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PRINTED MONOPOLE SLOT ANTENNA FOR PENTA-BAND OPERATION IN THE FOLDER-TYPE MOBILE PHONE

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Received 26 December 2007

ABSTRACT: *A monopole slot antenna suitable for folder-type mobile phone application is presented. The antenna is placed at the hinge position of the mobile phone and occupies a small area of 15 × 40 mm² on the top portion of the main circuit board of the mobile phone. The antenna can generate two wide operating bands to cover GSM850/900/1800/1900/UMTS penta-band operation for the mobile phone in either the open state (talk condition) or close state (standby condition), although the two states have different ground plane conditions for the antenna. This behavior is achieved by connecting the upper ground of the folder-type mobile phone to its main ground on the main circuit board not at the hinge position but at about the center of the side edge of the main ground where the excited surface current distributions are small. This greatly reduces the effects of the different orientations of the upper ground to the main ground on the antenna performances in the open and close states. Good radiation characteristics of the antenna over the operating bands are also obtained.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 2237–2242, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23636

Key words: *internal mobile phone antennas; monopole slot antennas; folder-type mobile phones; mobile antennas; penta-band operation*

1. INTRODUCTION

The folder-type mobile phone [1–9] is attractive for the wireless users because it is usually equipped with a large display, which makes it very suitable for the users using the multimedia function on the mobile phone, such as surfing the webs, watching DTV programs, checking emails, etc. For the folder-type mobile phone, however, there are two separate but electrically connected grounds, the main and upper grounds, which are quite different from the conventional bar-type mobile phone. The upper ground usually accommodates the loudspeaker and the LCD display, while the main ground usually accommodates the battery and the keypad. For the mobile phone in the open state (talk condition) and close state (standby condition), the upper ground is oriented differently to the main ground. Hence, the employed antenna in the folder-type mobile phone will encounter different ground conditions in the open and close states. For this reason, the performances of the employed antenna usually will be greatly varied when the mobile phone changes from the open state to the close state, or vice versa. This makes it difficult to directly apply the available internal antennas for the bar-type mobile phone to the folder-type mobile phone.

In this article, we present a technique of connecting the upper ground to the main ground through an extended conducting strip along the side edge of the main ground. By selecting a proper length of the extended conducting strip (about half length of the main ground in this study) such that the upper ground is connected to the main ground at a position where there are small excited surface current distributions. In this case, it is expected that the performances of the employed antenna in the open and close states of the folder-type mobile phone will not be greatly varied, although the ground condition differs greatly in the two different states. With this proposed technique, we apply a recently reported printed monopole slot antenna capable of penta-band operation in the bar-type mobile phone [10] to the folder-type mobile phone. Some related monopole slot antennas or quarter-wavelength slot antennas have also been demonstrated [11–15], however, the reported antenna in [10] can generate two wide bands centered at about 900 and 2100 MHz to cover GSM850 (824–894 MHz), GSM900 (890–960 MHz), GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), and UMTS (1920–2170 MHz) bands with a small area of 15 × 40 mm². Further, the antenna is to be placed at the top portion of the main circuit board of the mobile phone to avoid complicating the circuit floor planning and signal line routing [15]. By applying this monopole slot antenna and connecting the upper ground to the main ground using an extended conducting strip, penta-band operation with good radiation characteristics can also be easily achieved. Details of the proposed design are described, and results for the constructed prototype are presented and discussed. Effects of different lengths of the extended connecting strip on the antenna performances are also analyzed.

2. DESIGN OF THE PROPOSED ANTENNA

Figure 1(a) shows the configuration of the penta-band monopole slot antenna for folder-type mobile phone in the open state or talk condition, while Figure 1(b) shows the side view of the mobile phone in the close state or standby condition. Dimensions of the antenna are given in Figure 1(c). The two grounds are of the same size 40 × 85 mm². In the open state, the upper ground is inclined with respect to the central line of the mobile phone with an angle of 15°, which is a reasonable angle for the folder-type mobile phone in the talk condition. While in the close state, the upper ground is parallel to the main ground with a distance of 10 mm as shown in Figure 1(b).

