Simple Small-Size Coupled-Fed Uniplanar PIFA for Penta-Band WWAN Clamshell Mobile Phone

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1. Introduction

Owing to the rapid development in the mobile communication systems, penta-band operation for WWAN communications has been demanded for many modern mobile phones. In this paper, we present a small-size printed PIFA capable of generating two wide operating bands to cover GSM850/900 and GSM1800/1900/UMTS operations in the clamshell mobile phone. The proposed PIFA has a simple uniplanar structure formed by a single radiating strip coupled-fed by a feeding strip and is easily printed on a small area of 10×40 mm^2 only. By applying the proposed PIFA at the hinge of the clamshell mobile phone, whose two ground planes are connected through an extended connecting strip of proper length, both the PIFA and the two ground planes can be efficient radiators. Efficient dipole-like resonant modes (0.5λ and 1.0λ modes) can be excited and fine-adjusted to be at about 900 and 1700 MHz for covering GSM850/900/1800 operations. Also note that the excited 0.5λ dipole-like resonant mode at about 900 MHz has a dual-resonant behavior caused by the use of the coupling feed, hence resulting in a wide operating band capable of covering GSM850/900 operations. With the excited dipole-like resonant modes contributed by the two ground planes of the clamshell mobile phone, the proposed PIFA is only required to provide a resonant mode for covering GSM1900 and UMTS bands. For this reason, only one short resonant strip for the proposed PIFA is required. This behavior leads to a small printed area of 10×40 mm^2 required for the proposed PIFA. Moreover, when the clamshell mobile phone is in the idle condition, the proposed PIFA is still promising to cover WWAN operation with acceptable radiation efficiency. The SAR [1] results in 1 g of head tissue from exposure to the antenna radiation of the studied clamshell mobile phone are also tested, and meet the specification of 1.6 W/kg required for practical applications. Details of the proposed antenna and obtained results are presented and discussed.

2. Proposed Coupled-Fed PIFA

Fig. 1 shows the geometry of the proposed coupled-fed PIFA for a clamshell mobile phone in the open state (talk condition). In this case, the upper ground plane as the cover of the clamshell mobile phone has an angle of $\alpha = 15°$ to the main ground plane of the clamshell mobile phone. In the study, the upper ground plane is fabricated using a 0.2-mm thick copper plate; the main ground plane is printed on a 0.8-mm thick FR4 substrate treated as the main circuit board of the clamshell mobile phone studied here. The two ground planes have the same dimensions of 40×100 mm^2 and are connected through a 1-mm wide extended connecting strip of length 5 mm at the hinge and 36 mm (t) printed on the main circuit board. Through a via at point C in the main circuit board, the connecting strip connects the upper ground plane to the main ground plane. By selecting a proper length t (36 mm here) of the connecting strip, the 0.5λ and 1.0λ dipole-like resonant modes contributed by the two ground planes at about 900 and 1700 MHz can be excited. Detailed results of the connecting strip are analyzed in Section 3 with the aid of Fig. 3.

The proposed PIFA is printed on the small area of 10×40 mm^2 on the top portion of the main circuit board and is at the hinge of the clamshell mobile phone. The PIFA is formed by a simple inverted-L radiating strip coupled-fed by a simple feeding strip. The radiating strip is short-circuited to the top edge of the main ground plane through a via at point B and provides a resonant path of about 50 mm. Through a small coupling gap of 0.3 mm, the radiating strip is capacitively excited by the feeding strip of length 21 mm and width 0.5 mm, which is connected to the 50-Ω microstrip feedline of width 1.5 mm printed on the front surface of the main circuit board for testing the antenna. Owing to the use of the coupling feed, the large inductive reactance of the input impedance observed for frequencies at around 900 MHz is compensated. Furthermore, the large resistance of the input impedance at around 900 MHz can also be decreased to be close to 50-Ω. This behavior is similar to the coupled-fed PIFA applied to laptop computer studied in [2] and leads to the dual-resonant excitation of the 0.5λ dipole-like resonant mode in this study. Hence, a wide operating band of about 300 MHz for the antenna's lower band to cover GSM850/900 operations is obtained. Detailed results are presented in Fig. 4 and will be discussed in the next section.

The proposed PIFA also generates a wide operating band at about 2.3 GHz for covering GSM1900/UMTS operations. The open-end section of the radiating strip is widened for achieving bandwidth enhancement in the excited resonant mode [3]. The resonant mode contributed by the PIFA itself also shows a dual-resonant behavior and hence provides a wide operating band for the desired GSM1900/UMTS operations. This resonant mode incorporating the 1.0λ dipole-like resonant mode contributed by the two ground planes forms a very wide operating band of larger than 1 GHz for the antenna's upper band to cover GSM1800/1900/UMTS operations.

