terns, including the co-polarization and cross-polarization in the elevation direction ($x - z$ and $y - z$ planes) and azimuthal direction ($x - y$ plane) at 4 and 7 GHz. It is observed that the proposed antenna has monopole-like patterns in elevation and nearly omnidirectional radiation patterns in the azimuth. Figure 6 plots the measured gains for frequencies from 3.5 GHz to 7 GHz of the proposed antenna. The curve is shown to be flat, except in the 5-GHz WLAN band. Thanks to the low signal level and complex environments for the measurement of the proposed antenna, some measured patterns look rough in spots.

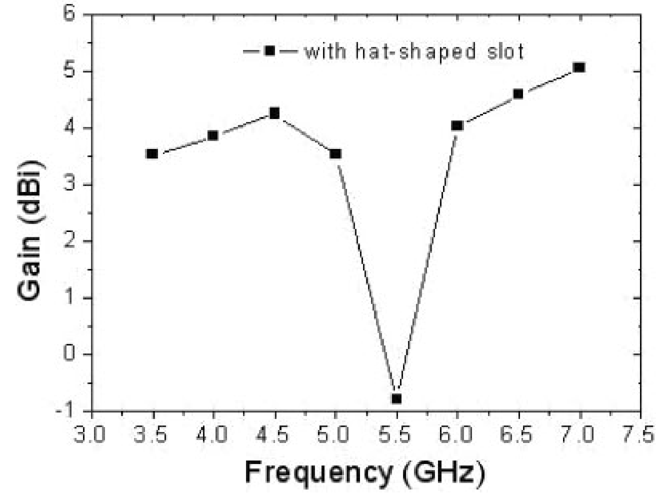

Figure 6 Measured gains vs. frequency of the proposed antenna

4. CONCLUSION

A small, lightweight, and low-cost swallow-tailed planar monopole antenna that exhibits a notch characteristic in the 5-GHz WLAN band is proposed. The band-notching is easily achieved by embedding a simple hat-shaped slot in the antenna. The proposed monopole is fabricated and exhibits ultra-wideband performance in the frequency band of 2.5 to 13 GHz for VSWR <2 with rejection band of 4.7 to 5.9 GHz. Besides, acceptable radiation patterns and gain flatness are observed.

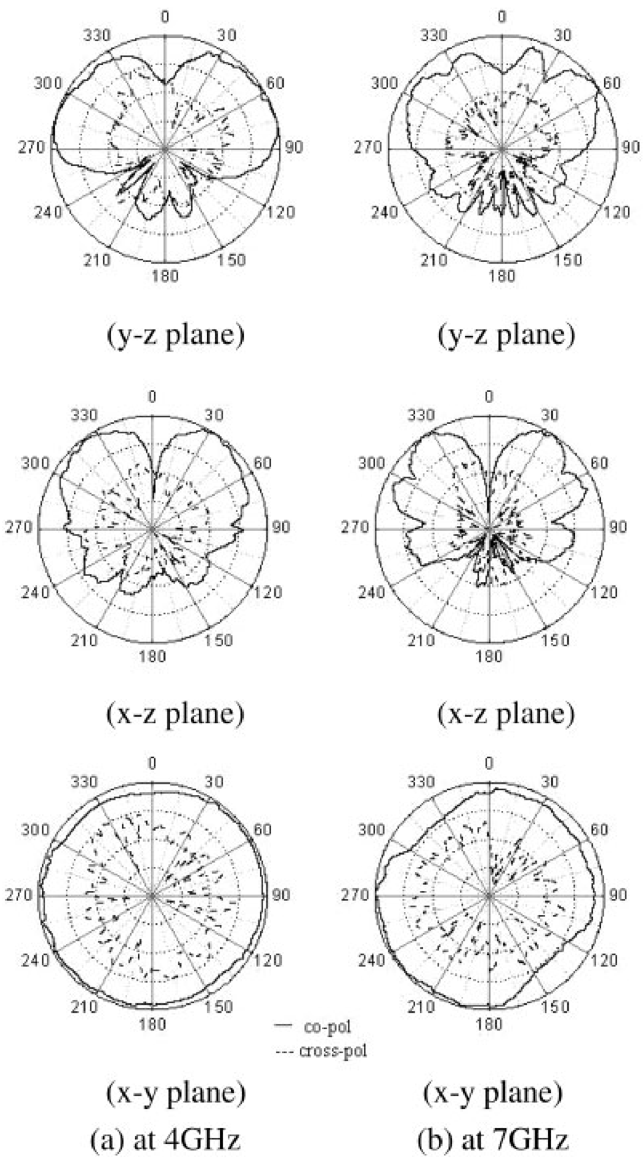

Figure 5 Measured radiation patterns of proposed antenna (10 dB/div). (a) at 4GHz; (b) at 7GHz