The monopole slot antenna occupies an area of 15 × 40 mm² and is printed on the top portion of the main circuit board, which is a 0.8-mm thick FR4 substrate in the study. The antenna consists of two monopole slots operated as quarter-wavelength resonant structures [10]. The longer monopole slot has a mean length of 44 mm and controls the excitation of the antenna's lower band centered at about 900 MHz to cover GSM850/900 operation (824–960 MHz). The shorter monopole slot has a mean length of 27.5 mm and controls the excitation of the antenna's upper band centered at about 2100 MHz to cover GSM1800/1900/UMTS operation (1710–2170 MHz). The width of the two monopole slots are both 5 mm, and the top ground portion of 4 mm in width is required to achieve good excitation of the antenna's lower and upper bands. Detailed design considerations of the antenna have been described in [10], where there is no upper ground.

For the folder-type mobile phone, the upper ground is usually directly connected to the main ground at its upper edge, where there are usually large excited surface current distributions. In this

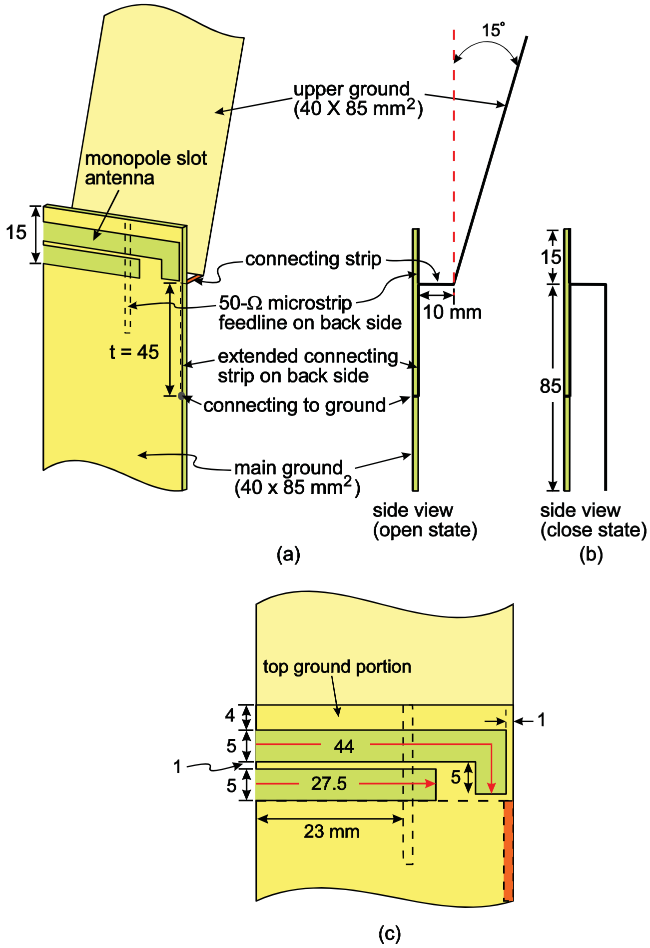


Figure 1 (a) Configuration of the penta-band monopole slot antenna for folder-type mobile phone in the open state (talk condition). (b) Side view of the mobile phone in the close state (standby condition). (c) Dimensions of the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

case, different orientations of the upper ground with respect to the main ground (that is, either the mobile phone in the open state or close state) will lead to large variations in the excited surface currents on the main ground. This behavior in turn will result in large variations in the performances of the embedded antenna. In this study, the upper ground is connected to the main ground at a position away from the hinge position or the top edge of the main ground through an extended connecting strip of width 0.5 mm and length t. The preferred length t in this study is 45 mm. One end of the extended connecting strip is connected to the main ground as shown in the figure, and the other end at the hinge position is connected to the connecting strip (width 0.5 mm and length 10 mm) across the hinge and then to the upper ground. With the proposed arrangement, the upper ground is connected to the main ground at a position where the excited surface currents are much smaller than those at the hinge position of the mobile phone. Hence, the variations in the antenna performances in the open and close states can be expected to be reduced. More detailed effects of the length t of the extended connecting strip are analyzed and discussed in the following section.

