ciency 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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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-

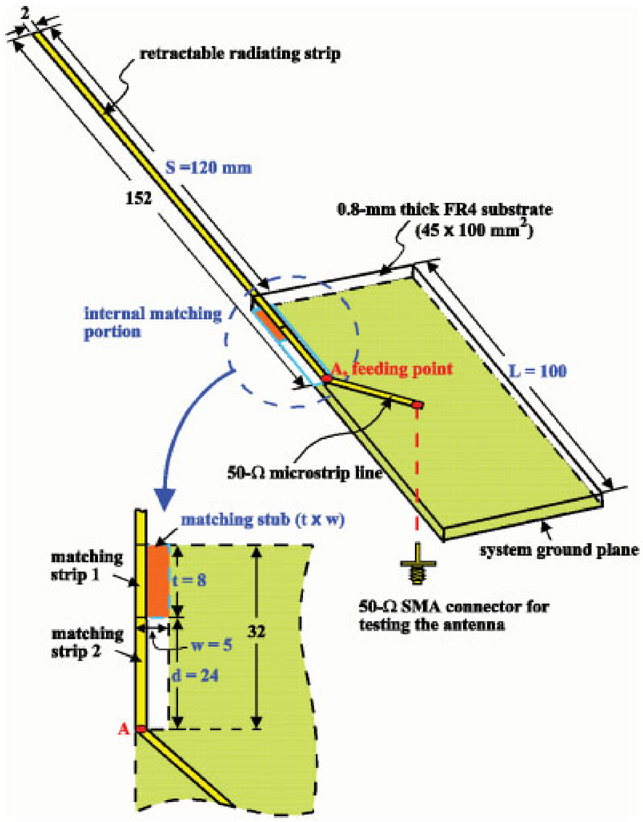

Figure 1 Geometry of the proposed wideband monopole antenna for DTV/GSM operation in the mobile phone. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

cealed inside the casing of the mobile phone when not in use. The length of the radiating strip is only about 0.19 wavelength of the frequency at 470 MHz, the lower edge frequency of the desired operating band to cover the DTV reception. This radiating strip is connected to the internal matching portion, which is designed to be integrated with the system circuit board of the mobile phone. In this study, a 0.8-mm thick FR4 substrate of width 45 mm and length (L) 100 mm is used as the system circuit board and, on its back surface, a ground plane is printed.

For the internal matching portion, it consists of two parts. The first part is formed by the matching stub of size 8 × 5 mm^2 (t × w) and the matching strip 1 of size 8 × 2 mm^2 as shown in the figure. In between the matching stub and the matching strip 1 is the 0.8-mm thick FR4 substrate. With this configuration, the first part can contribute some capacitance to the input impedance of the antenna. By adjusting the size of the matching stub, that is, its length t or width w is varied, the contributed capacitance can be adjusted. The second part is formed by the matching strip 2 of length (d) 24 mm and width 2 mm facing a small no-ground region (size 5 × 24 mm^2) in the FR4 substrate. The second part can hence contribute some inductance to the input impedance of the antenna, and the contributed inductance can be adjusted by varying the length d of the matching strip 2. Thus, by adjusting the parameters t, w, and d, the internal matching portion can provide proper capacitance and inductance to the input impedance of the antenna. This can lead to good impedance matching for frequencies over the operating band of the antenna.

Note that one end of the matching strip 2 is the feeding point (point A) of the antenna, which is connected to a 50-Ω microstrip line printed on the FR4 substrate for feeding the antenna. The microstrip line is further connected to a 50-Ω SMA connector to test the antenna in the experiment. When the matching stub is not present (w = 0), the antenna and the system ground plane together can be considered as a half-wavelength dipole with two asymmetric arms. In this case, the antenna can only be operated as a half-wavelength resonant structure with its resonant frequency at about 550 MHz. The achievable bandwidth of the excited half-wavelength resonant mode is usually far from covering the DTV reception in the UHF frequency band.