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INTERNAL HYBRID LOOP/MONOPOLE SLOT ANTENNA FOR QUAD-BAND OPERATION IN THE MOBILE PHONE

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Received 28 July 2007

ABSTRACT: *A novel printed hybrid loop/monopole slot antenna for quad-band operation in the mobile phone is presented. The proposed hybrid antenna is composed of a meandered loop antenna and a monopole slot antenna, and can generate two wide operating bands centered at about 900 and 1900 MHz to cover GSM850/900/DCS/PCS operation. The hybrid antenna is easily fabricated by bending the meandered loop antenna at low cost, which is connected to and centered at the top edge of the system ground plane where a straight monopole slot is embedded. With quad-band operation obtained, the hybrid antenna, however, occupies a small volume of $5.5 \times 6 \times 60$ mm^3 or 1.98 cm^3 only inside the mobile phone. A 50-Ω microstrip feedline is used to excite the meandered loop antenna and the monopole slot antenna in series. Detailed results and para-*

metric studies of the proposed hybrid antenna are presented. Microwave Opt Technol Lett 50: 795–801, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23201

Key words: *mobile phone antenna; hybrid antenna; loop antenna; monopole slot antenna; quad-band operation*

1. INTRODUCTION

Recently, internal multiband loop antennas suitable for application in practical mobile phones or PDA (personal digital assistant) phones have been reported in the open literature [1–5]. This kind of internal loop antennas shows an attractive feature of exciting smaller excited surface currents on the system ground plane of the mobile phone compared with the conventional internal mobile phone antennas, such as the PIFA (Planar inverted-F antenna), shorted patch antennas, and very-low-profile monopole antennas [6]. This feature can result in more stable antenna performances for the mobile phone with various possible groundplane lengths, reduction of the user's hand and head effects, and so on, making the internal loop antenna a very promising structure for mobile phone application. However, to achieve a compact occupied volume (preferably less than about 2 cm^3) of the internal multiband loop antenna inside the mobile phone is still a challenging problem.

Another promising antenna structure that can excite smaller surface currents on the system ground plane of the mobile phone is the slot antenna or monopole slot (open-end slot) antenna [7–12], which is easily printed on and integrated with the system circuit board of the mobile phone. For the mobile phone application reported in [10], however, the printed monopole slot is required to be located at the center of the ground plane to allow for maximum coupling to the low-Q chassis dipole type resonance obtained. In this condition, sufficient bandwidth and efficiency to cover multiband operation for the mobile phone can be obtained. However, it will also complicate the circuit floor planning and signal line routing, compared with the conventional internal mobile phone antennas that are usually located at the top or bottom edge of the system circuit board [6].

In this study, we propose an internal hybrid mobile phone antenna comprising the above two promising antenna structures to achieve a compact occupied volume inside the mobile phone and obtain quad-band operation covering GSM850 (824–896 MHz), GSM900 (880–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) bands. The hybrid antenna consists of a meandered loop antenna and a monopole slot antenna, which are to be placed at the top portion of the system circuit board and fed in series by using a 50-Ω microstrip feedline. The hybrid antenna occupies a small volume of <2 cm^3, yet it can generate two wide operating bands centered at about 900 and 1900 MHz to cover GSM850/900 and DCS/PCS operation, respectively. The lower band is formed by the 0.25-wavelength mode of the monopole slot antenna and the 0.5-wavelength mode of the meandered loop antenna. For the upper band, it is formed by the 1.0- and 1.5-wavelength modes of the meandered loop antenna. Details of the design considerations and antenna performances of the proposed hybrid antenna are presented. Parametric studies on the impedance characteristics of the antenna are also conducted.

2. DESIGN CONSIDERATIONS OF PROPOSED ANTENNA

Figure 1(a) demonstrates the geometry of the proposed hybrid antenna printed on the top portion of the system circuit board, and detailed dimensions of the antenna unbent into a planar structure are shown in Figure 1(b). The hybrid antenna consists of a meandered loop antenna and a straight monopole slot antenna, both