3. RESULTS AND DISCUSSION

The proposed antenna was fabricated and studied. Figure 2(a) shows the measured return loss of the fabricated prototype in the open and close states with the extended connecting strip of length 45 mm. The corresponding simulated results obtained using Ansoft HFSS (high frequency structure simulator) [16] are shown in Figure 2(b). The simulation is seen to agree with the measurement. From the measured results, when the mobile phone is in the open state, two wide bands centered at about 900 and 2100 MHz are obtained. The lower band has a 3:1 VSWR bandwidth (6-dB return loss) of 150 MHz (820–970 MHz), which covers GSM850/900 operation. For the upper band, a much larger bandwidth formed by two resonances is obtained; this dual-resonance behavior is similar to that observed in [10], which is mainly because the microstrip feedline functions as a virtual short-circuiting across the slot. In this case, the bandwidth reaches 925 MHz (1675–2600 MHz) and covers GSM1800/1900/UMTS operation. Note that the bandwidth definition of 3:1 VSWR has been generally used for the internal mobile phone antenna design for practical applications. On the other hand, for the mobile phone in the close state for standby operation, the bandwidth definition is 6:1 VSWR or 3-dB return loss, which is 3 dB lower than that in the open state for the talk condition and also has been generally used for practical applications. It can be seen that the impedance matching for the operating frequencies over the desired five operating bands is still better than 6:1 VSWR, as shown in Figure 2.

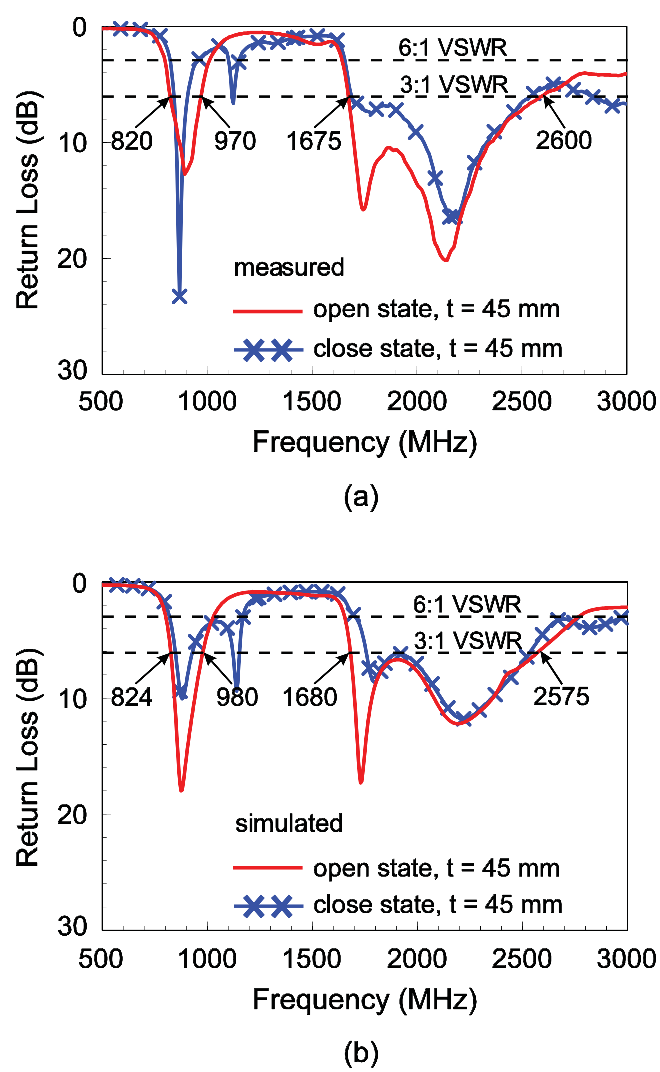


Figure 2 (a) Measured and (b) simulated return loss of the antenna in the open and close states shown in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

