An Internal Triple-Band Planar Inverted-F Antenna

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***Abstract*—A novel internal triple-band planar inverted-F antenna (PIFA) for operating at Personal Communication Services/International Mobile Telecommunications (PCS/IMT)-2000/Bluetooth bands is proposed. The proposed antenna can be reduced the size by using the radiating element with thickness and via hole. A broadband characteristic is obtained by optimizing the thickness of radiating patch and the offset gap between patch and ground. The dual resonant frequencies are obtained by optimizing the slit lengths and the location of via hole. This proposed antenna is well suited to the internal antenna due to small size and wide bandwidth of about 42%, which is covered with the PCS (1.75–1.87 GHz), IMT-2000 (1.92–2.17 GHz) and Bluetooth (2.402–2.48 GHz) bands. The design of proposed antenna and experimental results are discussed.**

***Index Terms*—Broadband, internal antenna, planar inverted-F antenna (PIFA), triple-band.**

I. Introduction

RECENTLY, the mobile handsets have been demanding that those are small, lightweight, and compact. These demands are brought on the development of low-profile internal antenna with superior performances in terms of the impedance bandwidth and gain. However, to design an internal antenna is technically challenging due to the limited antenna volume and influence of plastic case of the mobile handset. The several types of internal antennas have proposed as planar inverted-F antenna (PIFA) [1], [2], ceramic chip antenna (CCA) with meander lines [3], [4], and monopole antenna [5]–[7]. An advantage of PIFA is compact, low profile, easy to manufacture, and good electrical performance. However, it has a narrow bandwidth and needs a height from substrate to ground for matching and additional shorting pins near the feed to reduce the size of antenna [2]. For the ceramic chip antenna with meander lines, though CCA has a good characteristic in respect to small size, it is difficult to fine tune, weak to the impact, and has an expensive cost, and a low gain due to the high dielectric material. The planar monopole antenna has a simple structure, an isotropic radiation pattern, and low fabrication cost. To reduce the relatively large volume of the conventional monopole antenna, the planar monopole antenna that is printed on a substrate has proposed [5].

In this paper, we propose a novel PIFA, which combines the advantage of small and low-profile PIFA and the merit of the monopole antenna that has the broad impedance bandwidth [7]. This proposed antenna has the radiating element with thickness instead of a height from substrate to ground for matching and via hole instead of additional shorting pins in PIFA.

These result into a reduced size and broad bandwidth. The proposed antenna has enough bandwidth to cover the Personal Communications Services (PCS) (1.75–1.87 GHz), IMT-2000 (1.92–2.17 GHz), and Bluetooth (2.402–2.48 GHz) bands.

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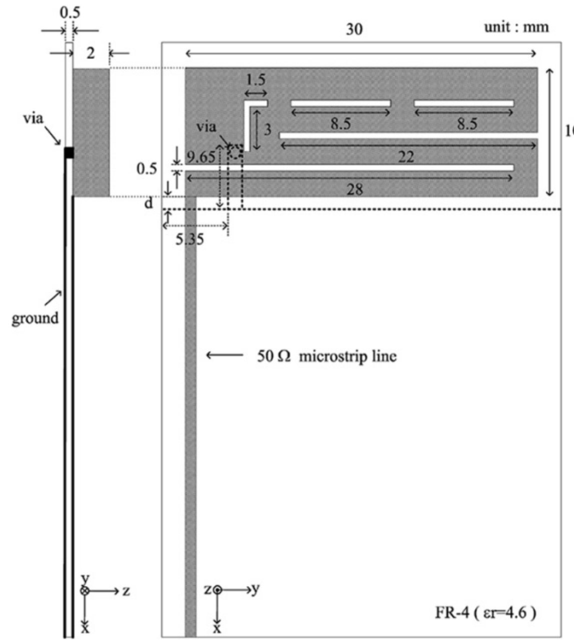


Fig. 1. The geometry of the proposed internal triple-band PIFA.