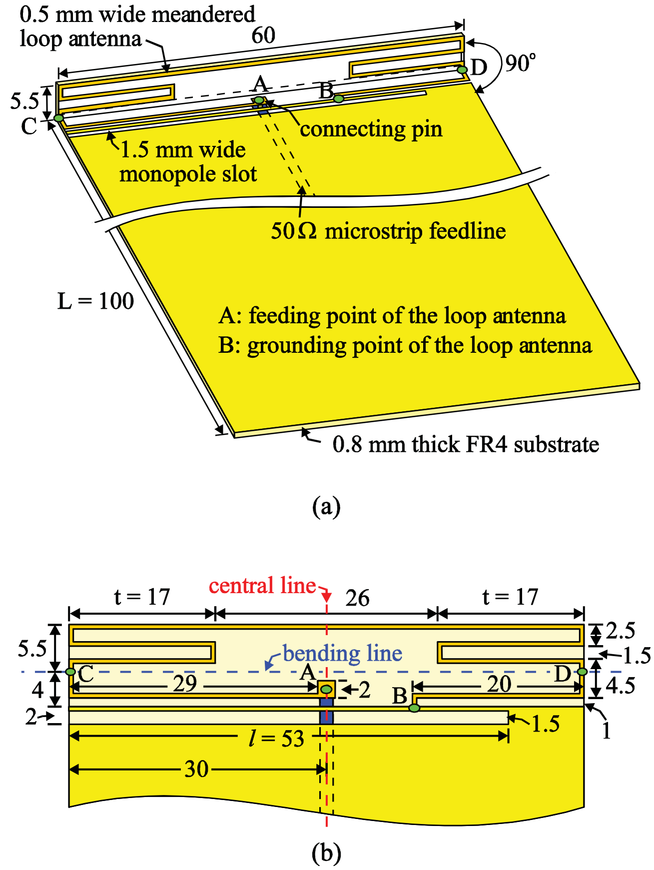


Figure 1 (a) Geometry of the proposed hybrid antenna for quad-band operation in the mobile phone. (b) Detailed dimensions of the antenna unbent into a planar structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

printed on the top portion of the system circuit board. In the study, a 0.8-mm thick FR4 substrate of length 100 mm (L) and width 60 mm considered as the system circuit board is used. The FR4 substrate has a relative permittivity of 4.4, and its conductivity is 0.0054 S/m at 900 MHz and 0.012 S/m at 1900 MHz.

The meandered loop antenna is formed by a 0.5-mm wide loop strip with its two side sections meandered to achieve a longer path on the fixed surface of the circuit board. The loop antenna is centered at the top no-ground portion of the circuit board and has a length of about 190 mm (from point A to point B shown in the figure), which is close to one wavelength at 1800 MHz. Point A (the feeding point of the loop antenna) is located at the central line of the circuit board and connects the loop strip to the 50-Ω microstrip feedline printed on the back side of the circuit board. Point B (the grounding point of the loop antenna) grounds the loop strip to the top edge of the ground plane printed on the circuit board. By adjusting the length t of the two meandered sections, the excitation of the 0.5-, 1.0-, and 1.5-wavelength modes of the loop antenna can be adjusted. The 0.5-wavelength mode can be excited at about 1000 MHz, while the 1.0- and 1.5-wavlength modes can be excited at about 1900 MHz. The former one can cover GSM900 operation, and the latter two modes can cover DCS/PCS operation. Detailed effects of the length t on the antenna performances are shown in Figure 4(a), and will be discussed in the next section. Also notice that the loop antenna is bent into an L shape [see the bending line [GRAPHIC] shown in Figure 1(b)] to achieve a smaller protruded length (4 mm here) from the top edge of the ground

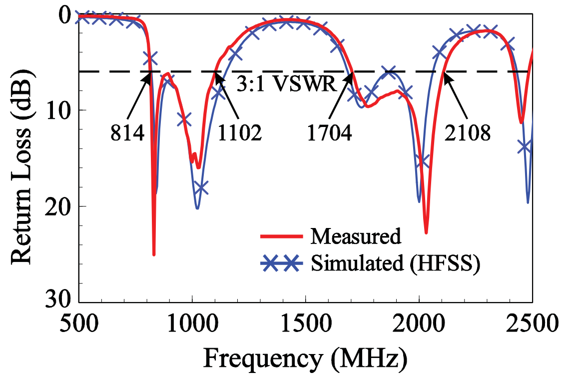


Figure 2 Measured and simulated return loss for the proposed hybrid antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

plane. The bending can also lead to a smaller occupied antenna volume inside the mobile phone.

The monopole slot is of a simple straight shape of width 1.5 mm and length (l) 53 mm. The monopole slot has a small spacing of 0.5 mm to the top edge of the ground plane and is to be excited through capacitive coupling to the 50-Ω microstrip feedline. As seen in the figure, the monopole slot antenna and the loop antenna are excited in series by the 50-Ω microstrip feedline, and the two antennas together occupy a compact volume of $5.5 \times 6 \times 60$ mm^3 (1.98 cm^2) only. The monopole slot antenna can generate a 0.25-wavelength mode at about 850 MHz to cover GSM850 MHz. With the 0.25-wavelength mode of the monopole slot antenna and the 0.5-wavelength mode of the loop antenna, which form the antenna's lower band, the antenna can easily cover GSM850 and GSM900 operation. The 0.25-wavelength mode of the monopole slot antenna can be effectively controlled by the slot length l, whose detailed effects are presented in Figure 4(b) and will be discussed in the next section.

