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INTERNAL MULTIBAND PRINTED FOLDED SLOT ANTENNA FOR MOBILE PHONE APPLICATION

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ABSTRACT: *A novel printed folded slot antenna suitable for GSM/DCS/PCS/UMTS multiband operation in the mobile phone is presented. The proposed slot antenna has a planar configuration and is easy to fabricate by printing on the system circuit board of the mobile phone. The slot antenna has a length of 106 mm and is folded into a compact structure with its two slot ends facing toward each other. This configuration allows the antenna to occupy a small area of 21 × 45 mm*^{2} *centered on the top portion of the system ground plane. By feeding the slot antenna using a 50 Ω microstrip line printed along the centerline of the system ground plane, two wide bands (the half- and one-wavelength modes) of the antenna can be generated, with the lower band covering GSM operation and the upper band covering DSC/PCS/UMTS operation. In addition, small excited surface currents in the system ground plane are observed, and the antenna's two operating bands are in general not sensitive to the ground-plane length variations. These features are attractive for practical applications and different from those of the conventional internal mobile phone antennas.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1833–1837, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22602

Key words: *mobile phone antennas; internal mobile phone antennas; printed slot*

1. INTRODUCTION

Metal-plate or printed slot antennas have been demonstrated to be promising for applications in mobile devices such as the laptop computer for 2.4 and 5 GHz WLAN (Wireless Local Area Network) operation [1, 2]. Such slot antennas are simple in configuration and easy to fabricate with a low cost. However, probably because the slot antenna is mainly operated as a half-wavelength resonant structure, not a quarter-wavelength resonant structure as the planar inverted-F antenna (PIFA) or the shorted patch antenna [3], the application of the slot antenna in lower frequencies such as in the GSM (Global System for Mobile Communication, 890–960 MHz) and DCS (Digital Communication System, 1710–1880 MHz) bands will require a large occupied volume inside the mobile device, and thus very few related reports are available in the open literature.

In this article, we demonstrate that the slot antenna is also very promising for application in the mobile phone. The proposed slot antenna in this study occupies a small area of 21 ′ 45 mm^2 only and is suitable to be printed on the system circuit board of the mobile phone to operate as an internal antenna. The antenna can also generate two wide operating bands, with the lower band covering GSM operation and the upper band covering DSC/PCS (Personal Communication System, 1850–1990 MHz)/UMTS (Universal Mobile Telecommunication System, 1920∼2170 MHz) operation. In addition, it was observed that, with the proposed slot antenna, there are small excited surface currents in the system ground plane of the mobile phone, and the antenna's two operating bands are generally not sensitive to the ground-plane length variations. This behavior is quite different from those of the conventional internal mobile phone antennas such as the PIFA, shorted patch antennas, and very-low-profile monopole antennas [3], in which large surface currents in the system ground plane are usually excited, thus making the system ground plane have a large effect on the achievable bandwidth of the conventional internal mobile phone antenna [4, 5]. Detailed design considerations of the proposed slot antenna are described in the article. The proposed antenna was also fabricated and tested. Results of the fabricated prototype are presented and discussed.

2. DESIGN CONSIDERATIONS OF THE PROPOSED ANTENNA

Figure 1(a) shows the geometry of the proposed folded slot antenna printed on the system circuit board of the mobile phone, and the side view of the geometry is shown in Figure 1(b). Notice that the system circuit board used here is a 0.8-mm thick FR4 substrate of relative permittivity (ε_r) 4.4, and its conductivity (σ) is 0.0055 S/m at 900 MHz and 0.0107 S/m at 2000 MHz. The studied mobile phone is also enclosed by a 1-mm thick plastic housing of relative permittivity 3.5, and its conductivity is 0.01 S/m at 900 MHz and 0.02 S/m at 2000 MHz. Note that the width of the plastic housing is 10 mm here, which is an attractive width for thin mobile phones, and the printed slot antenna is at the center of the plastic housing; that is, the antenna faces the two opposite inner surfaces of the plastic housing with the same distance of 4 mm.