II. Antenna Design

The geometry of the proposed internal triple-band PIFA for operating at PCS/IMT-2000/Bluetooth bands is shown in Fig. 1. The radiating element is made of copper and is a rectangular shape with slits which adjust to the surface current paths. Its size is 30 mm $\times$ 10 mm $\times$ 2 mm. The proposed PIFA is soldered on the same shaped metal that is etched on the FR4 substrate with the thickness of 0.5 mm, relative permittivity of 4.6, and the size of substrate is 76 mm $\times$ 38 mm. A 50 Ω microstrip line is used to feed this proposed PIFA and etched on the FR-4 substrate. On the other side of the substrate, the ground plane is cut at $d = 1$ mm away from the end of the microstrip feed line. The additional ground (1.3 mm $\times$ 9.65 mm) is used to connect the patch and ground through via hole. The offset gap affects the impedance matching. The small size of proposed antenna is suitable to design in practical mobile handsets. Though the PIFA is usually used to shorting pin for guiding the surface current to the ground, this proposed antenna is used to via hole instead of shorting pin to connect the patch to the ground plane. In addition, the air gap between patch and substrate of PIFA is required

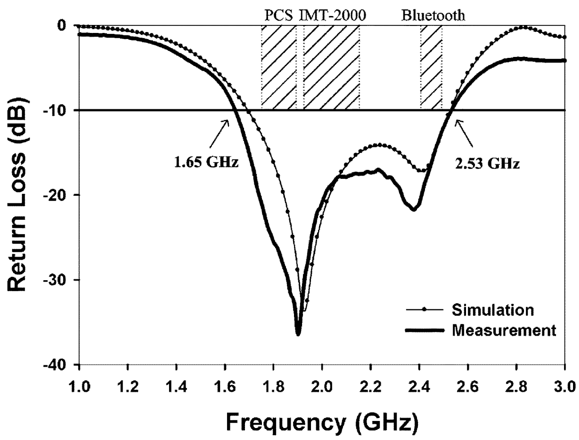


Fig. 2. Measured and simulated return losses of the proposed antenna.

more than 6 mm for impedance matching [1], [2]. However, this proposed antenna takes off the air gap for matching between the patch and substrate. The overall height of proposed antenna is 2 mm by using a thicker metal and via hole. The overall volume of proposed antenna can be attractive features in the internal antenna.

As the thickness of radiating element is increased, the impedance bandwidth is broadened. However, the gain is decreased so the thickness of radiating element is optimized by considering the impedance bandwidth and the gain simultaneously. Note that the resonant frequencies and impedance matching are mainly determined by the values of the thickness of metal, the location of via hole, and the offset gap ($\mathrm{d} = 1\ \mathrm{mm}$) between the ground and metal when the other parameters of the antenna are fixed. In order to obtain the triple bands, the parameters of antenna are tuned and optimized. The optimized dimensions are shown in Fig. 1.

III. Results

An HP8510C network analyzer is used for measurement. The commercial program high frequency structure simulator (HFSS) based on the finite-element method (FEM) is used for analyzing the behavior of proposed model and determining suitable values of parameters. The measured and simulated return losses of the proposed PIFA are shown in Fig. 2. As seen in Fig. 2, the broad impedance bandwidth can be obtained. This broadband characteristic is obtained by optimizing the thickness of patch and the offset gap between patch and ground. The dual resonant frequencies are obtained by optimizing the slit lengths, which act a role of making two surface current path and positions. The used width of slits are all 0.5 mm. Although the measured and simulated results have a good agreement with each other, there is a slight discrepancy. This is due to the fact that the height of radiating element is increased due to the lead, which is in the space between the radiating element and substrate. This fact is confirmed by the simulation. The proposed internal antenna operates from 1.65 to 2.53 GHz within $-10\ \mathrm{dB}$ return loss. The center frequency is operated at 2.09 GHz with the bandwidth about 42.1%. This operating bandwidth can cover PCS (1.75–1.87 GHz), IMT-2000 (1.92–2.17 GHz), and Bluetooth (2.402–2.48 GHz) bands.