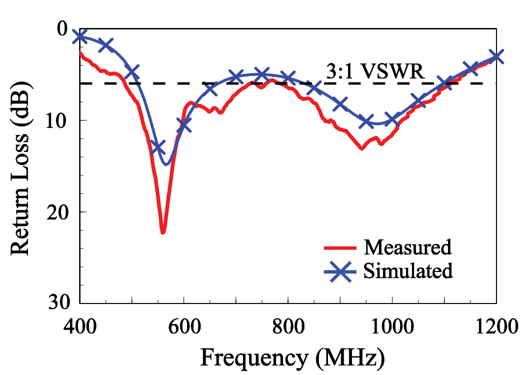

Figure 2 Measured and simulated (HFSS) return loss for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

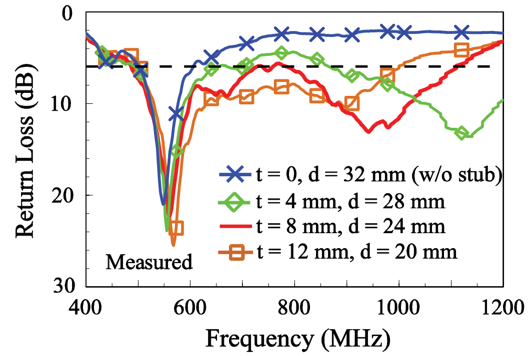

Figure 3 Measured return loss as a function of t, length of the matching stub; d = 32 mm (t). Other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

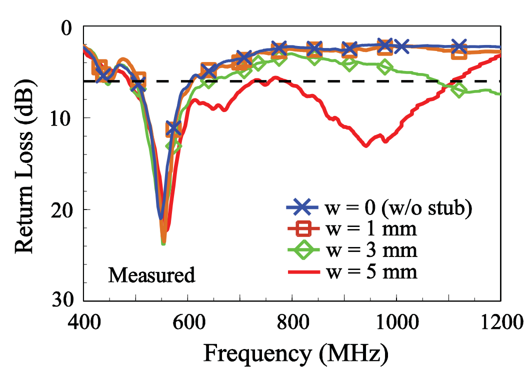

Figure 4 Measured return loss as a function of w, width of the matching stub; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

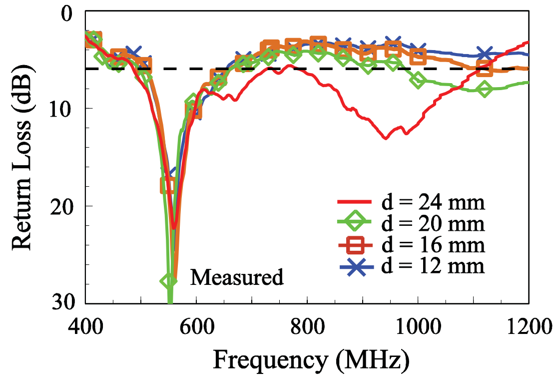

Figure 5 Measured return loss as a function of *d*, length of the matching strip 2; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

When the matching stub is present, it is found that the one-wavelength resonant mode of the antenna can also be excited. This is because the matching stub can effectively perturb the excited surface currents near the feeding point of the antenna and make the null or very small currents no longer exist at the feeding point for the excitation of the one-wavelength resonant mode of the dipole antenna [17]. With the modified surface currents at the feeding point, the excitation of the one-wavelength resonant mode becomes promising. By incorporating proper selection of the dimensions of the matching stub and the matching strips in the internal matching portion, good impedance matching for frequencies over the excited one-wavelength resonant mode can be achieved. In addition, the matching stub and the matching strips show very small effects on the half-wavelength resonant mode of the antenna. Hence, with the successful excitation of the half- and one-wavelength resonant modes, a very wide operating band covering the DTV reception in the UHF frequency band is obtained. This wide