With the compact integration of the meandered loop antenna and the monopole slot antenna, the proposed hybrid antenna yet can generate four resonant modes to provide two wide operating bands centered at about 900 and 1900 MHz for GSM850/900/DCS/PCS operation. In addition, small groundplane effects on the performances of the hybrid antenna are expected as discussed in

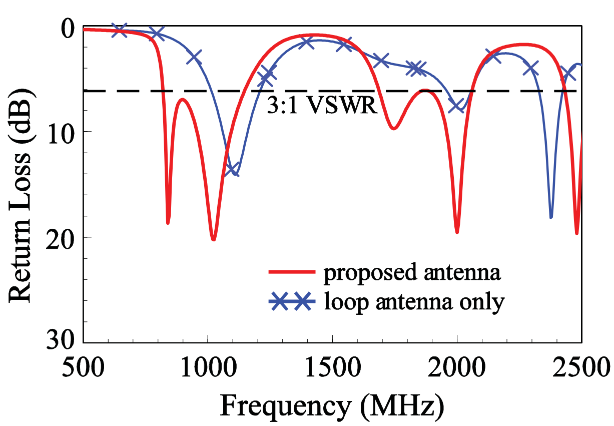


Figure 3 Comparison of the simulated return loss for the proposed hybrid antenna and the case with the loop antenna only; corresponding dimensions are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

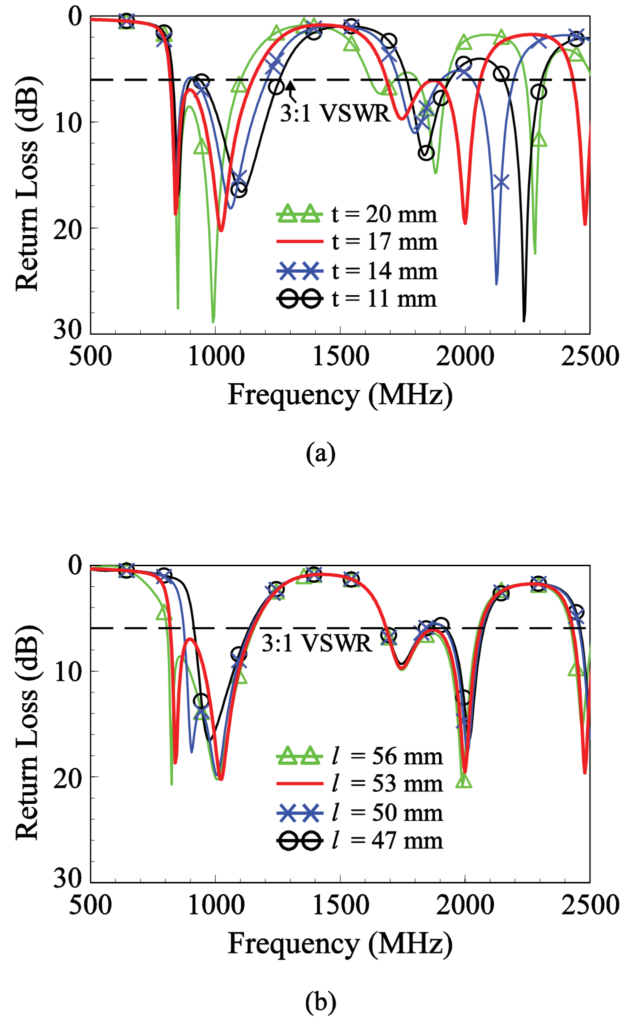


Figure 4 Simulated return loss as a function of (a) the meandered-section length t of the loop antenna and (b) the length l of the monopole slot antenna; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

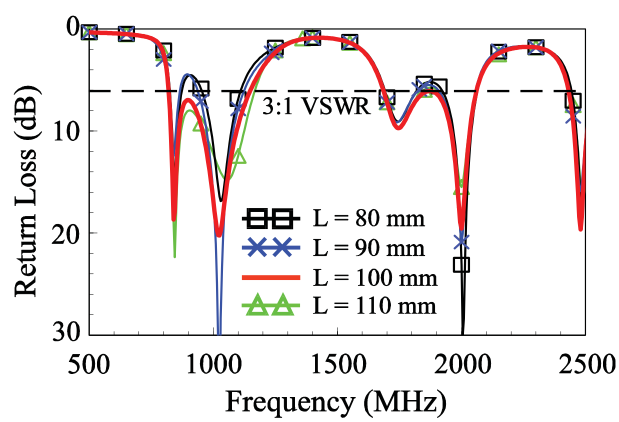


Figure 5 Simulated return loss as a function of the groundplane length L. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

