COUPLED-FED SMALL-SIZE PIFA FOR PENTA-BAND FOLDER-TYPE MOBILE PHONE APPLICATION

Chih-Hua Chang,[1] Kin-Lu Wong,[1] and Jeen-Sheen Row[2]
[1] Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 804, Taiwan; Corresponding author: wongl@ema.ee.nsysu.edu.tw
[2] Department of Electrical Engineering, National Changhua University of Education, Changhua 500, Taiwan

Received 9 May 2008

ABSTRACT: *A small-size planar inverted-F antennas (PIFA) for penta-band operation in the folder-type mobile phone is presented. The PIFA occupies a small volume of 2.1 cm^3 only. Instead of using the conventional direct contact feed, the proposed PIFA uses a coupling feed, which allows the antenna in its open state or talk condition to generate a dual-resonance lower band of bandwidth 300 MHz (780–1080 MHz, 3:1 VSWR or 6-dB return loss) to cover GSM850/900 operation. In addition, the PIFA can also generate a very wide upper band of bandwidth 925 MHz (1368–2293 MHz) to cover GSM1800/1900/UMTS operation. When the mobile phone is in its close state or standby condition, the obtained lower and upper bands can still cover GSM850/900/1800/1900/UMTS penta-band operation with impedance matching better than 6:1 VSWR or 3-dB return loss, which is acceptable for the mobile phone in standby condition for practical applications. Details of the proposed PIFA and the obtained results are presented.* Microwave Opt Technol Lett 51: 18–23, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23980

Key words: *internal mobile phone antenna; PIFA (planar inverted-F antenna); folder-type mobile phone; penta-band operation; coupled-fed*

1. INTRODUCTION

In recent years, the folder-type mobile phone or clamshell mobile phone [1–9] is increasingly becoming attractive for wireless users. It is because this kind of mobile phone is usually equipped with a large display, making it convenient for performing multimedia functions. For applications in the folder-type mobile phone, the planar inverted-F antennas (PIFAs) that have been widely applied in the conventional bar-type mobile phone [10] are also a promising candidate for the internal antenna. However, owing to the limited available volume that can be allocated for the internal antenna inside the mobile phone, it is usually not an easy task to obtain penta-band operation for the conventional PIFA to cover GSM850 (824–894 MHz) and GSM900 (880–960 MHz) operation in its lower band and GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), and UMTS (1920–2170 MHz) operation in its upper band.

Further, for the folder-type mobile phone, there are two separate but electrically connected grounds, which is quite different from the conventional bar-type mobile phone with a single main ground. When the folder-type mobile phone is in the open state (talk condition), a large effective ground plane is formed. On the other hand, for the folder-type mobile phone in the close state (standby condition), the effective ground plane is smaller. Because of the different effective ground sizes for the open and close states, large variations in the operating bandwidth of the conventional internal antenna will occur. To improve the performance of the antenna in the close state, the use of an external matching circuit has been demonstrated [9]. This technique, however, will occupy some valuable board space on the system circuit board of the mobile phone and increase some insertion loss also.

In this article, we propose a promising PIFA design with a coupling feed for the folder-type mobile phone application. The PIFA is to be mounted at the hinge position of the mobile phone with a small volume of 2.1 cm^3 only, yet it can generate two wide operating bands at about 900 and 1800 MHz for the mobile phone in either the open state or close state to cover GSM850/900/1800/1900/UMTS penta-band operation. The large bandwidth at 900 MHz for the antenna's lower band is achieved owing to the use of the coupling feed. Compared to the use of the direct contact feed for the conventional PIFA, the use of the coupling feed contributes additional capacitance to the antenna's input impedance [11–14], which not only compensates for the high input inductance of the antenna but also introduces additional resonances (zero reactance) at around 900 MHz. This behavior leads to a dual-resonance excitation for the antenna's lower band, hence a widened operating band covering GSM850/900 operation is obtained. Detailed design considerations of the proposed PIFA are described, and the experimental and simulation results are presented and discussed.

2. DESIGN CONSIDERATIONS OF PROPOSED PIFA

Figure 1(a) shows the geometry of the proposed PIFA with a coupling feed mounted at the hinge position of the folder-type mobile phone. The main ground and the upper ground are of the same length (L) 70 mm and width 40 mm, both are electrically connected through a 10-mm long conducting strip (width 2 mm) across the hinge. The main ground is printed on a 0.8-mm thick FR4 substrate of size 40 $\times$ 80 mm^2, which is considered as the main circuit board of the mobile phone. For the upper ground, it is inclined to the central line of the mobile phone or the main ground with an angle of 15° in the open state, which is reasonable for the mobile phone in the talk condition. In the close state for standby condition, the upper ground is parallel to the main ground as shown in the figure.