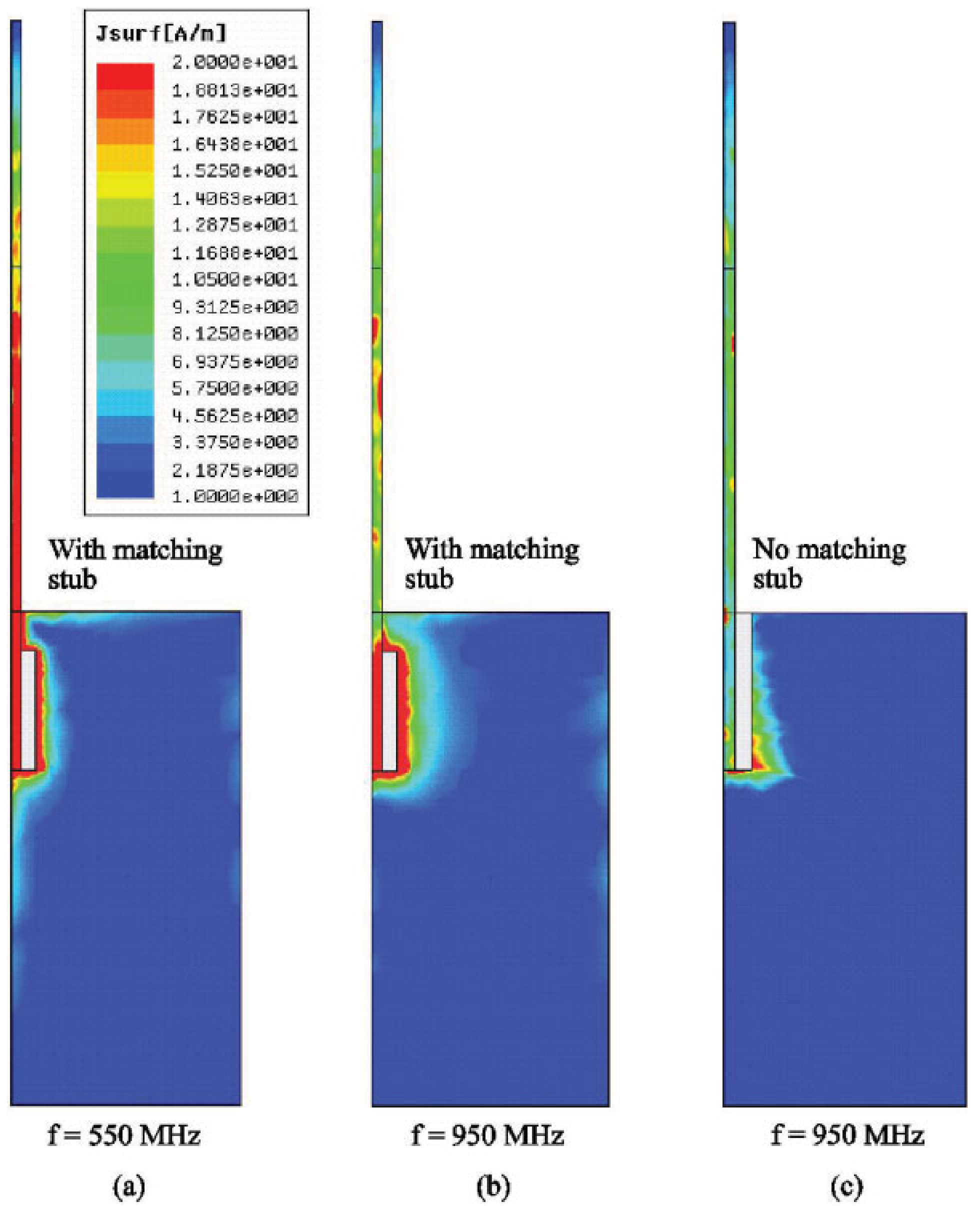

Figure 6 Simulated (HFSS) surface current distributions. (a) The proposed antenna at 550 MHz. (b) The proposed antenna at 950 MHz. (c) The case without the matching stub (d = 32 mm with t = 0 or w = 0 in Fig. 1) at 950 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

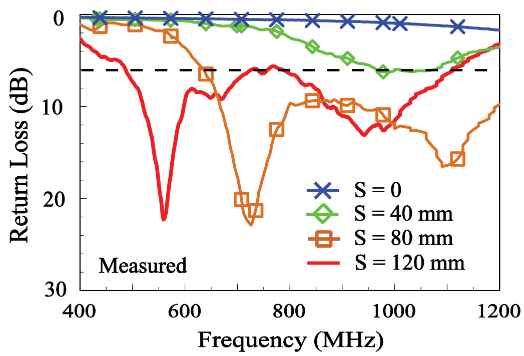

Figure 7 Measured return loss as a function of *S*, length of the retractable radiating strip; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

operating band can even cover the mobile communication in the GSM850/900 bands (824–894 MHz/890–960 MHz) [18].

3. RESULTS AND DISCUSSION

The proposed antenna with dimensions given in Figure 1 was fabricated and studied. Figure 2 shows the measured and simulated return loss of the antenna. The simulated results obtained using Ansoft high frequency structure simulator (HFSS) [19] are in good agreement with the measured data. It is seen that two resonant modes are excited and formed into a very wide band covering the DTV/GSM operation. The lower mode (half-wavelength mode) is centered at about 550 MHz, and the upper mode (one-wavelength mode) is at about 1000 MHz. For frequencies over the obtained wide band formed by the two modes, the impedance matching is all better than 3:1 VSWR, which is generally acceptable for DTV reception and GSM operation in practical applications.