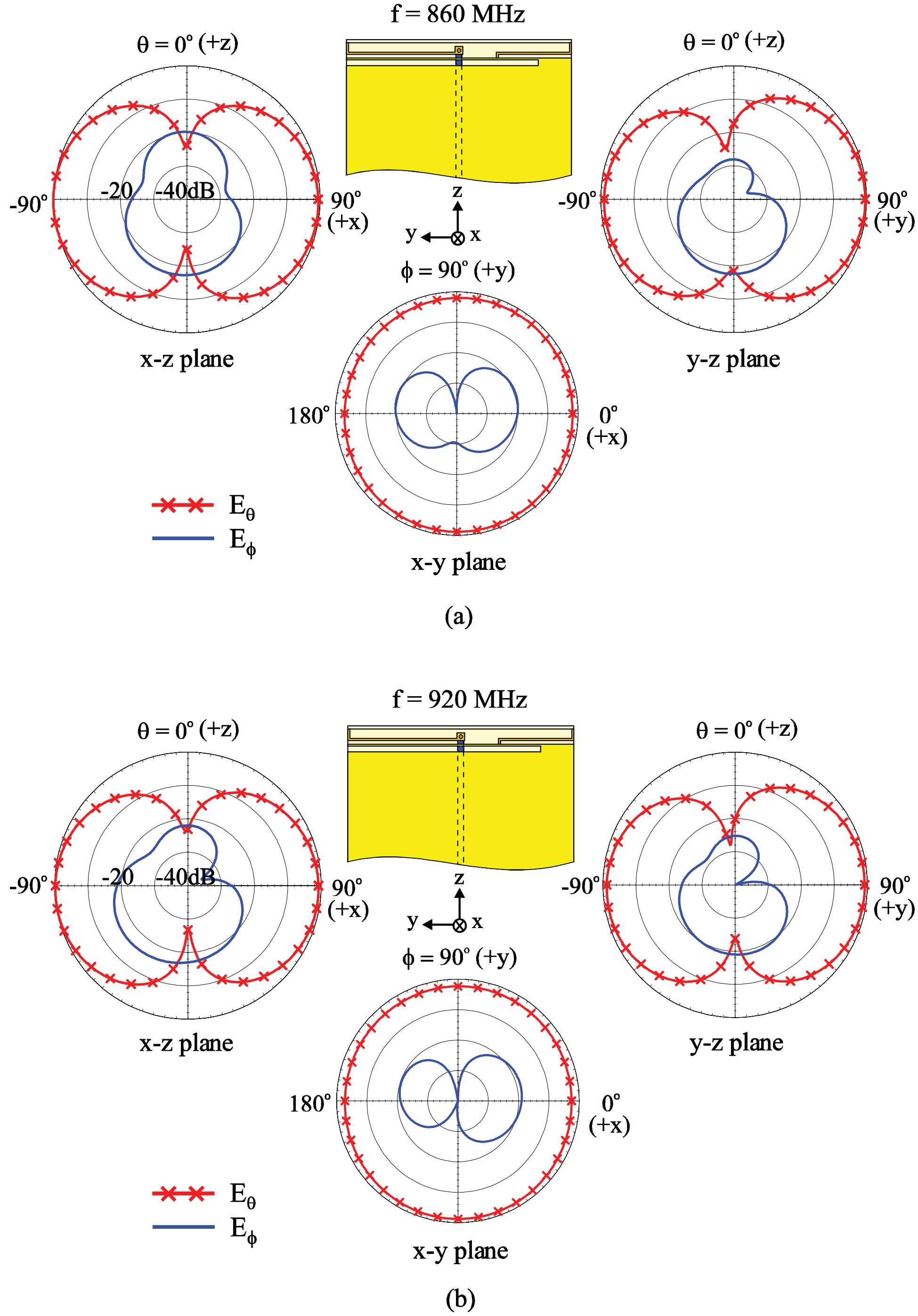


Figure 6 Measured radiation patterns for the proposed antenna at 860 and 920 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Section 1. Results of the hybrid antenna with various possible groundplane lengths are shown in Figure 5 and will be discussed in the next section.

3. RESULTS AND DISCUSSION

Figure 2 shows the measured and simulated return loss of the proposed hybrid antenna. The measured impedance bandwidth, defined by 3:1 VSWR (6-dB return loss), reaches 288 MHz (814–1102 MHz) for GSM850/900 operation and 404 MHz (1704–2108 MHz) for DCS/PCS operation. The simulated results are obtained from Ansoft HFSS (high frequency structure simulator) [13], and good agreement between the measurement and simulation are observed. This ensures the accuracy of the obtained simulated results in analyzing the antenna performances using the simulation software.

