA is first presented. The effect of antenna geometric parameters on performance is discussed in details. To validate our design, simulation and measurement results are demonstrated in Section 3 for comparison. Finally, conclusions are summarized in Section 4.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

The proposed antenna structure is shown in Figure 1. Length of handset boxes model used in the simulation and measurement is as those used today [10–22].

The dimensions are given as follows: $L_1 = 110\,\text{mm}$, $L_2 = 55\,\text{mm}$, $L_3 = 48\,\text{mm}$, $L_4 = 41\,\text{mm}$, $L_5 = 1\,\text{mm}$, $L_6 = 6.7\,\text{mm}$, $L_7 = 6\,\text{mm}$, $L_8 = 3\,\text{mm}$, $L_9 = 15\,\text{mm}$, $L_{10} = 6\,\text{mm}$, $L_{11} = 1\,\text{mm}$, $L_{12} = 3\,\text{mm}$, $L_{13} = 21\,\text{mm}$, $L_{14} = 22\,\text{mm}$, $L_{15} = 34\,\text{mm}$, $L_{16} = 2\,\text{mm}$.

Figure 1(a) shows the 3D view of the proposed antenna. Point A and point B are the shorting point and feeding point, respectively. At point C, there is a chip-inductor-loaded strip which contributes to a wide band covering the GSM1800/1900/LTE2500 and WLAN operation. The chip inductor used in the PIFA has an inductance of 11.5 nH. The proposed PIFA is mainly composed of two meandered

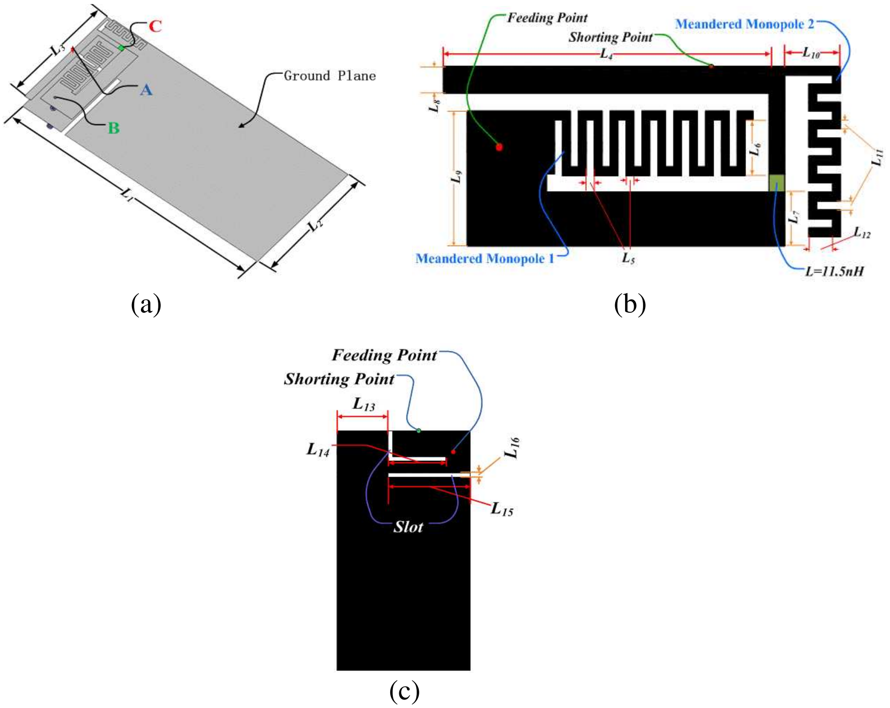


Figure 1. Proposed antenna configuration: (a) geometry of the proposed antenna, (b) detailed dimensions of the patch, (c) detailed dimensions of the ground plane.