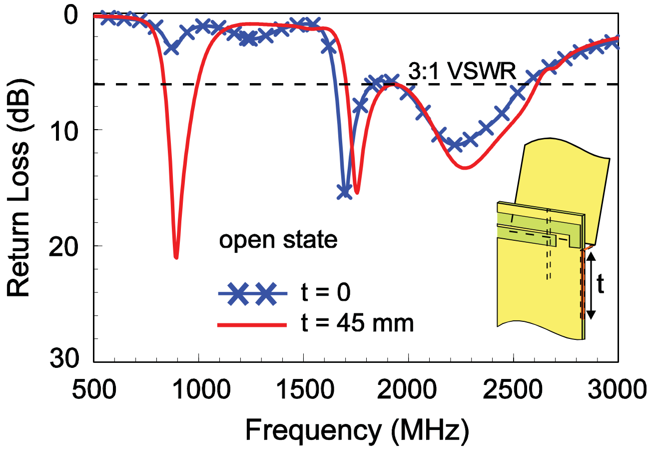


Figure 3 Simulated return loss for the antenna in the open state with no extended connecting strip (t = 0) and an extended connecting strip of length t = 45 mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 3 shows the simulated return loss for the proposed antenna in the open state with no extended connecting strip (t = 0) and an extended connecting strip of length t = 45 mm. It is clearly seen that the impedance matching for frequencies over the lower band can be effectively improved with the presence of the extended connecting strip. This behavior can be explained from the excited surface current distributions at 900 MHz shown in Figure 4. The excited surface currents for t = 45 mm at the connecting point (at about the center of the side edge of the main ground) are much smaller than those at the connecting point (at the top edge of the main ground) for t = 0. In this case, it indeed can be expected that the upper ground will have much smaller effects on the antenna performances for t = 45 mm. Also note that there are small variations for the upper band between the two cases of t = 0 and 45 mm. This is due to the slight differences in the excited surface current distributions for frequencies over the upper band between the two cases of t = 0 and 45 mm; the related results for the upper band are not shown in the article for brevity.

Figure 5 shows the simulated input impedance for the antenna in the close and open states. In Figure 5(a), results of the real (Re) and imaginary (Im) parts of the input impedance for t = 45 mm are

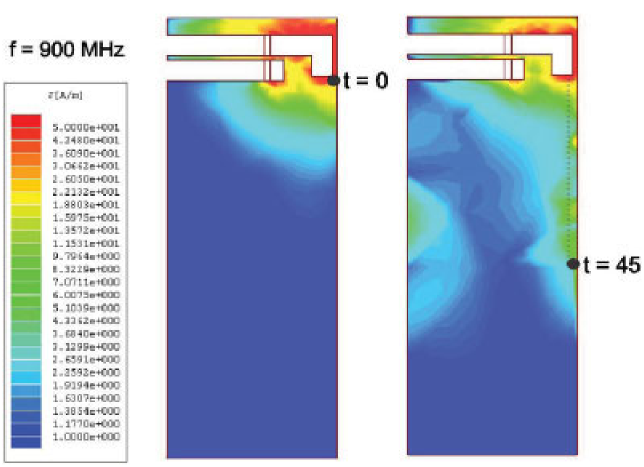


Figure 4 Simulated surface current distributions on the main ground of the mobile phone at 900 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