Figure 1(c) shows the detailed dimensions of the printed slot antenna. The antenna is centered at the top portion (area 21 ′ 45 mm^2) of the system circuit board and folded into a compact structure with its two slot ends facing toward each other. The printed slot has a length of 106 mm and a uniform width of 2.5 mm (w). A 50 Ω microstrip feedline with a tuning-stub length 9 mm (t) is printed and centered on the other side of the system circuit board to feed the proposed slot antenna. With this feed arrangement, the first two resonant modes (the half- and one-wavelength modes) of the printed slot antenna can be excited, and good impedance matching of the two excited resonant modes can be achieved by adjusting the tuning-stub length t and the slot width w. Detailed effects of t and w will be explored with the aid of Figure 5 in the next section.

The slot length can be fine-adjusted by the end-portion slot length a and the feed-portion slot length b shown in the figure. The end portion of the printed slot is defined here as the slot portion from the centerline of the system circuit board to the open end away from the microstrip feedline, while the feed portion of the printed slot is the slot portion from the microstrip feedline to the open end near it. The preferred lengths of a and b in this study are 27 and 24 mm, respectively. Since it can be expected that the excited field distribution in the feed portion of the printed slot is stronger than that in the end portion, the variation in the length b will be more effective in adjusting the antenna's resonant frequencies. Detailed effects of the lengths a and b on the antenna performances will be analyzed with the aid of Figure 6. Also note that, owing to the presence of the FR4 substrate, which can result in decreased resonant frequency of the printed slot antenna, the total length of the printed slot in this study requires only 106 mm (about 0.32 wavelength at 900 MHz) to generate a half-

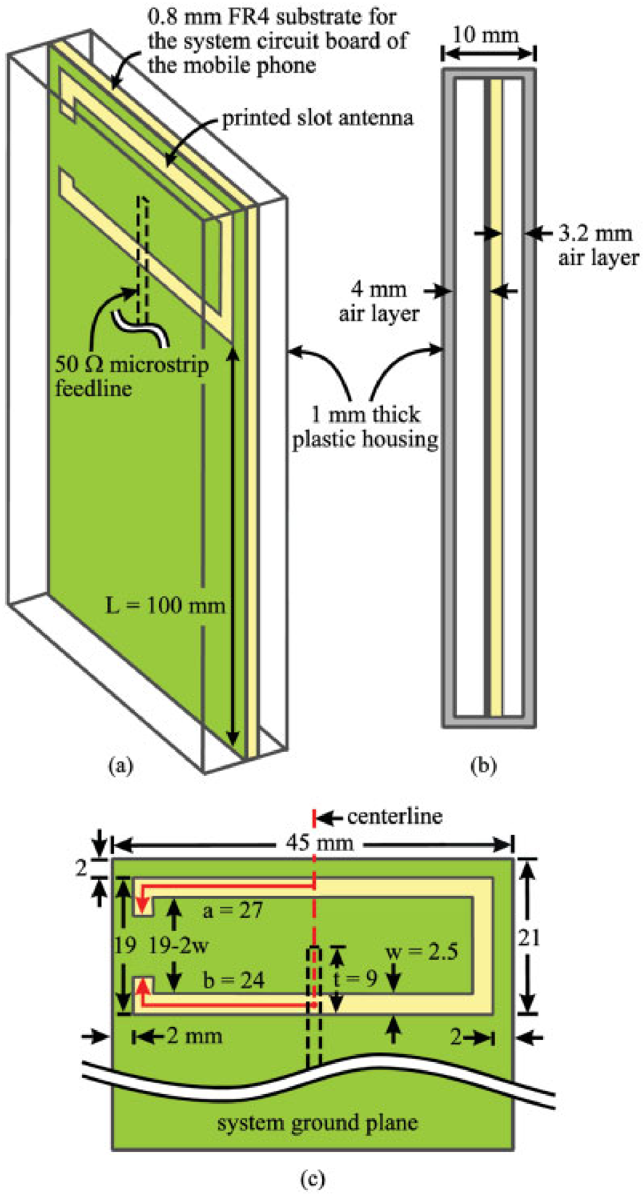

Figure 1 (a) Geometry of the proposed folded slot antenna printed on the system circuit board of the mobile phone; (b) Side view of the studied mobile phone with a plastic housing; (c) Detailed dimensions of the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

wavelength resonant mode at about 900 MHz for GSM operation. Further, the proposed antenna can generate a second resonant mode (the one-wavelength mode) with a wide bandwidth to cover the DCS/PCS/UMTS operation.