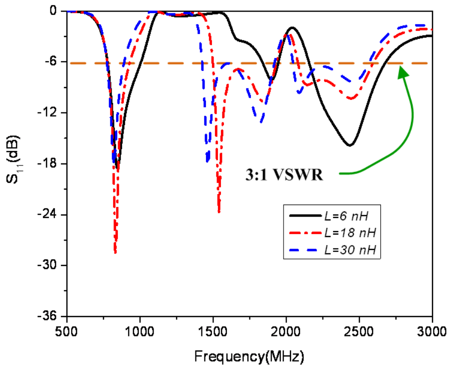
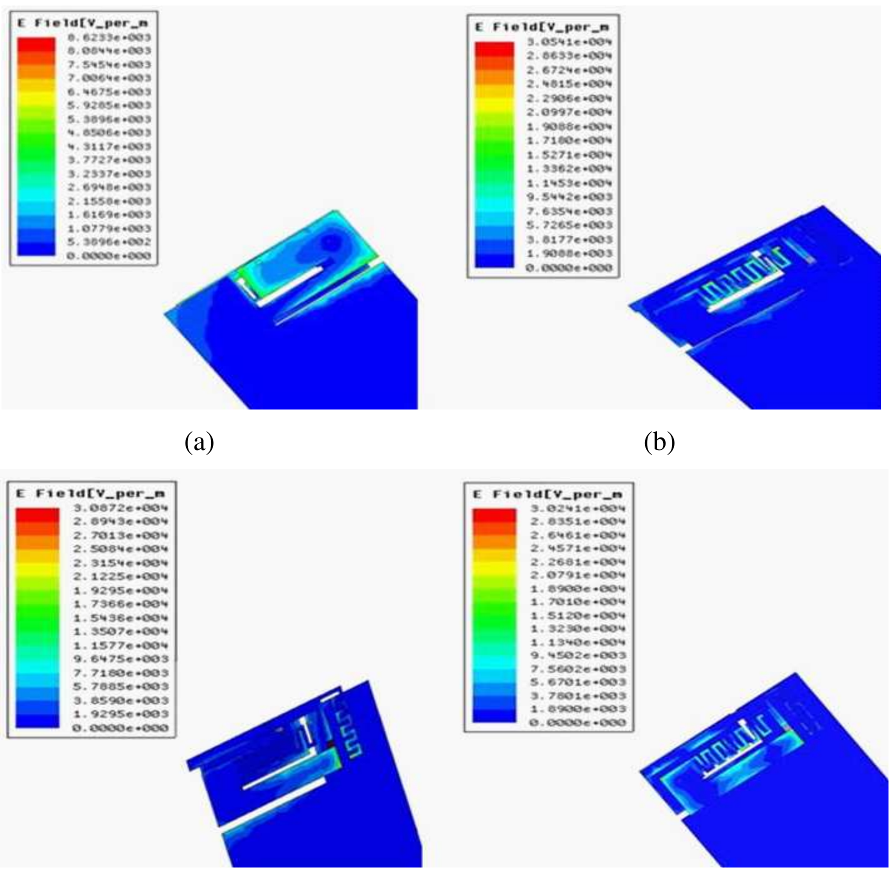


Figure 2. Simulated return loss for different chip inductance L.

monopoles and a probe feeding port. With the shorting point A in Figure 1(a), the meandered monopole 2 is proposed as a printed $\lambda/2$-PIFA. The width of the two meandered monopoles (monopole 1 and 2 in the Figure 1(b)) are the same, the lengths of them are 80.6 mm and 33 mm, which are close to $\lambda/2$ at 1860 MHz and $\lambda/4$ at 2270 MHz. Also, $3\lambda/2$ mode (5480 MHz) of meandered monopole 1 is used for WLAN 11.a. In Figure 1(c), the two slots of the ground plane are applied for the low resonant frequency band and enhancing the antenna return loss in lower part of the band [9].



(a) (b) (c) (d)

Figure 3. Simulated *E*-field distributions picture: (a) 900 MHz (back side), (b) 1900 MHz (top side), (c) 2500 MHz (top side), (d) 5.5 GHz (top side).