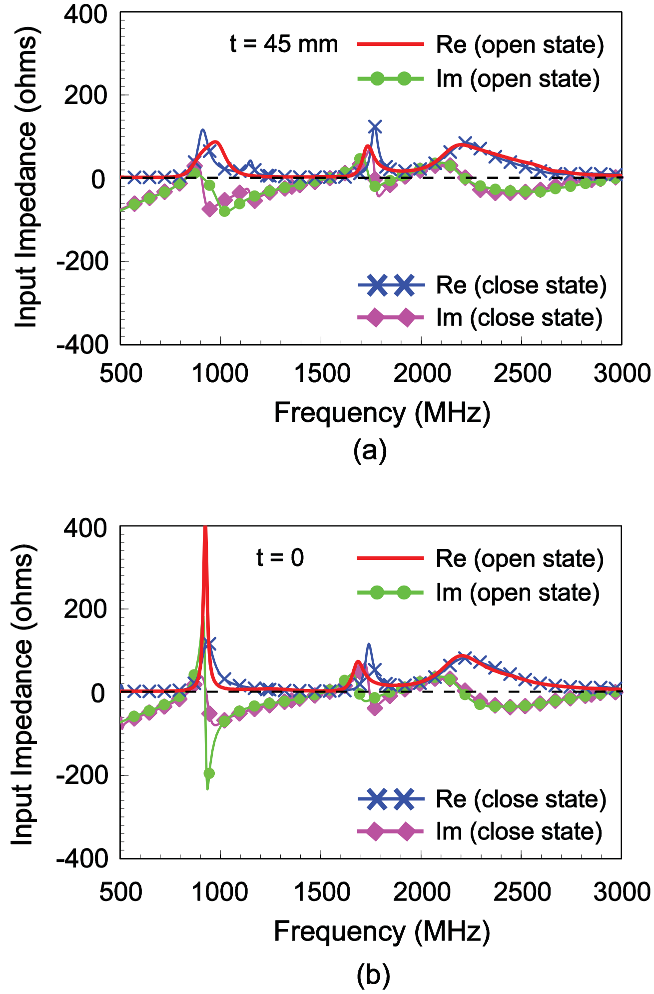


Figure 5 Simulated input impedance for the antenna in the close and open states; (a) t = 45 mm; (b) t = 0. Other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

presented, while those for t = 0 are shown in Figure 5(b). Results show that when the mobile phone is changed form the open state to the close state, the variations in the input impedance for fre-

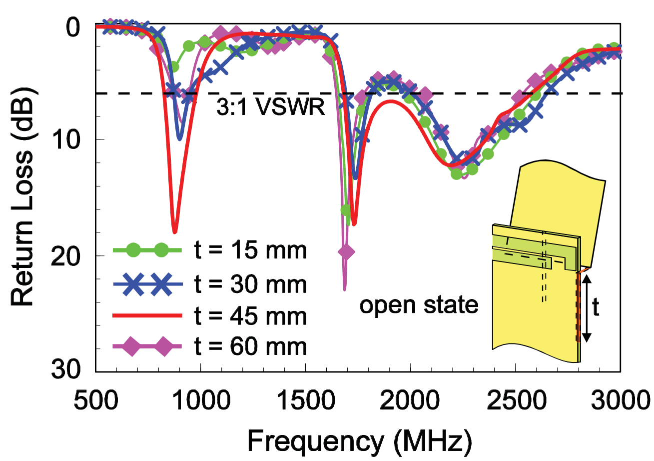


Figure 6 Simulated return loss as a function of the length t for the antenna in the open state; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

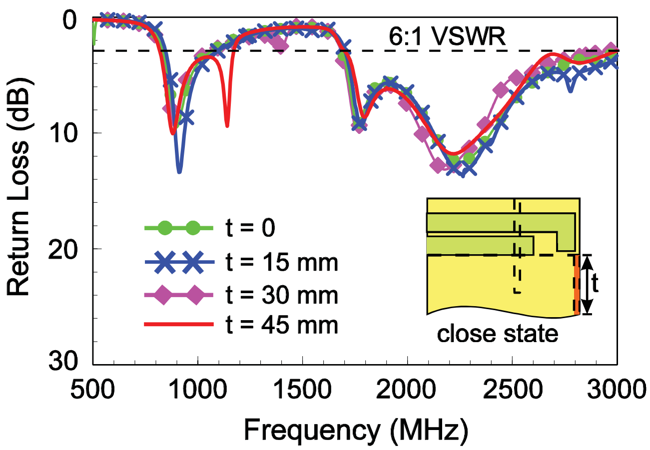


Figure 7 Simulated return loss as a function of the length t for the antenna in the close state; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

quencies over the lower band are much smaller for $t = 45$ mm than for $t = 0$. That is, when the upper ground is connected to the main ground at its top edge where there are large excited surface currents ($t = 0$), large variations in the impedance matching of the antenna will occur, which results in degraded impedance matching for the lower band.

Figure 6 shows the effects as a function of the length t of the extended connecting strip for the mobile phone in the open state, and results of the simulated return loss for the length t varied from 15 to 60 mm are shown. It is seen that a proper length t is important for achieving good impedance matching for the antenna, especially for frequencies over the lower band. For covering the desired GSM850/900/1800/1900/UMTS penta-band operation, the length t is selected to be 45 mm in this study.

The results for the simulated return loss for the length t varied from 0 to 45 mm for the mobile phone in the close state are shown in Figure 7. In this case, smaller variations in the impedance matching are seen as compared to those shown in Figure 6. This is largely because the upper ground is parallel to the main ground in the close state, different from that in the open state, which leads to different effects on the impedance matching of the antenna.