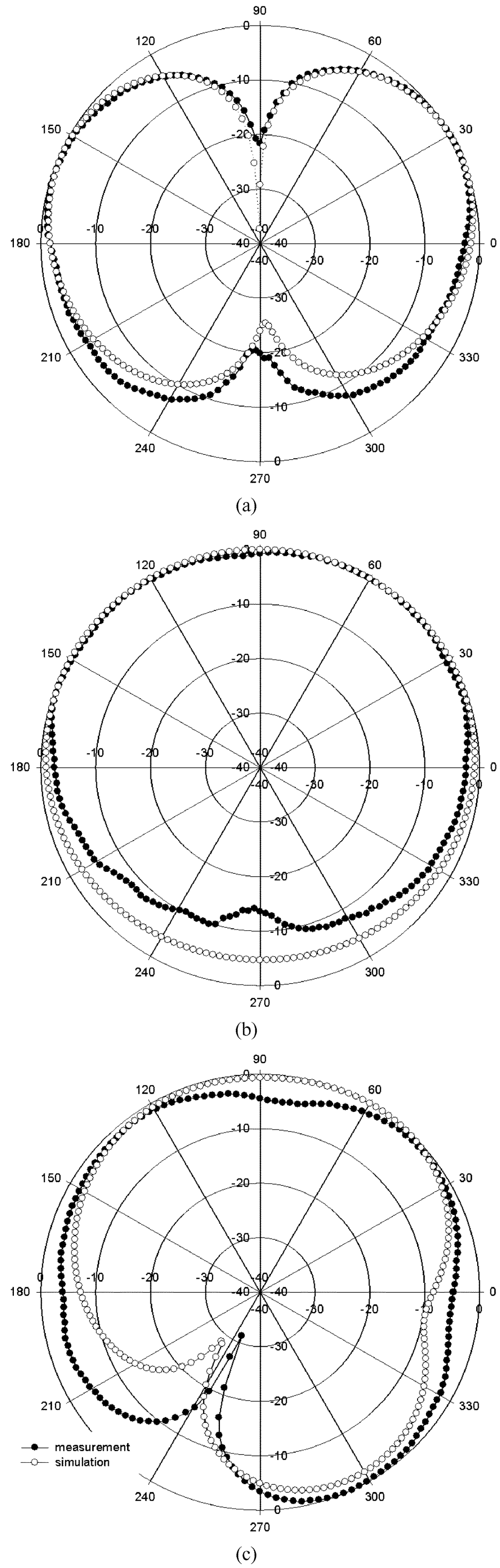
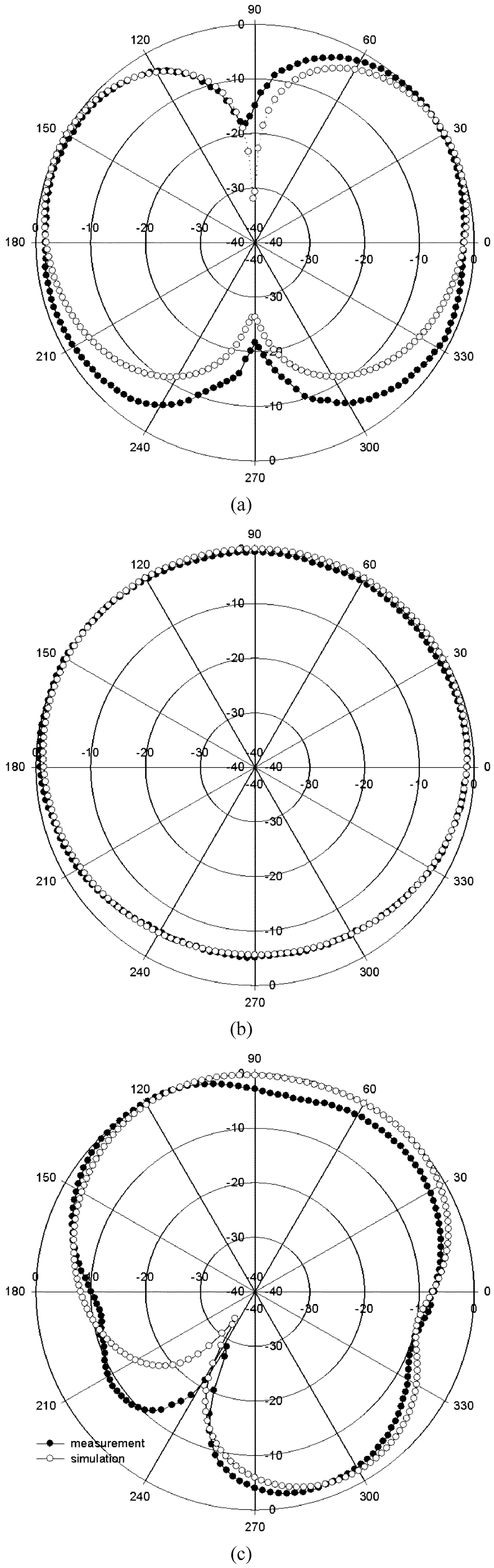