To analyze the effect of the matching stub in the internal matching portion, Figure 3 shows the measured return loss as a function of the length t of the matching stub. In this study, the length d of the matching strip 2 is varied as 32 mm (t), and other dimensions are the same as in Figure 1. When $t = 0$, it indicates that the matching stub is not present. In this case, only the half-wavelength resonant mode is excited. With the presence of the matching stub ($t = 4$, 8, and 12 mm), the one-wavelength resonant mode is seen to be excited, and small effects on the half-wavelength resonant mode are also seen. With an increase in the length t, the one-wavelength resonant mode can also be shifted to lower frequencies, such that a very wide operating band formed by the half- and one-wavelength resonant modes is obtained. With the definition of 3:1 VSWR, the maximum bandwidth of the antenna is obtained by selecting the length t to be 8 mm in this study.

Figure 4 shows the effects of the width w of the matching stub, and the measured results of the return loss for w varied as 0, 1, 3, and 5 mm are presented. When the width w is 0 (the matching stub is not present) or 1 mm or 3 mm, the one-wavelength resonant mode cannot be excited. Only when the width w is increased to be 5 mm, such that good coupling between the matching stub and the matching strip 1 can be obtained, the one-wavelength resonant mode can be excited. This again shows the importance of the matching stub on the wideband operation of the antenna.

Figure 5 shows the measured results of the return loss for the length d of the matching strip 2 varied as 12, 16, 20, and 24 mm. The results indicate that the length d also plays an important role on the wideband operation of the antenna, and the length d should also be properly selected for successful excitation of the one-wavelength resonant mode of the antenna. From the results, $d = 24$ mm is the preferred length for the wideband operation of the antenna.

To analyze the effects of the internal matching portion more clearly, Figure 6 shows the simulated (HFSS) surface current distributions for the proposed antenna at 550 MHz, the proposed antenna at 950 MHz, and the case without the matching stub ($d = 32$ mm with $w = t = 0$ in Fig. 1) at 950 MHz. For the results shown in Figure 6(c), i.e., the case without the matching stub at 950 MHz, very small excited surface currents are seen at the feeding point (point A), which will lead to large input impedance seen at the feeding point. In this condition, the excitation of the one-wavelength resonant mode will become difficult. This agrees with the results shown in Figures 3 and 4 for the condition that the matching stub is not present. On the other hand, when the matching stub is present, good excitation of the half- and one-wavelength resonant modes is seen [see Figs. 6(a) and 6(b)]. In addition, it can be seen that the very small currents seen at the feeding point in Figure 6(c) are shifted to be at about the matching stub in Figure 6(b). This condition is also helpful in the excitation of the one-wavelength resonant mode of the antenna.

Effects of the length S of the retractable radiating strip are also studied. Figure 7 shows the measured return loss of the length S varied as 0, 40, 80, and 120 mm. Results show that the half-wavelength resonant mode is strongly dependent on the length S. To cover the desired lower-edge frequency at 470 MHz for the DTV reception, the length of 120 mm is selected for the retractable radiating strip. This required length, however, is less than 0.2 wavelength of the frequency at 470 MHz.

Effects of the ground-plane length L on the performance of the antenna are studied in Figure 8. Measured results of the return loss for the length L varied as 60, 80, 100, and 120 mm are presented. When the length L is increased, the lower-edge frequency of the operating band of the antenna can be decreased. In this case, a smaller length for the retractable radiating strip can be selected.

Figures 9 and 10 plot the measured radiation patterns at 550 and 950 MHz, about the center frequencies of the excited half- and one-wavelength resonant modes, for the proposed antenna. Similar radiation patterns at 550 and 950 MHz are seen, and they all show dipole-like patterns. The radiation patterns at other frequencies over the operating band are also studied, and similar patterns as plotted here are observed. Figure 11 shows the measured maximum antenna gain and simulated (HFSS) radiation efficiency for the proposed antenna. Over the DTV band of 470–862 MHz, the antenna gain is varied from about −1.3 to 2.1 dBi, and the