The conducting portion with length *L* below the printed slot in the system circuit board is considered as the system ground plane of the mobile phone. The ground-plane length *L* is first selected to be 100 mm in the study. However, results have indicated that the impedance matching of the antenna's lower and upper bands is not sensitive to the possible variations in the length *L.* Detailed effects of the antenna's impedance matching as a function of ground-plane length *L* will be discussed with the aid of Figure 4.

3. RESULTS AND DISCUSSION

The proposed printed slot antenna with the design dimensions shown in Figure 1 was fabricated and tested. Figure 2 shows the

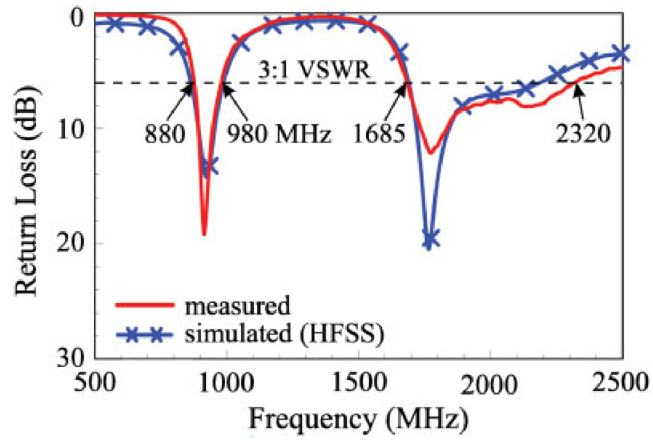

Figure 2 Measured and simulated (HFSS) return loss for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

measured and simulated return loss of the fabricated prototype. The simulated results are obtained using Ansoft simulation software HFSS (High Frequency structure Simulator) [6], and good agreement between the simulation and measurement is observed.