Radiation characteristics of the constructed prototype studied in Figure 2 are also studied, and the results are presented in Figures 8–10. The radiation patterns at 900 MHz for the mobile phone in the open state are plotted in Figure 8. At 900 MHz, dipole-like radiation patterns are seen, and good omnidirectional radiation in the azimuthal plane (x-y plane) is obtained. The radiation patterns for frequencies over the lower band are also measured, and the patterns are seen to be about the same as those plotted here, indicating that stable dipole-like radiation patterns are obtained over the lower band.

Figures 9 and 10 plot the measured radiation patterns at 1850 and 2045 MHz, respectively. Similar radiation patterns for the two frequencies are generally observed, and the radiation patterns are also very similar to those of the monopole slot antenna in the bar-type mobile phone [10]. That is, the upper ground of the folder-type mobile phone studied here does not cause large effects on the radiation patterns of the antenna. The measured antenna gain and simulated radiation efficiency are presented in Figure 11. For the lower band shown in Figure 11(a), when the antenna is in the open state, the antenna gain varies from about 0 to 1.9 dBi, and the radiation efficiency is larger than about 43%. For the upper band shown in Figure 11(b), the antenna gain varies from about 2.3 to 5.4 dBi, and the radiation efficiency is all larger than 50% for the antenna in the open state. For the antenna in the close state, the radiation efficiency is still larger than about 40% over the

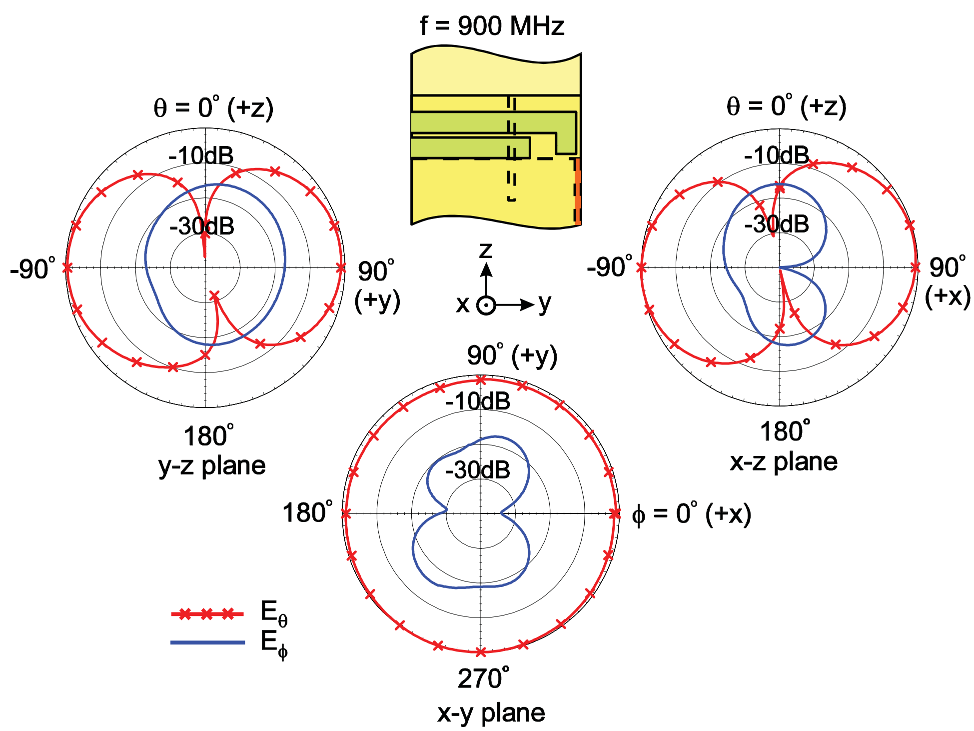


Figure 8 Measured radiation patterns at 900 MHz for the antenna in the open state. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