A comparison of the simulated return loss for the proposed antenna and the case with the loop antenna only is shown in Figure 3. For the loop antenna only, the second, third, and fourth resonant modes of the proposed antenna are generated, which are the 0.5-, 1.0-, and 1.5-wavelength modes of the loop antenna. With the inclusion of the monopole slot antenna, the first resonant mode of the proposed antenna is excited at about 850 MHz, which is the

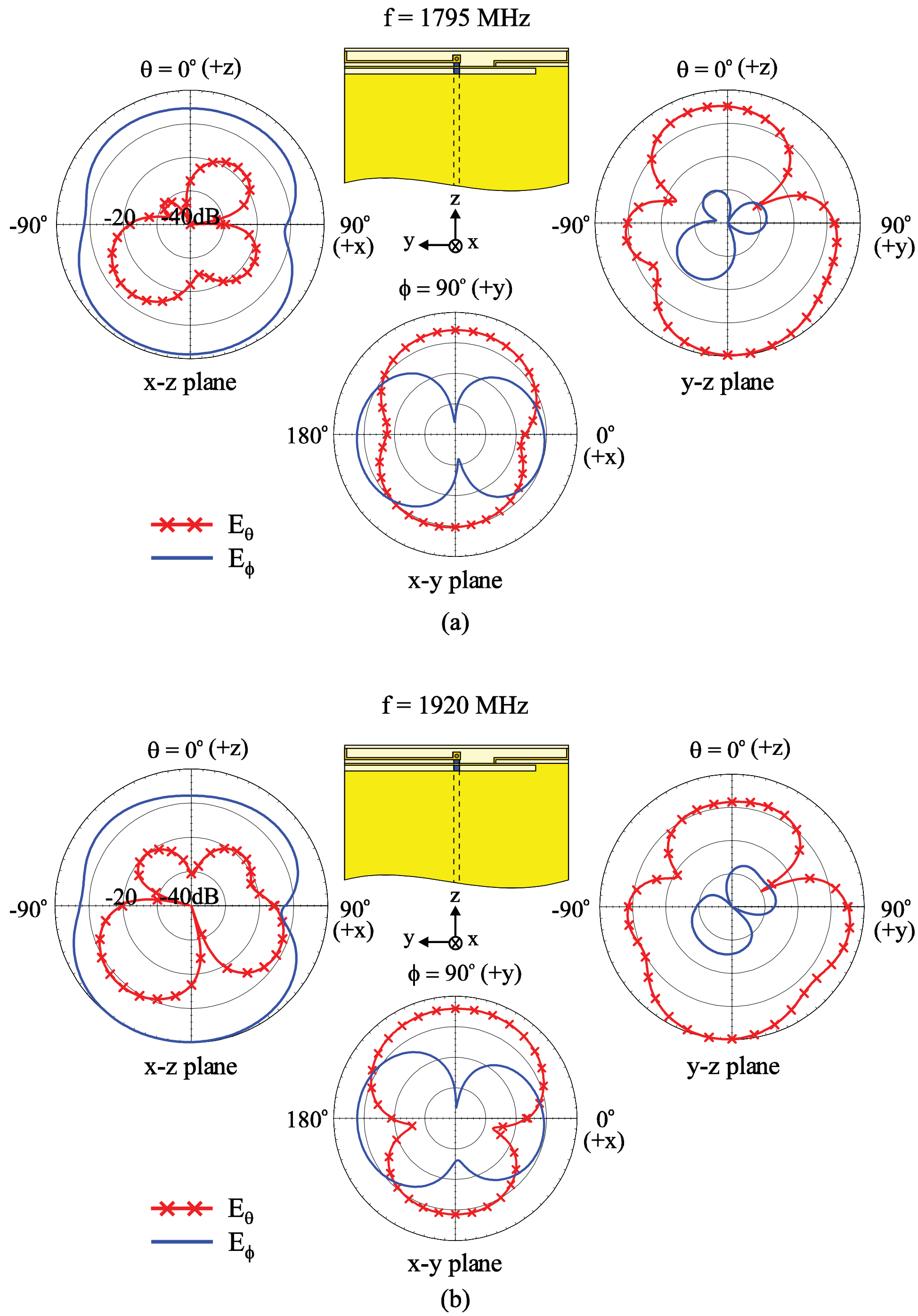
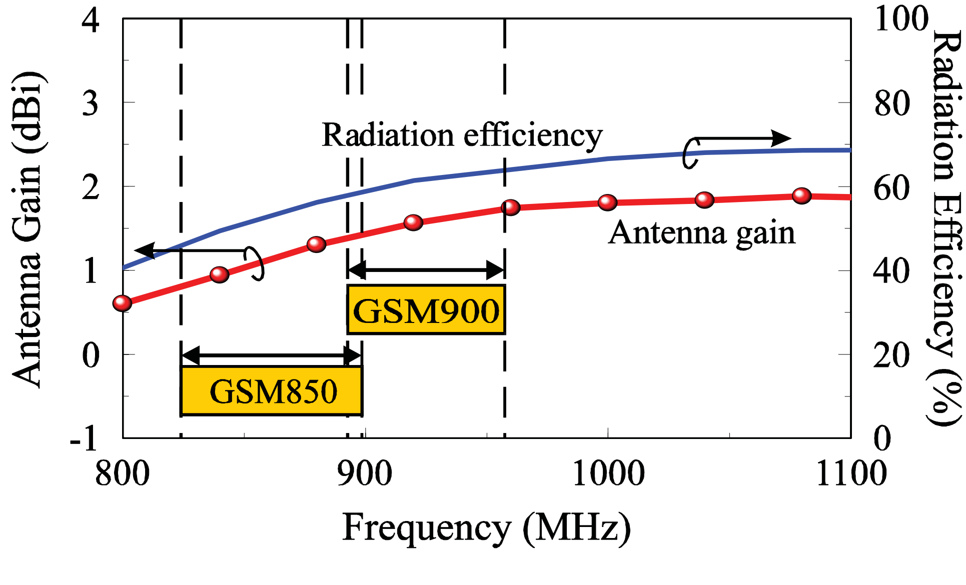