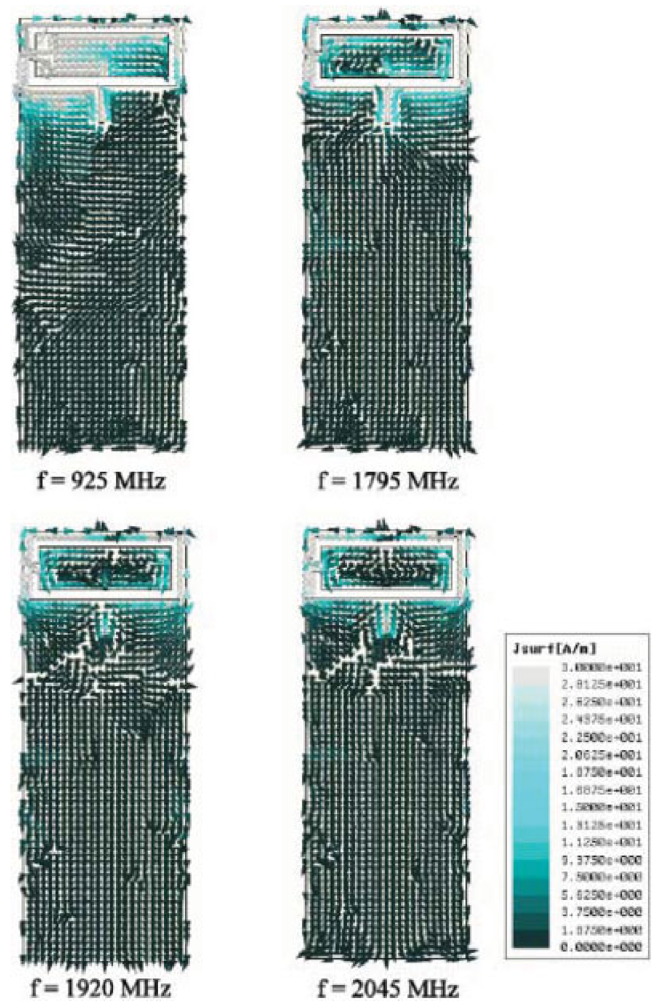

Figure 3 Simulated (HFSS) excited surface currents at 925, 1795, 1920, and 2045 MHz in the system ground plane of the mobile phone studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

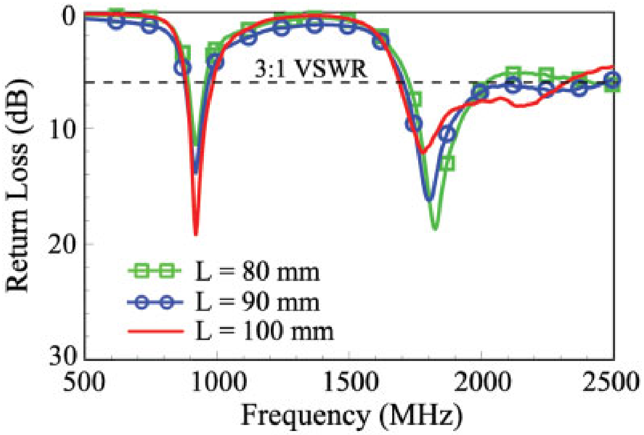

Figure 4 Measured return loss as a function of ground-plane length *L*. Other dimensions are the same as studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

From the obtained results, two wide bands with good impedance matching are successfully excited. The lower band has a 3:1 VSWR bandwidth of 100 MHz (880–980 MHz), easily covering the GSM operation. On the other hand, the upper band shows a much larger bandwidth of 635 MHz (1685–2329 MHz) or about 31% centered at about 2 GHz. This wide bandwidth allows the antenna to easily cover the DCS/PCS/UMTS band. Also note that the bandwidth definition of 3:1 VSWR (6 dB return loss) is widely accepted for practical applications for the general mobile phone antennas.

Figure 3 shows the simulated excited surface currents at 925, 1795, 1920, and 2045 MHz, center frequencies of the GSM, DCS, PCS, and UMTS bands, in the system ground plane of the mobile phone studied in Figure 2. It can be seen that, except for the portion at or near the printed slot antenna, the surface current distributions in the system ground plane are small and about the same for the four frequencies. This characteristic indicates that the system ground plane in the proposed design is not an efficient radiator as in the case with the conventional mobile phone antenna, and thus the antenna performances will not be strongly affected by the variations in the ground-plane length. To analyze it in more detail, measured results of the return loss for the ground-plane length varied from 100 to 80 mm are presented in Figure 4. For the lower band at 900 MHz, the obtained bandwidths are all about the same. On the other hand, the impedance matching for frequencies over the upper band is slightly varied; however, the impedance