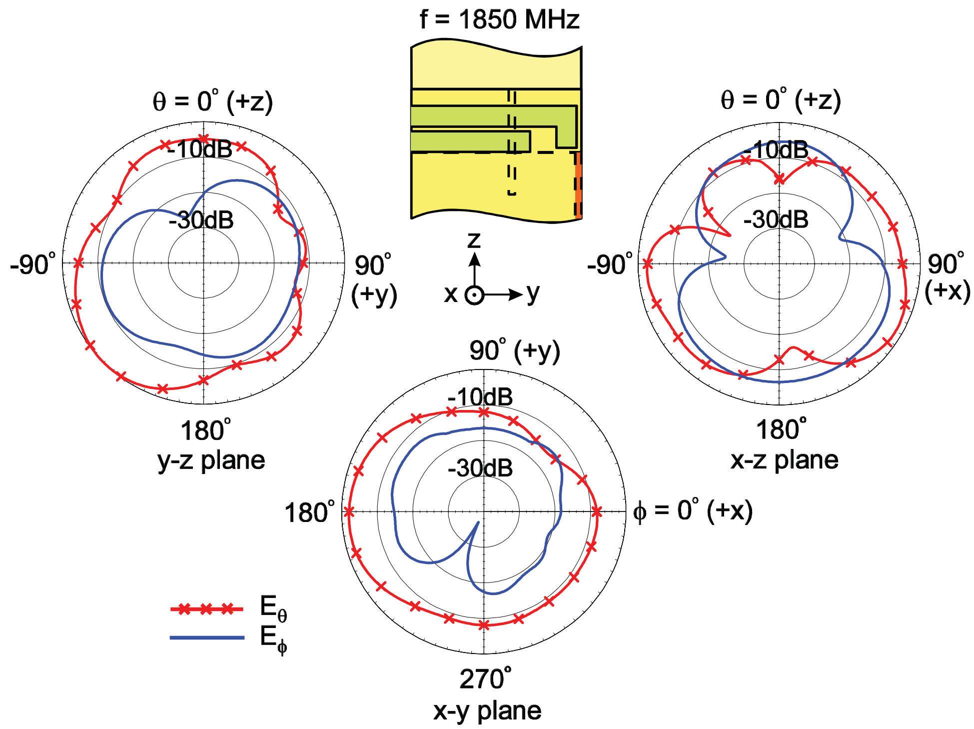


Figure 9 Measured radiation patterns at 1850 MHz for the antenna in the open state. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

GSM850/900 bands and 30% over the GSM1800/1900/UMTS bands. The obtained radiation efficiencies of the antenna are all acceptable for practical applications for the mobile phone in either the talk condition (open state) or the standby condition (close state).

4. CONCLUSION

A penta-band monopole slot antenna for application in the folder-type mobile phone has been proposed and studied. By properly connecting the upper ground of the mobile phone to be at about the