Figure 7 Measured radiation patterns for the proposed antenna at 1795 and 1920 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

0.25-wavelength mode of the monopole slot antenna. It can be seen that the 0.25-wavelength mode of the monopole slot antenna and the 0.5-wavelength mode of the loop antenna are formed into a wide lower band for the antenna, which covers GSM850/900 operation. Moreover, the presence of the monopole slot antenna improves the impedance matching of the 1.0- and 1.5-wavelength modes of the loop antenna to form a wide upper band for DCS/PCS operation.

Figures 4–6 show parametric studies of the meandered-section length t of the loop antenna, the length l of the monopole slot antenna, and the length L of the ground plane on the return loss of the proposed antenna. Effects of the lengths t and l are presented in Figures 4(a) and 4(b), respectively. When the length t varied from 11 to 20 mm [see Fig. 4(a), l fixed as 53 mm], the resonant modes of the loop antenna are varied, and hence the obtained bandwidth for the upper band can be adjusted, while that of the first resonant mode at about 850 MHz is almost unchanged. This indicates that the second, third, and fourth resonant modes of the hybrid antenna can be effectively controlled by the meandered-section length t of the loop antenna. Effects of the length l varied from 47 to 56 mm, with the length t fixed as 17 mm, are shown in Figure 4(b). It is seen that the first resonant mode of the antenna is shifted to lower frequencies as the length l increases. The results obtained in Figures 4(a) and 4(b) suggest that the four excited



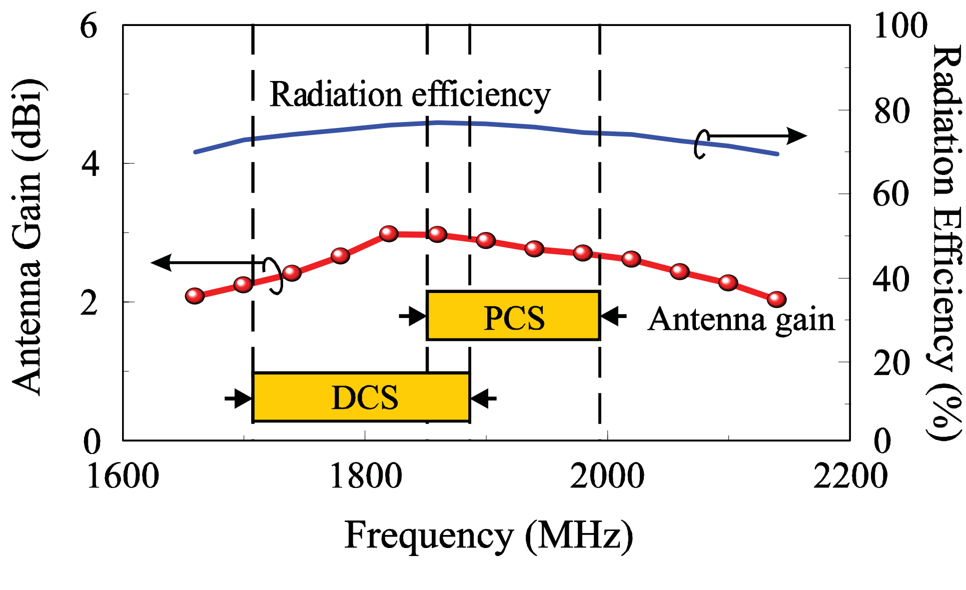


Figure 8 Measured antenna gain and simulated radiation efficiency for the proposed antenna. (a) GSM850/900 band. (b) DCS/PCS band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

resonant modes of the proposed hybrid antenna can be controlled by adjusting the length t of the two meandered sections of the loop antenna and the length l of the monopole slot antenna.

Effects of the groundplane length L are studied in Figure 5. When the length L is varied from 80 to 110 mm, with other antenna dimensions fixed, small effects on the obtained bandwidths of the lower and upper bands are observed. Even for $L = 80$ mm, the obtained bandwidths for the lower and upper bands of the antenna are larger than 4-dB return loss, which can be adjusted to be better than 6 dB with proper fine-tuning of the antenna dimensions. It can therefore be concluded that the excited resonant modes of the proposed hybrid antenna are generally not sensitive to the ground-plane length variations.