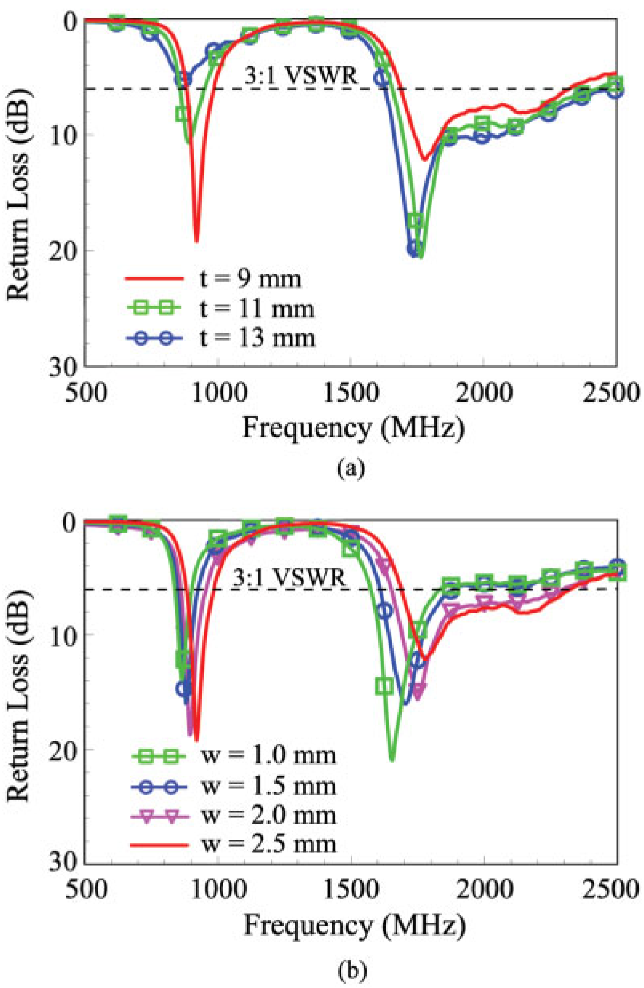

Figure 5 Measured return loss (a) as a function of tuning-stub length *t* and (b) as a function of slot width *w*. Other dimensions are the same as studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

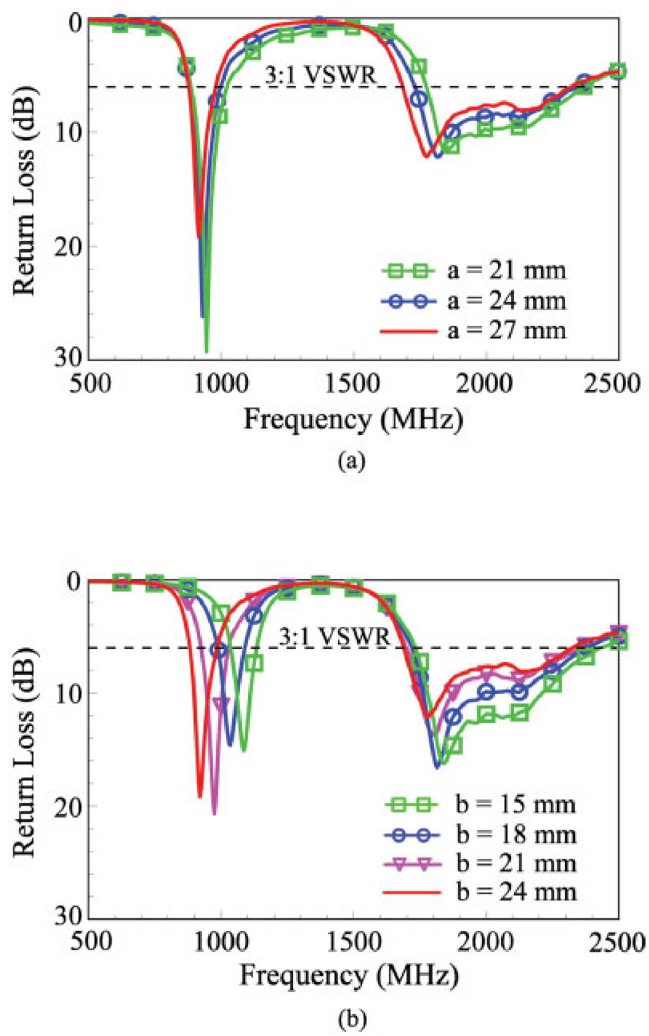

Figure 6 Measured return loss (a) as a function of end-portion slot length *a* and (b) as a function of feed-portion slot length *b*. Other dimensions are the same as studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