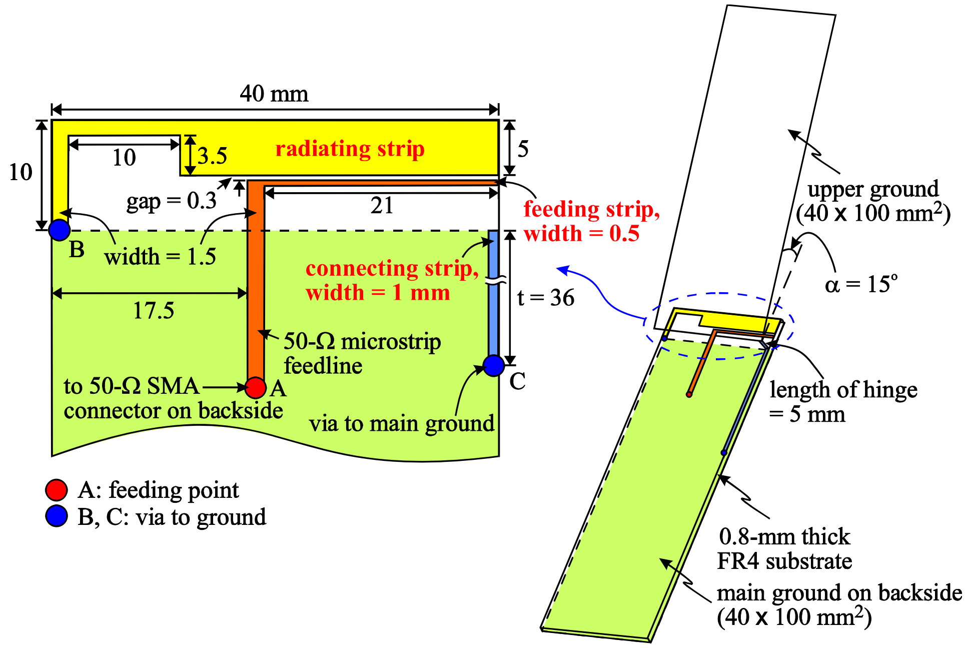

Figure 1: Geometry of the proposed coupled-fed PIFA for a clamshell mobile phone in the open state (talk condition).

3. Results and Discussion

The proposed antenna was fabricated and tested. Fig. 2 shows the measured and simulated return loss for the fabricated prototype in the open state. From the results, two wide operating bands are obtained to cover penta-band operation.

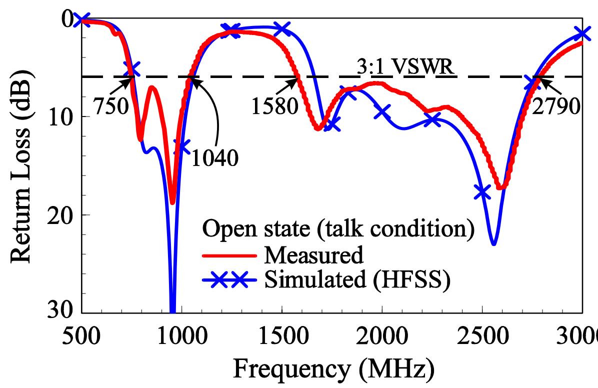

Figure 2: Measured and simulated return loss for the proposed antenna in the open state (α = 15°).

To analyze the effects of the coupling feed and the connecting strip in the proposed antenna, the simulated return loss for the reference antenna as a function of the connecting-strip length *t* is first studied. All the dimensions are the same as given in Fig. 1, except that the reference antenna uses a direct feed. Results for the different length *t* are presented in Fig. 3(a). Except for the case of *t* = 0, there are three resonant modes excited. It is observed that the variations in the length *t* show very small effects on the mode 3 since it is mainly contributed by the PIFA itself. With the proper length *t* selected, mode 2 can be excited. This is because the connecting strip can perturb the surface current distributions excited on the two ground planes such that the null or very small currents no longer exist at around the hinge position or in-between the two ground planes [shown in Fig. 3(b)]; in this case, the 1.0λ dipole-like resonant mode is promising to be excited. This behavior is similar to that used for achieving a wideband monopole antenna for DTV/GSM operation in the mobile phone in [4]. Further, a longer connecting strip can increase the effective resonant length of the 1.0λ dipole-like mode, which makes the mode 2 shifted to lower frequencies with increasing length *t*. This shifting in frequency is also observed in Fig. 3(a) for the mode 1 (the 0.5λ dipole-like mode), whose excited surface current distribution for the case of *t* = 36 mm is shown in Fig. 3(b).