The proposed PIFA is mounted at the top no-ground region of the system circuit board. The detailed dimensions of the proposed PIFA are shown in Figure 1(b). Similar to the conventional PIFA, the proposed PIFA mainly consists of a feeding portion, a radiating portion, and a shorting portion. However, instead of using the direct contact feed for the conventional PIFA, the feeding portion here is a coupling feed comprising a coupling pad of 6 $\times$ 3.5 mm^2 ($a \times b$) printed on the back side of the circuit board. The coupling pad is connected to the 50-Ω microstrip feedline, also printed on the back side of the circuit board, through a printed strip of length 3 mm, and capacitively excites the radiating portion of the PIFA.

The radiating portion is composed of two radiating strips of different lengths. The longer radiating strip starting from point A to point C has a length of about 75 mm, close to a quarter-wavelength at 900 MHz. This allows the excitation of a quarter-wavelength mode at about 900 MHz for the proposed PIFA, which can further be tuned to become a dual-resonance mode by using the coupling feed. The dual-resonance excitation can lead to bandwidth enhancement for the antenna's lower band to cover GSM850/900 operation. Also note that the longer radiating strip is short-circuited to top edge of the main ground at point B through a 6-mm long shorting strip of width 1 mm and also connected to the shorter radiating strip printed on the front side of the top no-ground region of the circuit board at point A through a 6-mm long connecting strip of width 1 mm. The longer radiating strip, the feeding strip, and the shorting strip are together fabricated from line-cutting a metal plate (a 0.2-mm thick copper plate used here) into the planar metal pattern shown in Figure 1(b), which is then bent into a compact configuration shown in Figure 1(a).

The shorter radiating strip starting from point D (the antenna's feeding point) to its open end has a length of about 38 mm, which