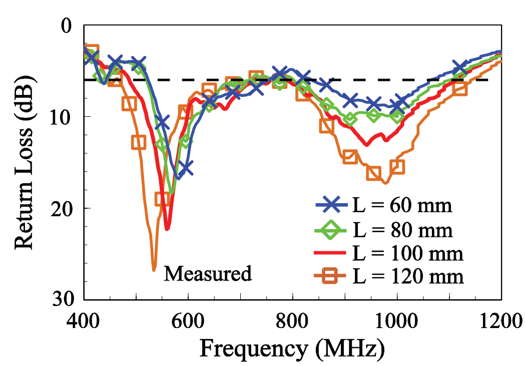

Figure 8 Measured return loss as a function of *L*, length of the system ground plane; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

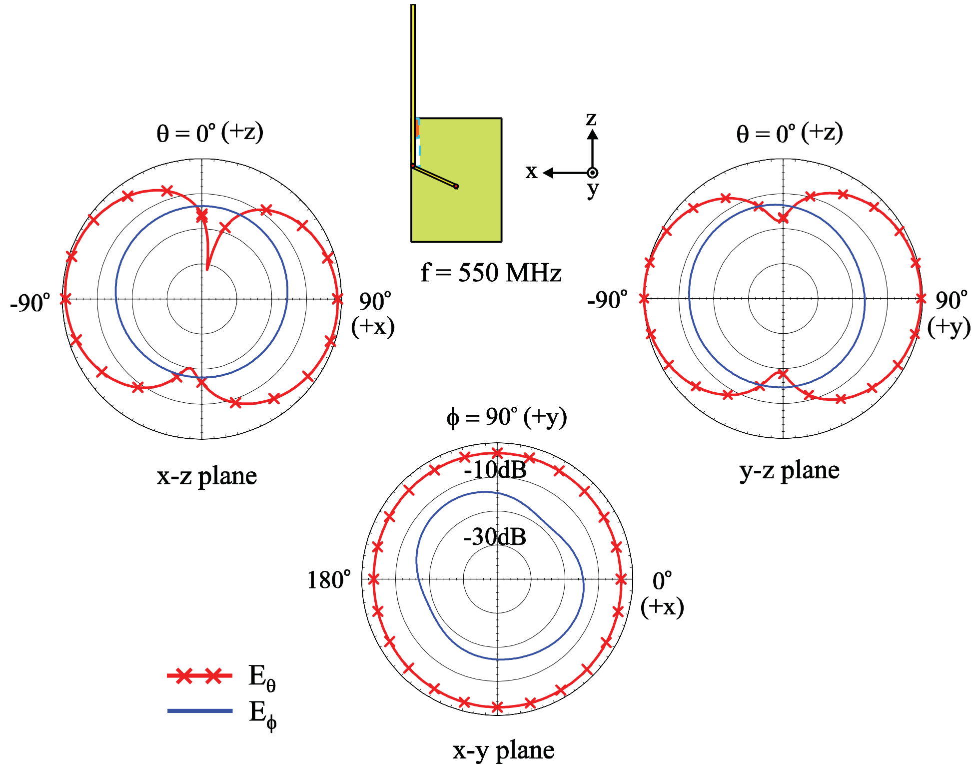

Figure 9 Measured radiation patterns at 550 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