Based on the bandwidth specification of 3 : 1 VSWR (6 dB return loss), which is widely accepted as the fundamental design requirement of the internal handset antenna, the simulated S parameter of proposed PIFA covers 750–1010 MHz, 1620–2000 MHz, 2200 MHz–2700 MHz and 5.25–5.85 GHz. The chip inductor with an inductance of 11.5 nH (L) is applied in the proposed PIFA. This chip inductor is used to improve the bandwidth required for DCS/PCS with a $\lambda/2$ monopole resonant mode. Figure 2 shows the influence of the chip inductor L in return loss. Stronger influence on the impedance matching of DCS/PCS can be observed when inductor L is changed from 6 to 30 nH. After optimization, the impedance matching is improved when L is 11.5 nH. Figure 2 shows the E-field distribution pictures of proposed antenna separately under different frequency.

The simulated results are obtained using the full-wave electromagnetic field simulation software HFSS version [21–28]. In Figure 4(a), the simulated return loss (1000–2200 MHz) is presented when

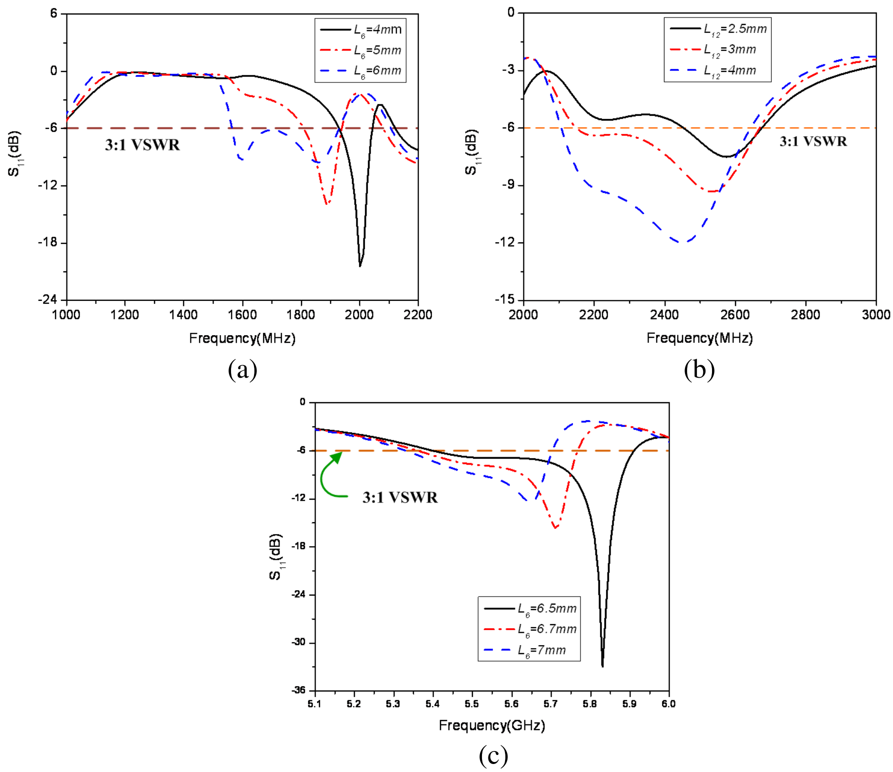
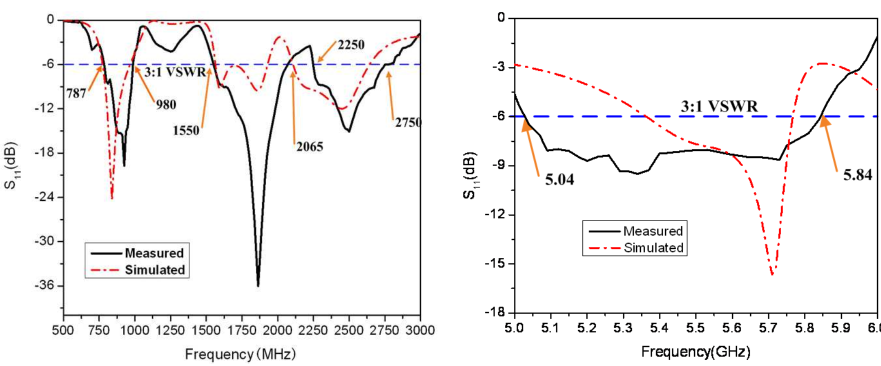