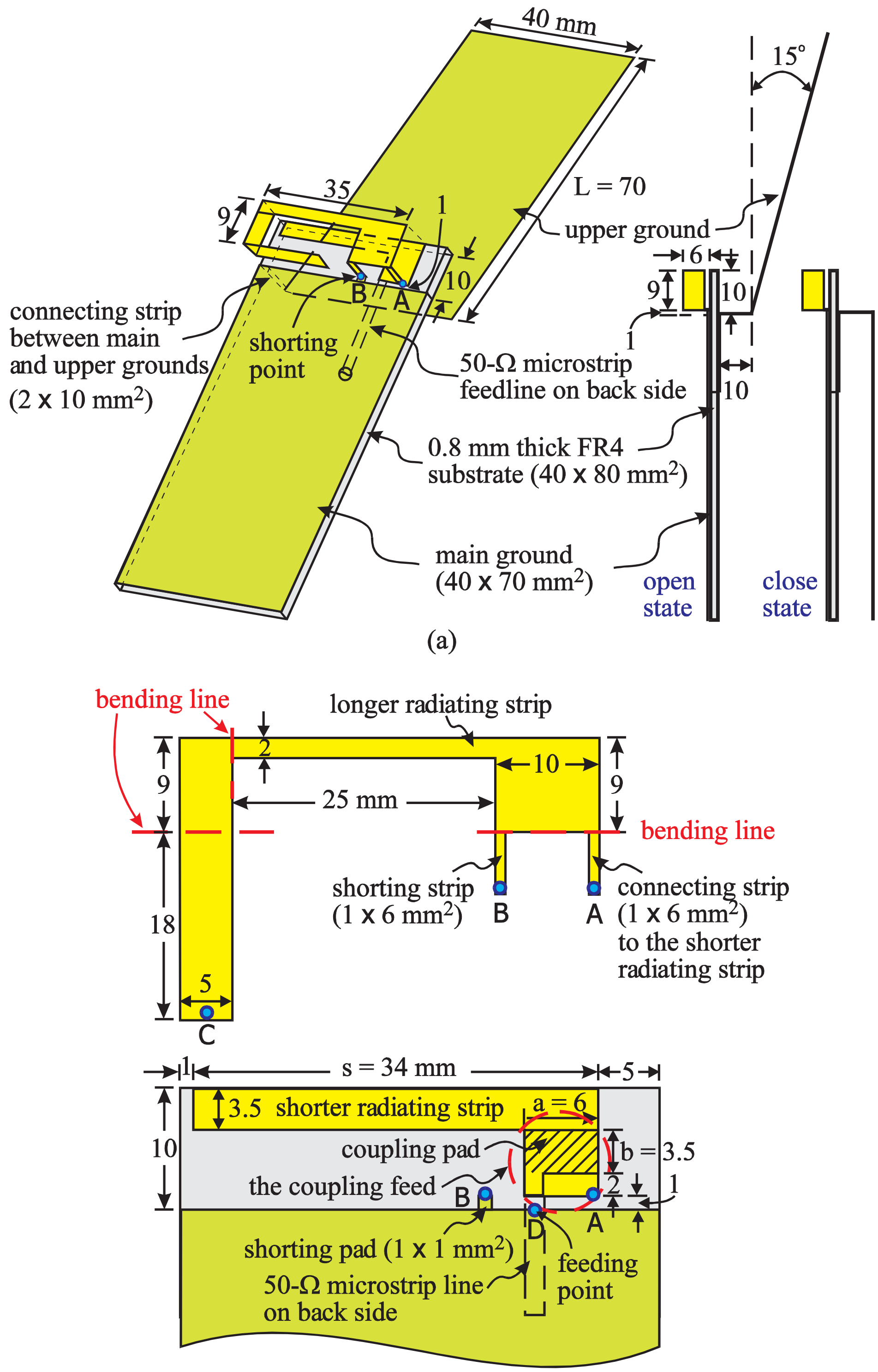


Figure 1 (a) Geometry of the proposed PIFA for the penta-band folder-type mobile phone. (b) Dimensions of the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

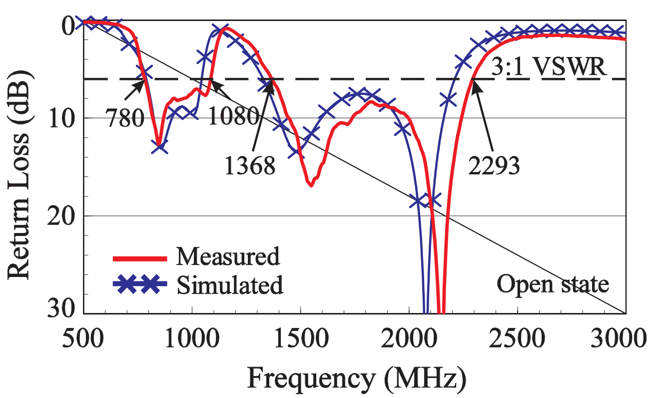
is close to a quarter-wavelength at 1800 MHz and allows the excitation of a wide-band resonance mode for the antenna's upper band to cover GSM1800/1900/UMTS operation. The front section of the shorter radiating strip faces the coupling pad of dimensions $a \times b$; in between the radiating strip and the coupling pad there is the 0.8-mm thick FR4 substrate. By tuning the parameters *a* and *b,* the contributed capacitance of the coupling feed to the antenna's input impedance can de adjusted. In this study, the antenna's high input reactance around 900 MHz can be effectively decreased, and additional resonances (zero reactance) around 900 MHz can be obtained. This behavior results in a dual-resonance excitation at about 900 MHz for the antenna's lower band. At the same time, a wide operating band at about 1800 MHz for the upper band can also be achieved. This allows the proposed PIFA to easily cover

GSM850/900/1800/1900/UMTS penta-band operation with a small occupied volume of $10 \times 35 \times 6$ mm^3 (2.1 cm^3) only. More detailed effects of the coupling feed are studied with the aid of Figures 3–5 to in the next section.

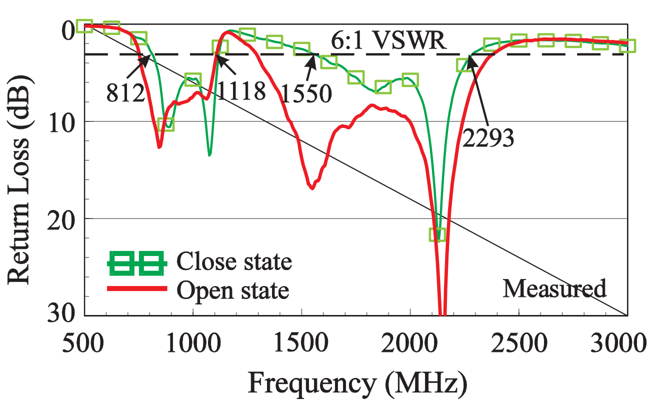
3. RESULTS AND DISCUSSION

The proposed PIFA was fabricated and studied. Figure 2(a) shows the measured and simulated return loss for the fabricated prototype in the open state. Good agreement between the measurement and the simulation obtained using Ansoft HFSS is observed [15]. For the measured results, dual-resonance excitation at about 900 MHz is clearly seen, and a wide impedance bandwidth, define by 3:1 VSWR or 6-dB return loss, of 300 MHz (780–1080 MHz) is achieved. The wide bandwidth reaches about 33% with respect to 900 MHz and allows the antenna's lower band to easily cover GSM850/900 operation. For the antenna's upper band, a wide bandwidth is also obtained. The obtained impedance bandwidth reaches 925 MHz (1368–2293 MHz) or about 51% with respect to 1800 MHz, allowing the antenna to easily cover GSM1800/1900/UMTS operation.