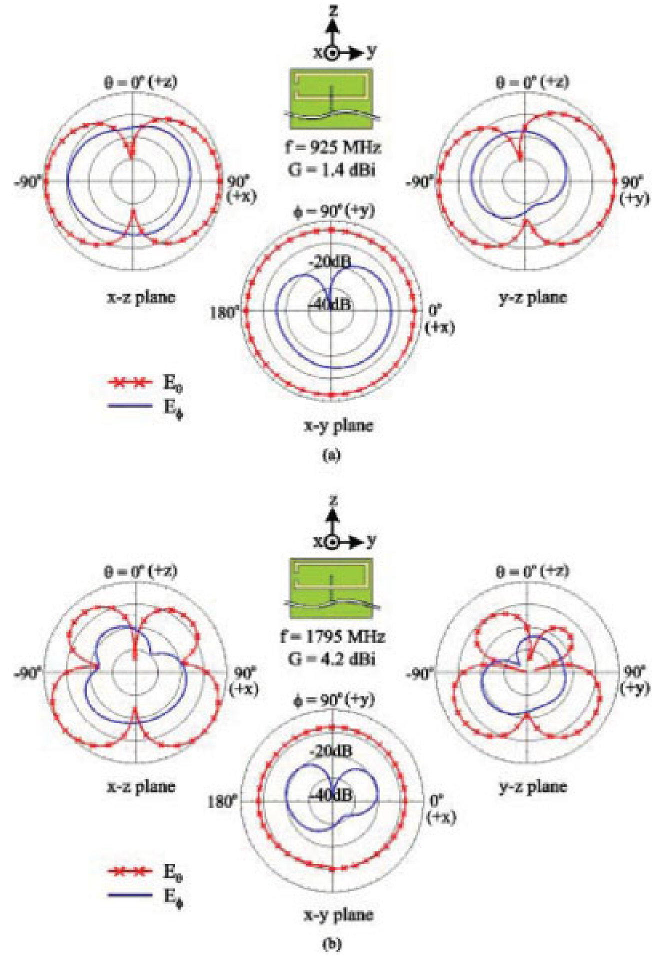

Figure 7 Measured radiation patterns for the antenna studied in Figure 2: (a) 925 MHz; (b) 1795 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

matching over the upper band is still better than about 5 dB, which is still acceptable for most practical applications for internal mobile phone antennas.

Effects of the tuning-stub length t and slot width w on the impedance matching of the proposed printed slot antenna are studied in Figure 5. In Figure 5(a), measured results of the return loss for the length t varied from 9 to 11 mm are shown; other dimensions are the same as studied in Figure 2. It is seen that a proper length t can lead to good impedance matching for frequencies over the lower and upper bands. In this study, the preferred length of t is selected to be 9 mm. Note that, when the tuning-stub length is increased (for example, $t = 11$ or 13 mm shown in the figure), the impedance matching over the lower band is quickly degraded, although the obtained bandwidth for the upper band is increased. Figure 5(b) presents the measured return loss for the slot width w varied from 1.0 to 2.5 mm. Results show that the impedance bandwidth of the lower and upper bands can generally be enhanced when a larger slot width is selected. The center frequencies of the lower and upper bands are also shifted to higher frequencies with an increase in the slot width. From the results, to cover the desired GSM/DCS/PCS/UMTS bands, the preferred slot width is selected to be 2.5 mm in this study.

Effects of the end-portion and feed-portion slot lengths a and b on the antenna performances are studied in Figure 6. Results of the measured return loss for the end-portion slot length a varied from 21 to 27 mm are presented in Figure 6(a), while the results for the feed-portion slot length b varied from 15 to 24 mm are shown in Figure 6(b). It is first noted that the effect of the end-portion slot length a is relatively small, as compared to that of the feed-portion slot length b. This behavior is reasonable, because the excited field distribution in the feed portion of the printed slot is expected to be stronger than that in the end portion of the printed slot. Hence, it will be more effective to select a larger feed-portion slot length a to achieve a larger effective length of the proposed printed slot antenna. In this case, the antenna's fundamental mode (the half-wavelength mode) can be shifted to lower frequencies. This behavior is seen in Figure 6(b), in which the antenna's lower band is shifted to lower frequencies at about 900 MHz to cover the GSM band by increasing the feed-portion slot length b to be 24 mm in the study.