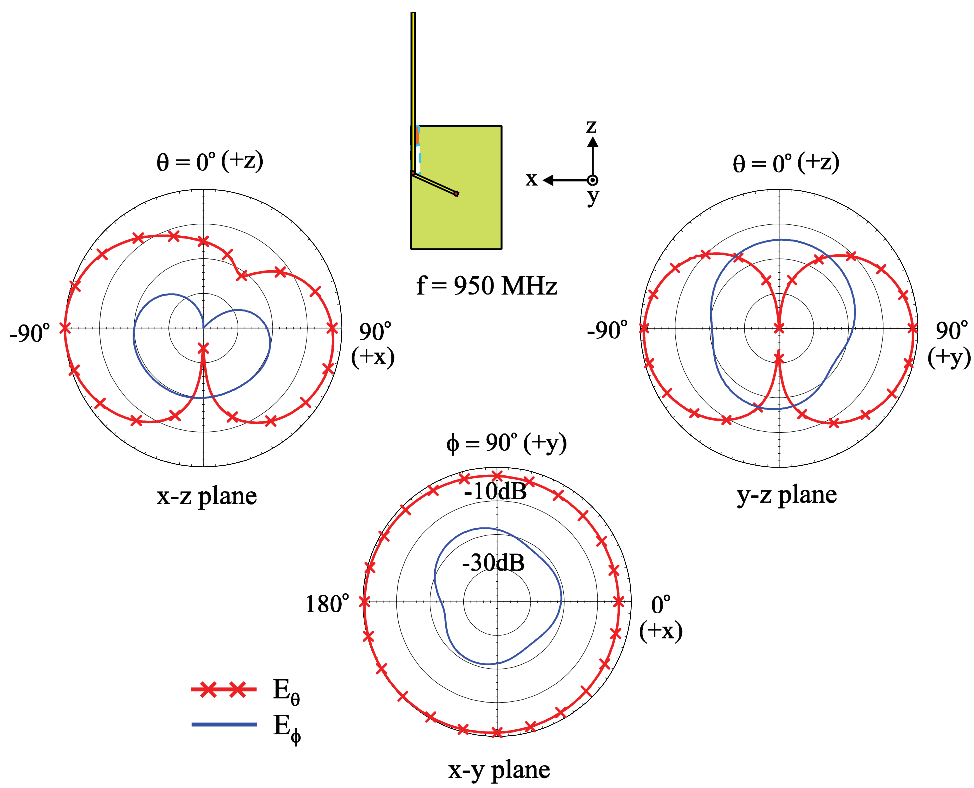

Figure 10 Measured radiation patterns at 950 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

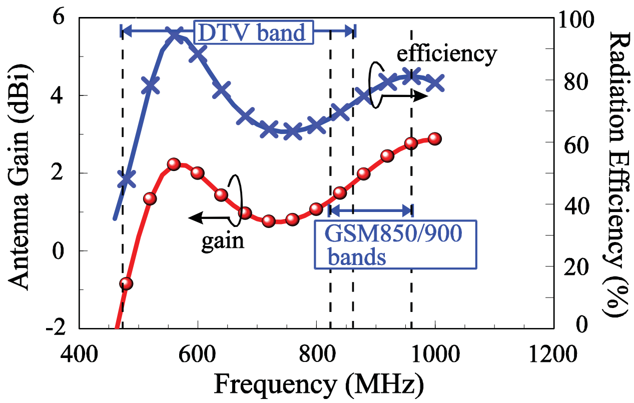

Figure 11 Measured maximum antenna gain and simulated (HFSS) radiation efficiency for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

efficiency is varied in the range of about 45–90%. For frequencies over the GSM band, the antenna gain is varied from about 1.2–2.7 dBi, and the efficiency reaches about 68–82%.

4. CONCLUSION

A simple monopole antenna capable of generating a very wide operating band covering the DTV reception in the 470–862 MHz band and the GSM operation in the 824–894/890–960 MHz band for mobile phone application has been proposed. The antenna uses a novel and simple internal matching portion to be integrated with the system circuit board of the antenna. With the internal matching portion, the half- and one-wavelength resonant modes of the antenna can be excited and formed into a very wide operating band. A parametric study of the internal matching portion has also been studied, and detailed design considerations have been described. Good radiating characteristics for frequencies over the operating band of the antenna have been obtained. It is promising that the proposed antenna be made to be retractable for practical applications in the mobile phones.

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AN LC-TANK INJECTION LOCKED FREQUENCY DIVIDER WITH RECORD LOCKING RANGE PERCENTAGE

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ABSTRACT: *This article presents a wide locking range injection locked frequency divider (ILFD) implemented using a standard 0.18-μm CMOS process. The ILFD consists of a double-cross-coupled VCO and an injection MOS for coupling injection signal to the resonator. At the supply voltage of 1.8 V, the free-running ILFD is tunable from 4.46 to 4.91 GHz. At the injection power of 0 dBm, the locking range of ILFD is tunable from 6.2 to 11 GHz. The percentage of ILFD locking range is 55.8%, which is the highest among similar published LC-tank ILFDs. The phase noise of the ILFD can track with the injection source. The ILFD has been applied to form a quadrature ILFD and an on-chip VCO has been designed to verify the function of the quadrature ILFD.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 806–809, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23193

Key words: *CMOS; injection-locked frequency divider; wide locking range; quadrature generation*

1. INTRODUCTION

Injection-locked frequency dividers (ILFDs) are analog circuit blocks widely used in phase-locked loops (PLLs) and carrier recovery circuits; they consume much less power than conventional digital implementations. They are free-running oscillators