Figure 2(b) shows the comparison of the measured return loss of the fabricated prototype in the open and close states. The results indicate that there are large variations on the impedance matching of the two states. However, the lower and upper bands can still cover GSM850/900 and GSM1800/1900/UMTS operation with impedance matching better than 6:1 VSWR or 3-dB return loss for the mobile phone in the close state or standby condition. Note that for the mobile phones in the standby condition, the bandwidth definition of 6:1 VSWR (3 dB lower than that for the mobile phone in the talk condition) is acceptable for practical applications.

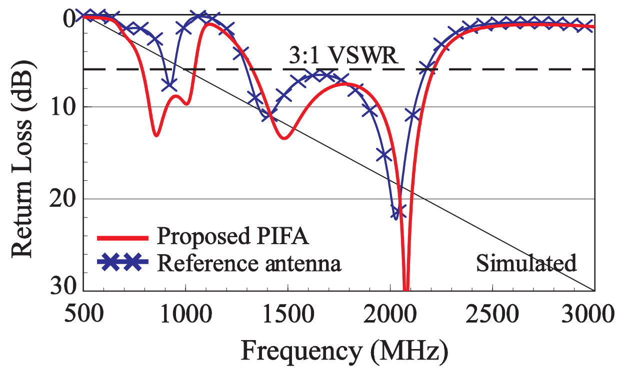


(a)

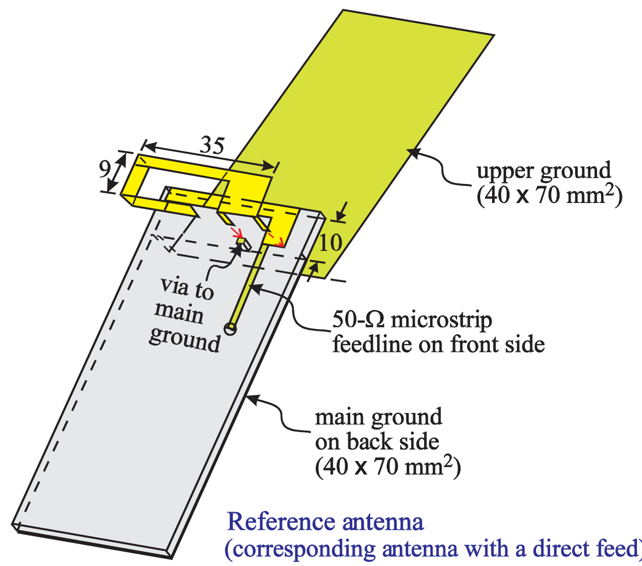


(b)

Figure 2 (a) Measured and simulated return loss for the proposed PIFA in the open state. (b) Measured return loss for the proposed PIFA in the open and close states. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



(a)

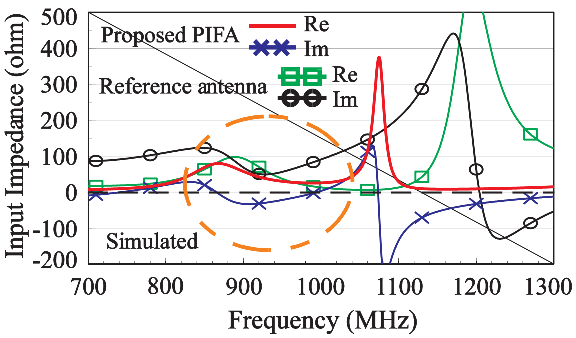


(b)

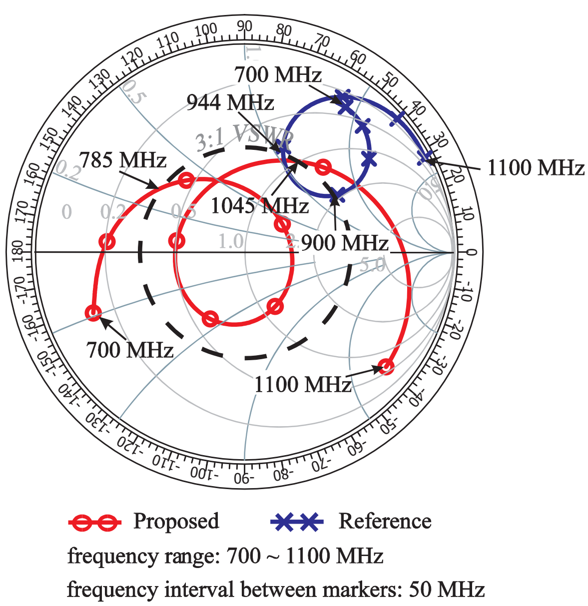
Figure 3 Comparison of the simulated return loss of the proposed PIFA and the reference antenna (the corresponding antenna with a direct feed). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

To study the effects of the coupling feed, Figure 3(a) shows the simulated return loss of the proposed PIFA and the reference antenna (the corresponding conventional PIFA with a direct contact feed). The dimensions of the reference antenna are shown in Figure 3(b), whose occupied volume is the same as that of the proposed PIFA. Note that the dimensions of the reference antenna are adjusted to achieve optimal impedance bandwidths of the lower and upper bands. From the results, the lower band of the reference antenna can cover GSM900 operation only. Conversely, the proposed PIFA has a bandwidth-enhanced lower band, allowing it to cover GSM850/900 operation. For the upper band, both the reference antenna and the proposed PIFA have a wide bandwidth to cover GSM1800/1900/UMTS operation.