Radiation characteristics of the proposed printed slot antenna are also studied. Figure 7 plots the measured radiation patterns at 925 and 1795 MHz, while those at 1920 and 2045 MHz are shown in Figure 8. Note that the radiation patterns in three principal planes at each frequency are normalized with respect to the antenna's peak gain, which is 1.4, 4.2, 3.5, and 3.4 dBi for 925, 1795, 1920, and 2045 MHz, respectively. Monopole-like radiation patterns at 925 MHz are first observed, which is similar to those of the conventional internal mobile phone antennas operated in the GSM band [3]. It is also observed that the radiation patterns at 1795, 1920, and 2045 MHz are similar to each other. That is, stable radiation characteristics for frequencies over the antenna's upper

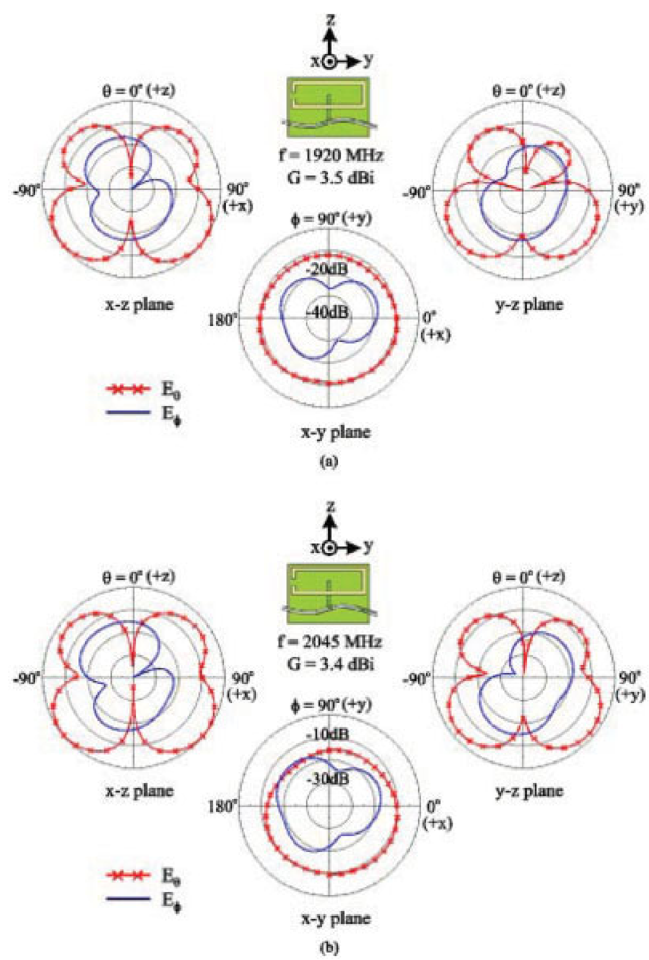

Figure 8 Measured radiation patterns for the antenna studied in Figure 2: (a) 1920 MHz; (b) 2045 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