Figure 4. Simulated return loss as a function of (a) L_6 (1000–2200 MHz), (b) L_{12} (1000–2200 MHz), (c) L_6 (5.1–6.0 GHz).

the length L_6 varies from 4 mm to 6 mm. Other parameters of the antenna are the same as given in Figure 1. Strong affects on the resonant frequency and impedance matching in DCS/PCS are shown. It indicates that the resonant mode at 1800 MHz shift down with increasing the length of meandered monopole 1. The impedance matching over the DCS/PCS band is also improved. Similar results can be obtained from Figure 4(b), where the length L_{12} of meandered monopole 2 affects LTE2300/2500/WLAN 11b frequency band significantly. At last, Figure 4(c) shows the influence of varying the length L_6. The ex-

(a) (b)

Figure 5. Photos of the manufactured antenna: (a) top side, (b) back side.



(a) (b)

Figure 6. Measured and simulated return loss: (a) 500–30000 MHz, (b) 5.0–5.8 GHz.

cited resonant effects on simulated return loss are shown (5.1–6.0 GHz, WLAN 11a).

3. MEASURED RESULTS

Based on the parameter study from the previous section, the PFIA prototype is fabricated as shown in Figure 5. Figure 6 presents the measured and simulated return loss of the antenna. Because the value of L is not accurate to 11.5 nH, the measured data result is even better than the simulated one. Three wide operating bands have been obtained for the antenna.

The radiation patterns, total efficiency, and peak gain are measured in SATIMO StarLab measurement system. SATIMO StarLab is the ultimate tool for antenna pattern measurement in

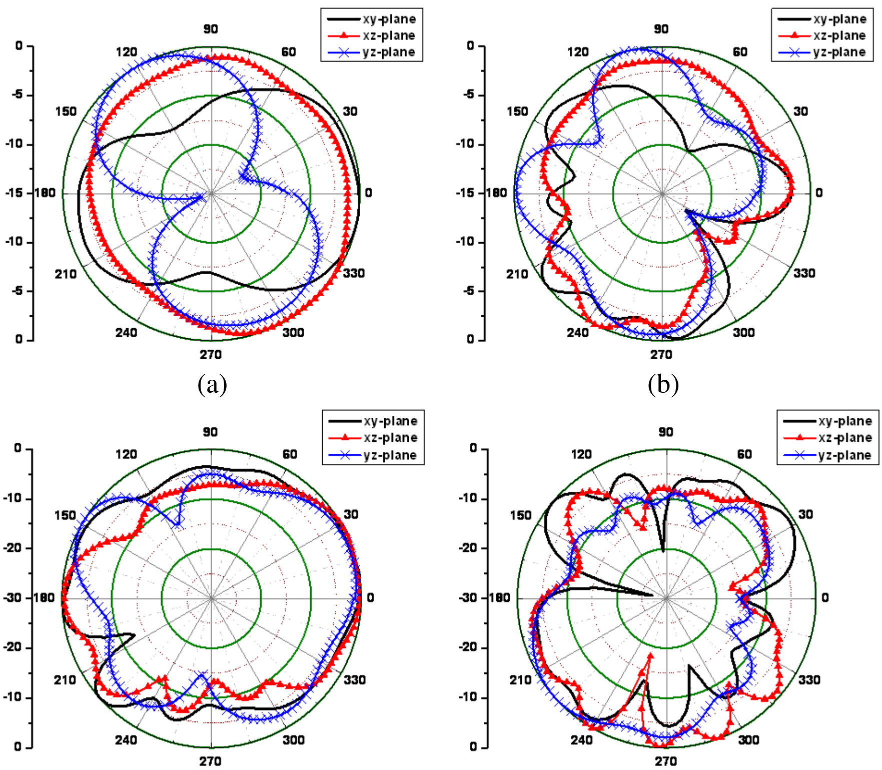


Figure 7. Measured 2-D radiation patterns: (a) 900 MHz, (b) 1900 MHz, (c) 2500 MHz, (d) 5.5 GHz.