Figure 4(a) shows the simulated real (Re) part and imaginary (Im) part of the input impedance versus frequency, and Figure 4(b) shows the simulated input impedance on the Smith chart for the reference antenna studied in Figure 3(b) and the proposed PIFA. In the figure, only the results for the lower band are shown. In Figure 4(a), mainly owing to the contributed capacitance of the coupling feed, the input reactance (Im curves) of the proposed PIFA is smaller than that of the reference antenna. The variations of the input reactance (Re curves) are also seen to be much smaller for the reference antenna. In addition, two additional resonances (zero reactance) occur at about 870 and 995 MHz, which result in a dual-resonance excitation for the antenna's lower band as seen in Figure 2. In Figure 4(b), the simulated impedance curves for the frequency range of 700–1100 MHz are shown, and the frequency intervals between markers of the impedance curves are 50 MHz. It is clearly seen that, compared to the reference PIFA, the loop of the impedance curve for the proposed PIFA is shifted inside the 3:1 VSWR circle, making the bandwidth increased from 44 MHz (900–944 MHz, simulated results) for the reference antenna to be



(a)



(b)

Figure 4 (a) Simulated input impedance versus frequency and (b) simulated input impedance on the Smith chart for the reference antenna studied in Figure 3 and the proposed PIFA. Only the results for the lower band of the antenna are shown. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

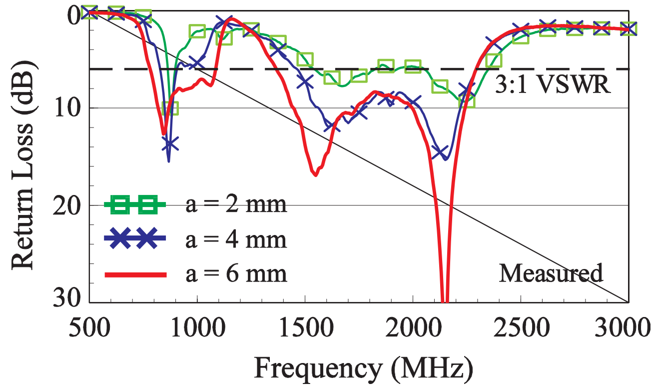


Figure 5 Measured return loss for the proposed PIFA as a function of the length a of the coupling pad; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

260 MHz (785–1045 MHz, simulated results) for the proposed PIFA.

Effects of the length a of the coupling pad on the antenna performances are studied in Figure 5, in which the measured return loss for the length a varied from 2 to 6 mm is presented. Other dimensions of the antenna are the same as given in Figure 1. The results indicate that the dual-resonance excitation for the antenna's lower band can be obtained when proper values of the length a are selected. In addition, the impedance matching of the antenna's upper band will also be affected by the variation in the length a. However, for the length a varied from 2 to 6 mm shown in the figure, the obtained bandwidths all cover the desired GSM1800/1900/UMTS bands. Also note that the antenna performances will be affected by the width b of the coupling pad. The obtained results are very similar to those shown here and hence are not presented for brevity.

Effects of the length L of the main and upper grounds on the achievable bandwidth are also studied. Figure 6 shows the measured return loss for the length L varied from 70 to 90 mm, whereas other dimensions of the antenna are the same as given in Figure 1. From the results, small effects on the impedance matching of the antenna are seen, and the obtained bandwidths still easily cover GSM850/900/1800/1900/UMTS operation. The results indicate that the proposed PIFA is suitable to be applied in the

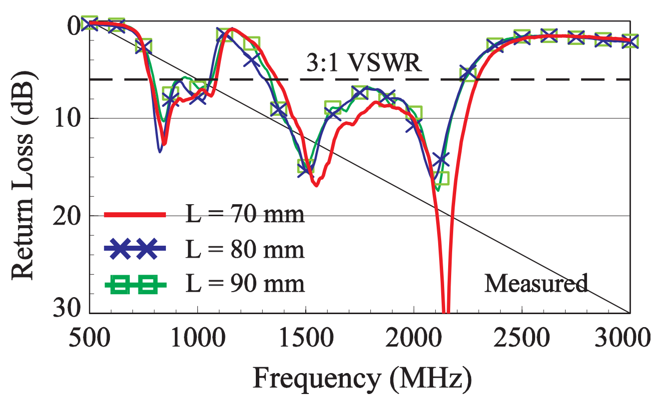


Figure 6 Measured return loss for the proposed PIFA as a function of the length L of the main ground and upper ground; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

folder-type mobile phone with various possible groundplane lengths for practical applications.