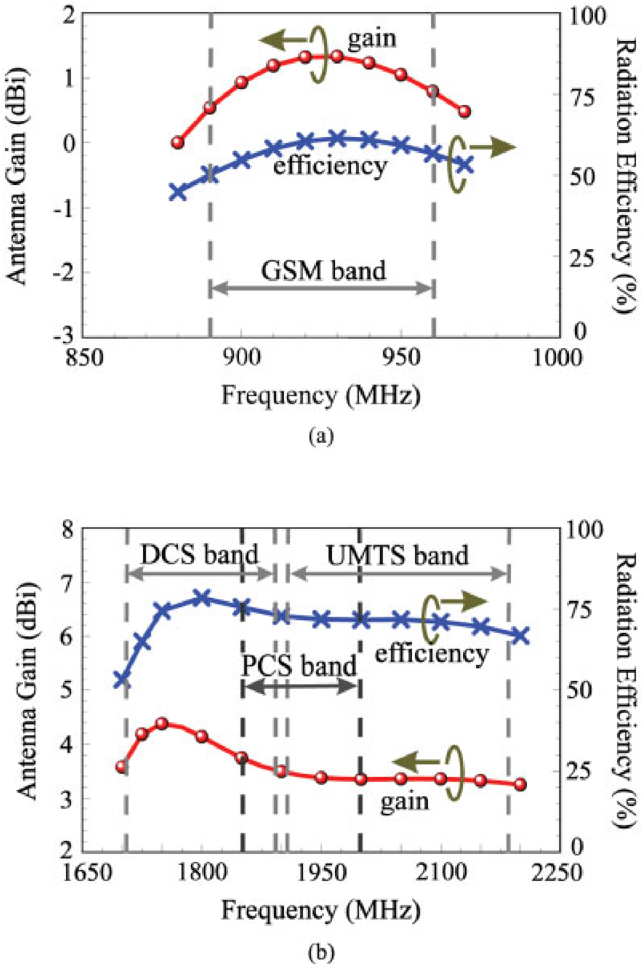

Figure 9 Measured antenna gain and simulated (HFSS) radiation efficiency for the antenna studied in Figure 2: (a) The lower band; (b) The upper band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

band are obtained. This characteristic can also be expected from the excited surface current distributions shown in Figure 3, in which one can observe that the surface current distributions at or near the printed slot antenna are all about the same for the frequencies at 1795, 1920, and 2045 MHz. Also, the measured radiation patterns over the antenna's upper band are similar to those of the conventional internal mobile phone antennas operated in the DCS band [3]. Figure 9 presents the measured antenna gain and simulated radiation efficiency over the lower and upper bands of the antenna. From the results shown in Figure 9(a), over the GSM band, the antenna gain is seen to vary from about 0.6 to 1.4 dBi, while the radiation efficiency is varied from about 52 to 64%. Over the DCS band [see the results in Fig. 9(b)], the antenna gain is seen to vary from about 3.7 to 4.4 dBi, and the radiation efficiency is varied from about 53 to 78%. Over the PCS and UMTS bands, the antenna gain is about 3.5 and 3.4 dBi, and the radiation efficiency is generally better than about 70%.

4. CONCLUSION

A novel multiband printed folded slot antenna for mobile phone applications has been proposed, fabricated, and tested. The proposed folded slot antenna can be easily fabricated by printing on the system circuit board of the mobile phone. With a small area of 21 ′ 45 mm^2 occupied, the folded slot antenna can provide two wide bands at about 900 and 2000 MHz to cover the GSM/DCS/PCS/UMTS operations. Improved impedance matching over the antenna's two wide bands can be obtained by selecting proper tuning-stub length and slot width. On the other hand, the antenna's two operating bands can be effectively controlled by adjusting the feed-portion and end-portion slot lengths of the antenna. Furthermore, by employing the proposed slot antenna, small excited surface currents in the system ground plane of the mobile phone have been observed. This behavior makes the antenna's two operating modes not sensitive to the variations in the ground-plane length of the mobile phone, which is attractive for practical applications.

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A NOVEL FOUR-STAGES DOUBLE-LAYERED DIELECTRIC WAVEGUIDE BANDPASS FILTER IN LTCC

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ABSTRACT: *This study presents a novel four-stage double-layered waveguide bandpass filter and its simulation method. The longitudinal size of the waveguide filters is reduced by 50% due to the application of double-layered structure. The four-stage double-layered bandpass filter with a 8.8 mm length, 6.2 mm width, and 1.6 mm height is manufactured by LTCC. It has a center frequency of 5.21 GHz, bandwidth of 300 MHz, pass-band ripple of 0.1 dB, and insertion loss of 0.8 dB, which shows miniaturization, low insertion losses and meets the demand of next generation of WLAN system.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1837–1840, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22587

Key words: *waveguide filter; FEM; double-layered*

1. INTRODUCTION

Recently, There is a tremendous request for the development of wireless communication systems for local access networks (WLAN) including personal digital assistant (PDA), portable PCs,