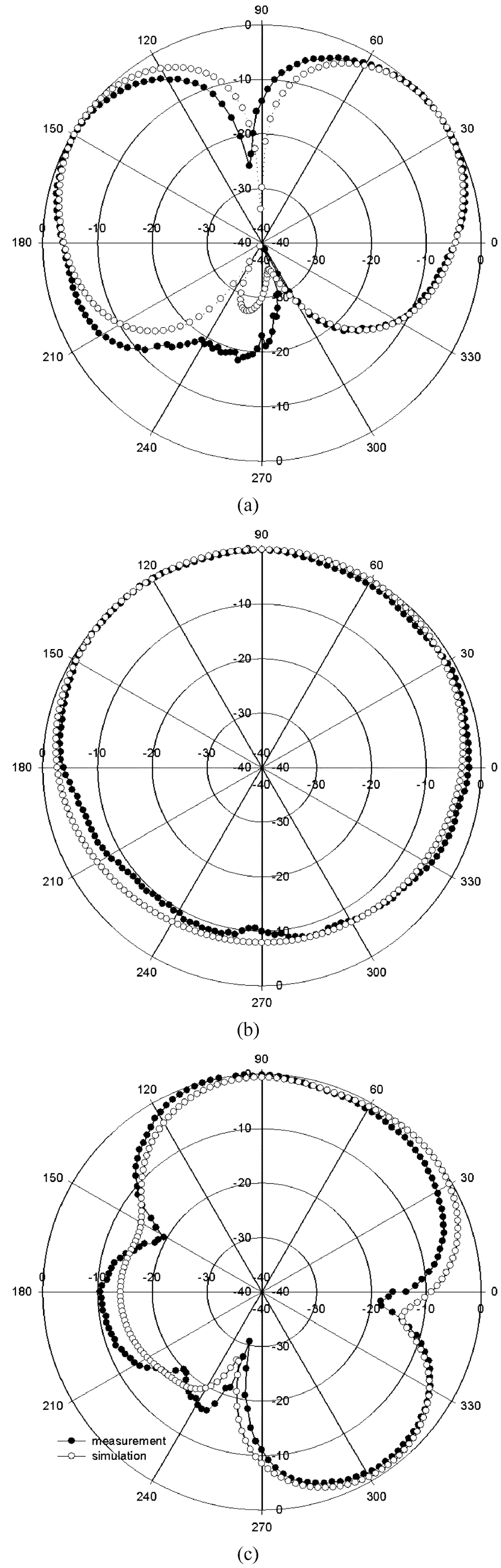
Fig. 3. Radiation pattern at the frequency of 1.8 GHz. (a) x-z plane. (b) y-z plane. (c) x-y plane.

The measured and simulated radiation patterns at the resonant frequencies of 1.8, 2.0, and 2.44 GHz are shown in Figs. 3–5, respectively. This slight difference can be attributed to the fact that the feeding cable influences the radiation patterns. The simulated and measured antenna gains in the x-z plane have



(a) (b) (c)

Fig. 4. Radiation pattern at the frequency of 2.0 GHz. (a) x-z plane. (b) y-z plane. (c) x-y plane.



(a) (b) (c)

Fig. 5. Radiation pattern at the frequency of 2.44 GHz. (a) x-z plane. (b) y-z plane. (c) x-y plane.

1.38 and 1.34 dBi at 1.8 GHz in PCS band, 1.68 and 1.49 dBi at 2.0 GHz in IMT-2000 band, and 3.0 and 2.64 dBi at 2.44 GHz in Bluetooth band, respectively. This slight difference of gain can be attributed to the effects of conductor and dielectric loss.

IV. Conclusion

A novel internal triple-band PIFA suitable for PCS/IMT-2000/Bluetooth bands has been proposed and verified with measurement and simulation. The size of proposed antenna can be reduced by using the metal with thickness and via hole. The proposed antenna has a small size (30 mm $\times$ 10 mm $\times$ 2 mm) and wide impedance bandwidth of about 42%, which covers the PCS/IMT-2000/Bluetooth bands. These features are attractive for PCS/IMT-2000/Bluetooth internal antenna applications.

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