Radiation patterns of the proposed PIFA in the open state are also studied. Figures 7 and 8 plot the measured radiation patterns at 859, 925, 1795, 1920, and 2045 MHz (central frequencies of the respective operating band). The results at other frequencies are also studied. Over each operating band, very similar measured radiation patterns as shown here are obtained, indicating that stable radiation patterns are achieved for every operating band. The radiation patterns shown in Figures 7(a) and 7(b) are similar to each other, and omnidirectional radiation in the *x*–*y* plane (azimuthal plane) is seen, which is similar to the conventional PIFA [10]. The radiation patterns at 1795, 1920, and 2045 MHz plotted in Figures 8(a)–8(c) are also similar to each other. Moreover, the results show that omnidirectional radiation in the *x*–*y* plane is also obtained. Because there are no nulls in the azimuthal plane, the obtained radiation patterns are advantageous for practical applications.

The measured antenna gain and simulated radiation efficiency for the proposed PIFA in the open state are presented in Figure 9. Over the GSM850/900 bands shown in Figure 9(a), the antenna gain is varied from about 0.7 to 1.2 dBi, and the radiation efficiency is all large than 80%. For GSM1800/1900/UMTS bands, the results in Figure 9(b) indicate that the antenna gain is varied from about 1.8 to 3.6 dBi, and the radiation efficiency is all better than 75%. Generally, good radiation characteristics for the proposed PIFA are obtained.

Finally, a study for the simulated radiation efficiency of the proposed PIFA in the open and close states is also conducted. The

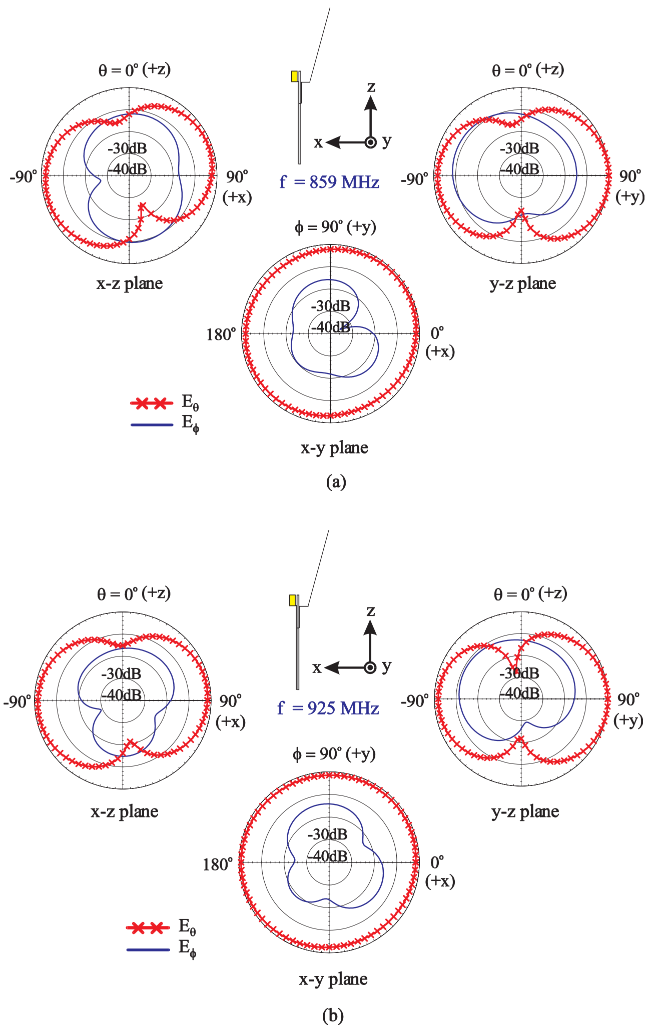


Figure 7 Measured radiation patterns at (a) 859 MHz and (b) 925 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