Radiation characteristics of the fabricated hybrid antenna are also measured. Figures 6(a) and 6(b) plots the measured radiation patterns at 860 and 920 MHz, the center frequencies of GSM850 and GSM900 bands. Monopole-like radiation patterns are observed, which are similar to those of the conventional internal mobile phone antennas for GSM operation [6], since the system ground plane of the mobile phone is an efficient radiator at about 900 MHz. Figures 7(a) and 7(b) presents the measured radiation patterns at 1795 and 1920 MHz, the center frequencies of DCS and PCS bands. Large variations on the radiation patterns are seen, and similar radiation patterns compared with those of the conventional internal mobile phone antennas for DCS operation [6] are observed. The measured antenna gain and simulated radiation efficiency are shown in Figure 8. Over the GSM850/900 band shown in Figure 8(a), the antenna gain varied from about 0.7–1.6 dBi is seen, and the radiation efficiency is all larger than 55%. For the DCS/PCS band [see the results in Fig. 8(b)], the antenna gain is varied from about 2.0–3.0 dBi, and the radiation efficiency is all larger than 70%.

4. CONCLUSION

A novel printed hybrid antenna consisting of a meandered loop antenna and a monopole slot antenna for GSM850/900/DCS/PCS operation in the mobile phone has been presented and successfully fabricated. The meandered loop antenna and the monopole slot antenna can be configured to occupy a compact volume at the top portion of the mobile phone and series-fed by a 50-Ω microstrip feedline. With a small volume of $5.5 \times 6 \times 60$ mm^3 only, which is <2 cm^3, the hybrid antenna can generate two wide operating bands at about 900 and 1900 MHz to cover GSM850/900/DCS/PCS quad-band operation. Good radiation characteristics of the hybrid antenna have also been observed. Moreover, with the incorporation of the meandered loop antenna and the monopole slot antenna, the proposed hybrid antenna are generally not sensitive to the groundplane length variations in the mobile phone, which is attractive for practical mobile phone applications.

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WIDEBAND MONOPOLE ANTENNA FOR DTV/GSM OPERATION IN THE MOBILE PHONE

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Received 2 August 2007

ABSTRACT: *A wideband monopole antenna comprising a narrow radiating strip of length 120 mm and a simple internal matching portion for mobile phone application is presented. The monopole antenna can generate a wide operating band to cover the DTV reception in the UHF frequency band (470–862 MHz) and mobile communication in the GSM850/900 bands (824–894 MHz/890–960 MHz). The radiating strip is also promising to be retracted to be concealed inside the casing of the mobile phone when not in use. Details of the proposed antenna are described in the study.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 801–806, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23194

Key words: *mobile phone antennas; wideband monopole antennas; DTV antennas; GSM operation*

1. INTRODUCTION

Digital television (DTV) reception [1] is very attractive for many mobile users. It has thus become a great demand that the mobile devices be equipped with the DTV function. For such DTV applications, various promising antenna designs suitable for mobile phones [2–4], universal series bus (USB) dongles [5], portable media players (PMPs) [6, 7], laptop computers [8, 9], and vehicles [10–14] have been reported. For mobile phone applications, the DTV antenna reported in Ref. 2 is especially suited for folder-type mobile phones, and the upper and lower ground planes of the folder-type mobile phone are used as the two radiating arms of the antenna. This antenna design is not suitable to be employed in the bar-type mobile phone. While in Ref. 3, an earpiece cord is designed as the antenna for DTV reception in the mobile phone. The antenna reported in Ref. 4 is an external monopole antenna having a wide bandwidth of 470–702 MHz for DTV reception in the bar-type mobile phone. Other designs in Refs. 5–14, however, are not suited for mobile phone applications.

In this study, we demonstrate a new and simple external monopole antenna for mobile phone applications. The antenna has a size comparable with that of the reported antenna in Ref. 4, and it is capable of generating a very wide band covering the European DVB-H band (470–862 MHz) [3, 15] or the 470–806 MHz band (channels 14–69 [16]) for DTV reception. In addition, the obtained wide band allows the antenna to further cover the mobile communication in the GSM850/900 bands (824–894 MHz/890–960 MHz). Design considerations of the proposed antenna are described in the study, and results of the constructed prototypes are presented and discussed.

2. DESIGN CONSIDERATIONS OF PROPOSED ANTENNA

Figure 1 shows the proposed wideband monopole antenna for DTV/GSM operation in the mobile phone. The antenna consists of an external narrow radiating strip of length 120 mm (S) and an internal matching portion. The width of the radiating strip is 2 mm only, which allows it very promising to be retracted to be con-