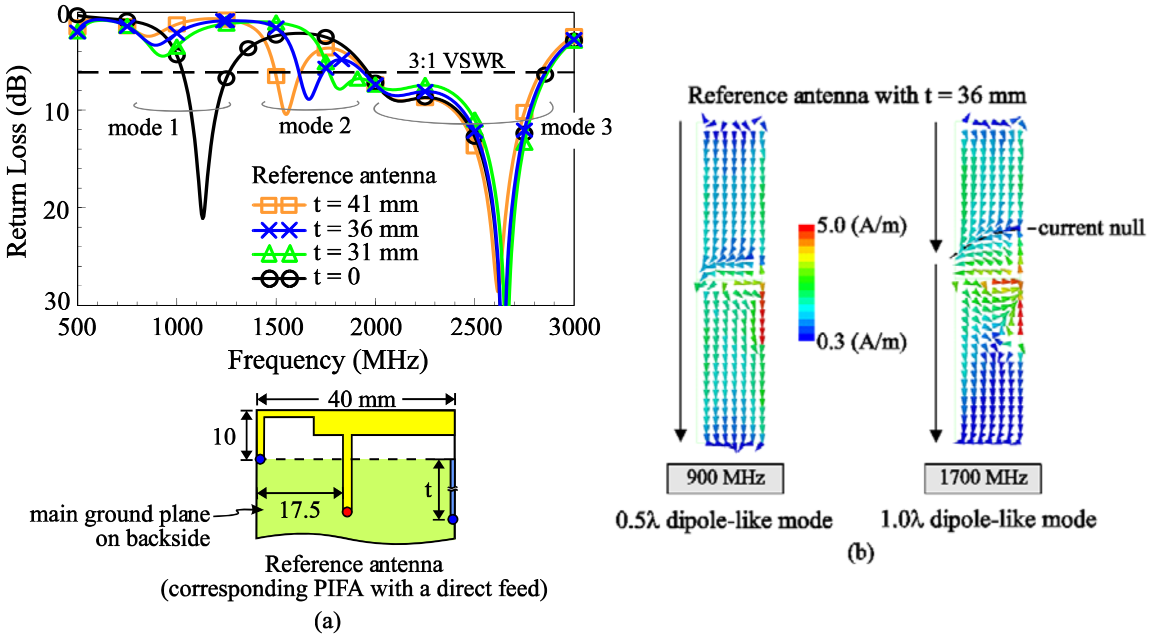

Figure 3: Simulated (a) return loss for the reference antenna as a function of the length *t*, and (b) surface current distributions at 900 and 1700 MHz for the reference antenna with *t* = 36 mm.

By applying the coupling feed to the reference antenna, dual-resonant excitation for mode 1 at about 900 MHz can be excited to achieve a wide operating band covering GSM850/900 operations. Fig. 4 presents the simulated return loss for the proposed antenna and the reference antenna with *t* = 36 mm studied in Fig. 3. This behavior is similar to those observed in [5].

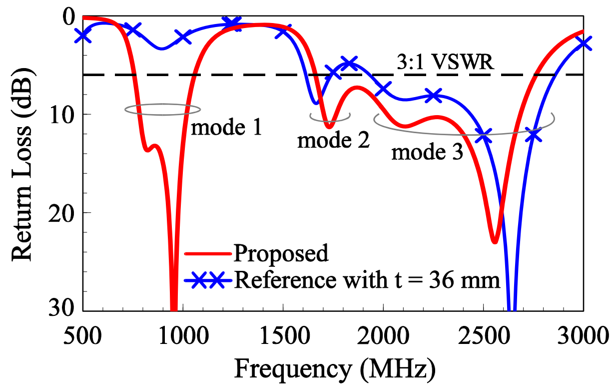

Figure 4: Simulated return loss for the proposed antenna and the reference antenna with *t* = 36 mm.