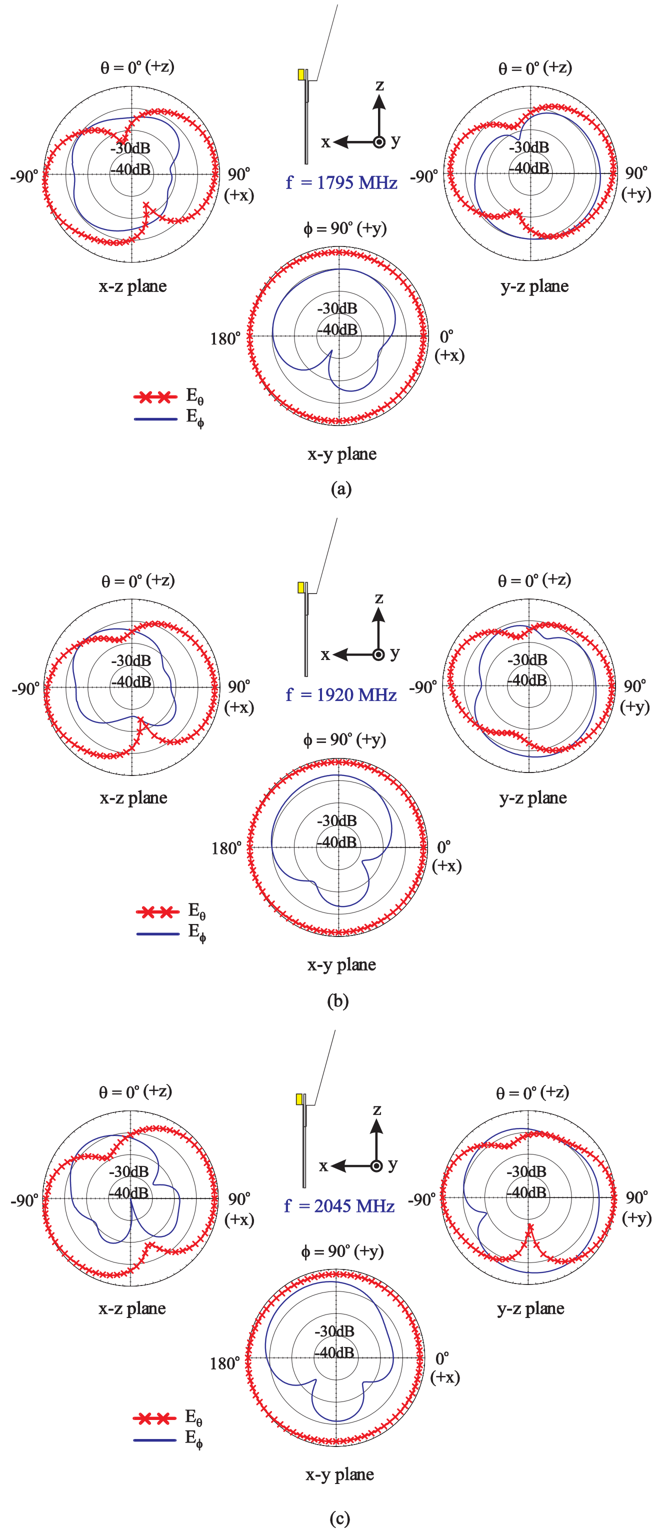


Figure 8 Measured radiation patterns at (a) 1795 MHz, (b) 1920 MHz, and 2045 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

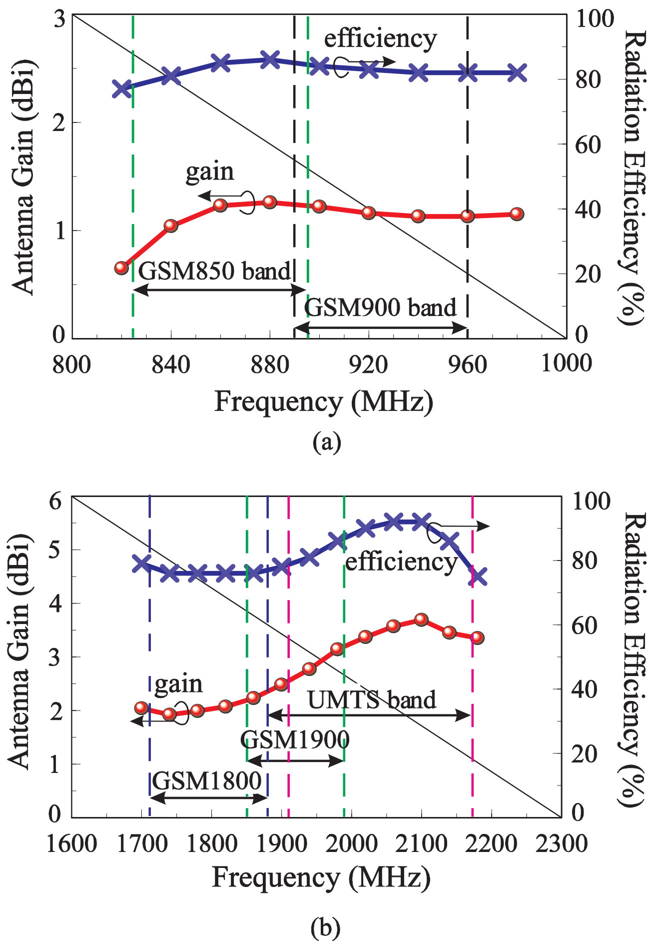


Figure 9 Measured antenna gain and simulated radiation efficiency of the proposed PIFA. (a) Lower band for GSM850/900 operation. (b) Upper band for GSM1800/1900/UMTS operation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