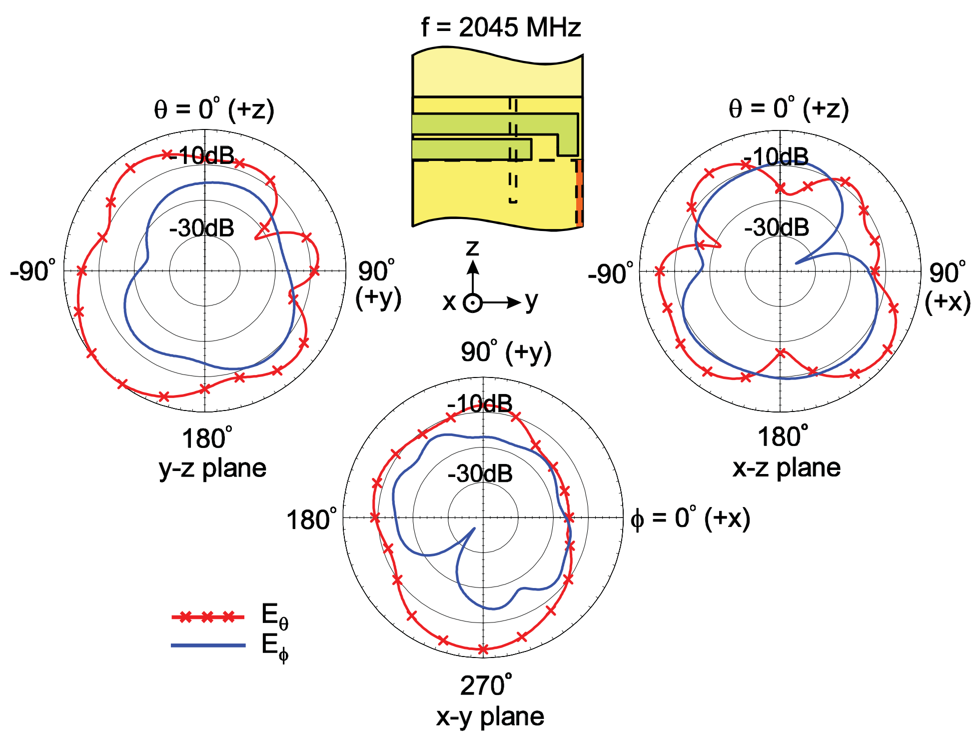
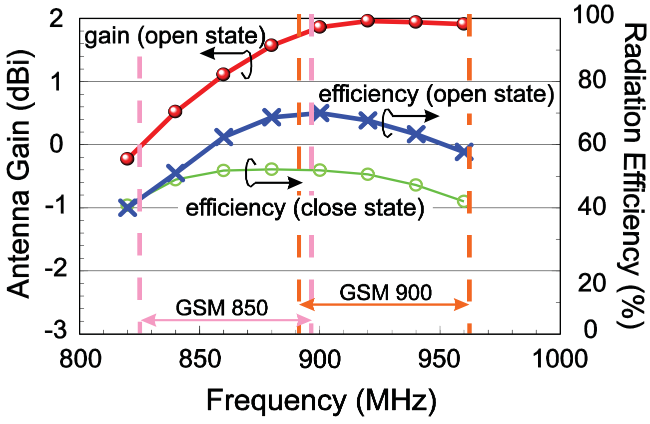
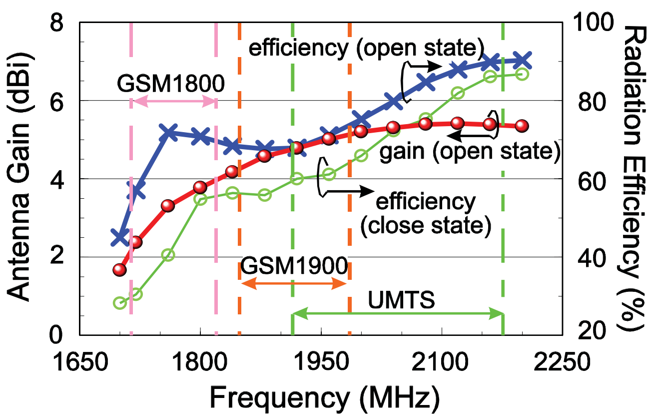


Figure 10 Measured radiation patterns at 2045 MHz for the antenna in the open state. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



(a)



(b)

Figure 11 Measured antenna gain and simulated radiation efficiency for the antenna. (a) The GSM850/900 bands. (b) The GSM1800/1900/UMTS bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

center of the side edge of the main ground using an extended connecting strip, variations of the antenna performances for the mobile phone in either the open or close states can be greatly reduced. Detailed effects of the extended connecting strip on the antenna performances have also been analyzed. In this study, the antenna can provide two wide bands to cover GSM850/900/1800/1900/UMTS operation, and good radiation characteristics over the operating bands have been obtained.

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SIX-BAND INTERNAL ANTENNA FOR SMALL-SIZE MOBILE PHONE

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Received 2 January 2008

ABSTRACT: *A promising six-band internal antenna suitable for small-size mobile phone application is presented. The mobile phone considered in this study has a system ground plane of length 60 mm only, much less than that of the general mobile phones. For such small-size mobile phones, it is not easy for the embedded antenna to achieve a wide operating band at 900 MHz for GSM850/900 operation. The proposed antenna solved the problem with a reasonable occupied volume. The antenna mainly comprises three radiating elements of two longer monopoles and a shorter monopole, which are configured to occupy a volume of 3.6 cm^3 only. The two longer monopoles incorporating an external parallel chip inductor lead to the successful excitation of a wide operating band for the antenna's lower band to cover GSM850/900 operation. Moreover, the three monopoles together contribute to the excitation of a very wide upper band to cover GSM1800/1900/UMTS/WLAN operation. That is, the antenna can perform six-band operation for WWAN and WLAN communications. The proposed antenna is studied in detail in this article.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 2242–2247, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23659

Key words: *internal mobile phone antennas; small-size mobile phone; six-band operation; WWAN operation; WLAN operation*