The groundplane condition varies greatly when it is in the open state and the closed state for clamshell mobile phone. Fig. 5 shows the measured radiation efficiency for the proposed antenna in both the states. Over the GSM850/900 bands in Fig. 5(a), the radiation efficiency in the open state is varied from about 77 to 89%. For the GSM1800/1900/UMTS bands in Fig. 5(b), the radiation efficiency in the open state is ranged from about 60 to 92%. Although the radiation efficiency in the close state over operating bands is decreased by about 1.0 to 3.5 dB compared to that in the open state, the obtained results indicate that the proposed antenna is promising for the clamshell mobile phone application in both states.

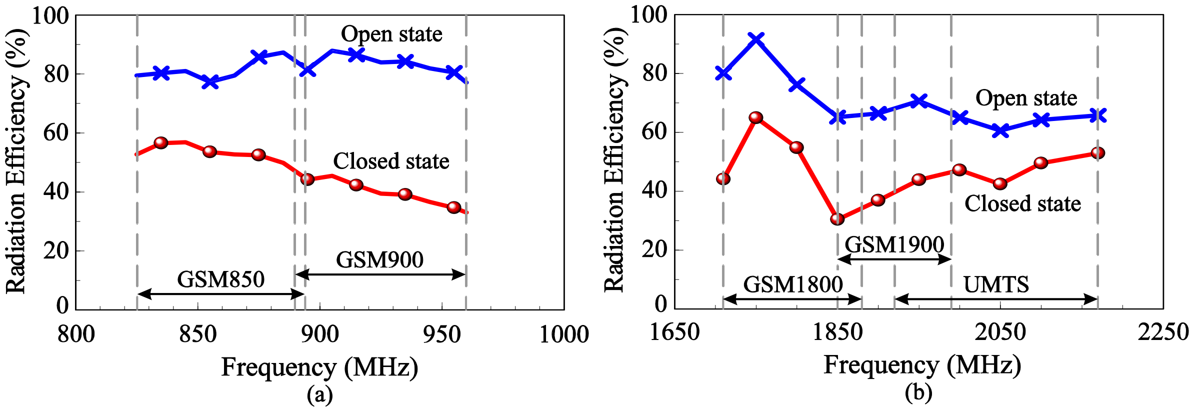

Figure 5: Comparison of the measured radiation efficiency for the proposed antenna in the open state and the close state. (a) The GSM850/900 bands. (b) The GSM1800/1900/UMTS bands.

The SAR results, simulated by SEMCAD, of the proposed antenna are also studied. The upper ground plane is spaced 5 mm to the phantom head for considering the housing of phone. The obtained SAR results are found to be less than 0.8 W/kg, much smaller than the 1-g SAR specification of 1.6 W/kg. More related results will be given in the presentation.

4. Conclusion

Penta-band WWAN operation in the clamshell mobile phone has been proposed and studied. The proposed antenna uses the two ground planes of the clamshell mobile phone as an efficient radiator for covering the lower frequencies of the desired penta-band operation, while the printed PIFA itself is for generating a resonant mode for covering the higher frequencies only. This leads to a small printed area required for the proposed antenna. Good radiation characteristics over the five operating bands have also been obtained for the proposed antenna applied in the clamshell mobile phone in the open state (talk condition) and the closed state (idle condition) as well. The obtained SAR results in 1-g head tissue from exposure to the radiation of the proposed antenna are found to be less than 0.8 W/kg, much less than the SAR limit of 1.6 W/kg required for practical applications.

References

[1] American National Standards Institute (ANSI), “Safety levels with respect to human exposure to radio-frequency electromagnetic field, 3 kHz to 300 GHz,” ANSI/IEEE standard C95.1, 1999.
[2] C.H. Chang and K.L. Wong, ”Internal coupled-fed shorted monopole antenna for GSM850/900/1800/1900/UMTS operation in the laptop computer,” IEEE Trans. Antennas Propagat., vol. 56, pp. 3600-3604, 2008.
[3] K.L. Wong, Y.C. Lin and B. Chen, ”Internal patch antenna with a thin air-layer substrate for GSM/DCS operation in a PDA phone,” IEEE Trans. Antennas Propagat., vol. 55, pp. 1165-1172, 2007.
[4] C.T. Lee, K.L. Wong and Y.C. Lin, ”Wideband monopole antenna for DTV/GSM operation in the mobile phone,” Microwave Opt. Technol. Lett., vol. 50, pp. 801-806, 2008.
[5] K.L. Wong and C.H. Huang, ”Bandwidth-enhanced internal PIFA with a coupling feed for quad-band operation in the mobile phone,” Microwave Opt. Technol. Lett., Vol. 50, pp. 683-687, 2008.