radiation efficiencies at 859, 925, 1795, 1920, and 2045 MHz in the open and close states are listed in Table 1 for comparison. From the obtained results, as expected, the radiation efficiencies in the close state are seen to be lower than those in the open state. However, the decrease in the radiation efficiency for the mobile phone changed from its open state to close state is less than 3 dB, except at 859 MHz where the decrease from 85 to 34% is about 4 dB. For the mobile phone in the close state for standby operation, the obtained radiation efficiencies are still acceptable for practical applications.

TABLE 1 Simulated Radiation Efficiency of the Proposed Antenna for the Folder-Type Mobile Phone in Its Open and Close States; f_c Is the Center Frequency for Each Operating Band

	Radiation Efficiency (%)	
f_c (MHz)	Open State	Close State
859 MHz for GSM850	85	34
925 MHz for GSM900	83	53
1795 MHz for DCS	77	62
1920 MHz for PCS	79	56
2045 MHz for UMTS	90	64

4. CONCLUSION

A small-size PIFA with a coupling feed for penta-band operation in the folder-type mobile phone has been proposed and studied. The proposed PIFA has a simple configuration and occupies a small volume of 2.1 cm^3 for penta-band operation. Owing to the use of the coupling feed, a dual-resonance excitation at about 900 MHz for the antenna's lower band and a wide operating band at 1800 MHz for the upper band have been obtained. The operating bandwidths of the lower and upper bands easily cover the desired GSM850/900/1800/1900/UMTS penta-band operation for the mobile phone in both the close and open states, although the ground conditions for the two states are greatly different. Good radiation characteristics over the operating bands have also been obtained. The proposed PIFA is also promising to be embedded inside the casing of the folder-type mobile phone to operate as an internal antenna.

REFERENCES

1. J.H. Byun, J.H. Lee, B.M. Lim, and S.K. Kim, Dual antenna capable of controlling radiation characteristics in a mobile communication terminal, U.S. Patent 6,707,431 B2, March 16, 2004.
2. T. Sugiyama, M. Ikegaya, and H. Tate, Triple band built-in antenna for clamshell type mobile phones, URSI North America Radio Science Meeting, Columbus, OH, 2003, p. 615.
3. P.L. Teng, C.Y. Chiu, and K.L. Wong, Internal planar monopole antenna for GSM/DCS/PCS folder-type mobile phone, Microwave Opt Technol Lett 39 (2003), 106–108.
4. C.Y. Chiu and K.L. Wong, Internal metal-plate antenna for folder-type mobile phone, Microwave Opt Technol Lett 42 (2004), 294–296.
5. S.W. Su, and K.L. Wong, Integrated internal PIFA for UMTS operation of clamshell mobile phones, Microwave Opt Technol Lett 47 (2005), 546–548.
6. K.L. Wong, S.W. Su, C.L. Tang, and S.H. Yeh, Internal shorted patch antenna for a UMTS folder-type mobile phone, IEEE Trans Antennas Propag 53 (2005), 3391–3394.
7. K.L. Wong, W.C. Su, and F.S. Chang, Wideband internal folded planar monopole antenna for UMTS/WiMAX folder-type mobile phone, Microwave Opt Technol Lett 48 (2006), 324–327.
8. K.L. Wong, Y.W. Chi, B. Chen, and S. Yang, Internal DTV antenna for folder-type mobile phone, Microwave Opt Technol Lett 48 (2006), 1015–1019.
9. M. Tzortzakakis and R.J. Langley, Quad-band internal mobile phone antenna, IEEE Trans Antennas Propag 55 (2007), 2097–2103.
10. K.L. Wong, Planar antennas for wireless communications, Wiley, New York, 2003.
11. C.R. Rowell and R.D. Murch, A compact PIFA suitable for dual-frequency 900/1800-MHz operation, IEEE Trans Antennas Propag 46 (1998), 596–598.
12. C.M. Su, K.L. Wong, W.S. Chen, and Y.T. Cheng, A microstrip-coupled printed inverted-F monopole antenna, Microwave Opt Technol Lett 43 (2004), 470–472.
13. R. Borowiec and P.M. Slobodzian, A miniaturized antenna for 2G/3G frequency-band application, Microwave Opt Technol Lett 48 (2006), 399–402.
14. K.L. Wong and C.H. Huang, Bandwidth-enhanced PIFA with a coupling feed for quad-band operation in the mobile phone, Microwave Opt Technol Lett 50 (2008), 683–687.
15. Ansoft Corporation HFSS [Online]. Available: http://www.ansoft.com/products/hf/hfss/