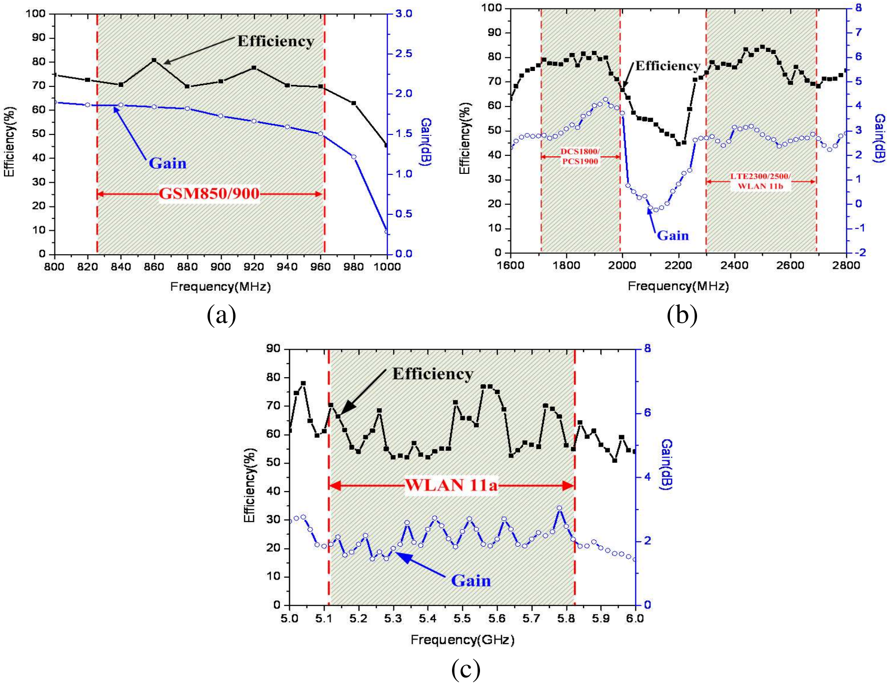


Figure 8. Measured antenna peak gain and radiation efficiency: (a) GSM850/900, (b) DCS1800/PCS1900/WLAN 11b/LTE2300/2500, (c) WLAN 11a.

laboratories and production environment and where space is limited, cost is critical and the flexibility of portable system is required. Figure 7 shows the normalized pattern in three principal planes (900, 1900, 2500 and 5500 MHz). Measured total efficiency including the mismatching loss for the proposed antenna is presented in Figure 8. Over the lower frequency band (500–3000 MHz). The total efficiency and peak gain of the operation frequency band are 69–80% and 1.5–1.8 dBi, respectively. For the upper band shown in Figure 8(c), the antenna gain varies from 1.5 to 3.2 dBi, while the total efficiency is better than 50%. From the obtained results, it can be shown that the proposed design of PIFA is a good candidate for practical internal mobile applications.

4. CONCLUSIONS

This paper presents a novel design of PIFA. Using two open-end parallel slots in the ground plane, a significant improvement in the antenna operational bandwidth at the lower frequency band is achieved. The upper frequency operating band is achieved by comprising two meandered monopoles. Thus, quad-band impedance (787–980 MHz, 1550–2065 MHz, 2250–2750 MHz, 5.04–5.84 GHz) for VSWR $\leqq 3$ are obtained. The main design dimensions of meandered monopole 1 and 2 are studied and discussed. Measured results show that the proposed antenna has good radiation characteristics, including total efficiency and peak gain. With the presence of the multiband and wideband features, the proposed design of PIFA is attractive for the practical mobile phones.

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