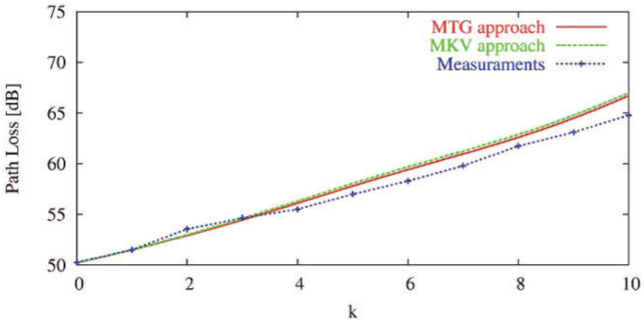

Figure 5 Estimated and reference values of ⟨PL(*k*)⟩ vs. *k* for the Profile L2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

not infinite grid in the horizontal direction, not perfect two-dimensional structure, limited data sample) are present, a good matching between theoretical and reference data can be noticed whatever the obstacles distribution and the prediction approach.

4. CONCLUSIONS

In this letter, some representative results from an experimental validation of percolation-based approaches for the prediction of wave propagation in random media have been presented. The matching between measured and computed data values has assessed the reliability of statistic strategies.

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GSM850/900/1800/1900/UMTS PRINTED MONOPOLE ANTENNA FOR MOBILE PHONE APPLICATION

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ABSTRACT: *The design of a printed monopole antenna on the system circuit board of the mobile phone for achieving GSM850/900/1800/1900/UMTS operation with a small area of 10 mm × 60 mm is presented. The antenna is easy to fabricate at low cost and mainly comprises a driven strip, a coupled strip, and a high-pass matching network for providing two wide operating bands at about 900 and 1900 MHz to cover GSM850/900 and GSM1800/1900/UMTS operations, respectively. The wide lower band is controlled by the driven strip excited as a quarter-wavelength mode, which is further tuned to become a dual-resonance excitation by incorporating the high-pass matching network for effective bandwidth enhancement. For the wide upper band, it is formed by a quarter-wavelength mode excited at about 1800 MHz by the coupled strip and the higher-order mode contributed by the driven strip. Furthermore, with the proposed antenna structure, the lower and upper bands can generally be tuned separately, which is an attractive feature and makes it easy to design for practical applications.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 3192–3198, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23936

Key words: *mobile antennas; printed monopole antennas; mobile phone antennas; multiband antennas; penta-band operation*

1. INTRODUCTION

Owing to the rapid growth in mobile communications, the internal antenna for the mobile phone is generally required to be capable of multiband operation, especially penta-band operation covering GSM850/900/1800/1900/UMTS (824∼894/890∼960/1710∼1880/1850∼1990/1920∼2170 MHz) operation. However, owing to the limited space available inside the mobile phone, it is usually a big challenge for antenna engineers to achieve penta-bend operation for the internal mobile phone antenna with a small size.

In this article, we present a promising design of using a printed monopole antenna to achieve penta-band operation for the mobile phone. The proposed printed monopole antenna is to be printed directly on the system circuit board of the mobile phone, hence making it easy to fabricate at low cost. In addition, the printed monopole antenna is of low profile in appearance and, thus, especially suitable for application in a thin mobile phone [1–4]. The proposed antenna also provides a promising solution for the printed monopole for internal mobile phone antenna applications to easily generate two wide operating bands for covering GSM850/900 and GSM1800/1900/UMTS operations. The proposed printed monopole shows a simple radiating metal pattern of a driven strip and a coupled strip. The enhanced bandwidth in the lower band at about 900 MHz is obtained by incorporating a high-pass matching network [5–10] to the printed monopole, which results in a dual-resonance excitation for the excited resonant mode in the lower band; this leads to a wide lower band for the antenna to cover GSM850/900 operation. On the other hand, the coupled strip can contribute an additional resonant mode for the antenna's upper band to achieve a much widened bandwidth to cover GSM1800/1900/UMTS operation. In addition, as the coupled strip is excited through a small coupling gap by the driven strip [11], not through direct excitation as the traditional two-branch monopole antenna [12–14], its effect on the existing resonant modes contributed by the driven strip are found to be very small. This behavior makes the lower and upper bands of the proposed monopole antenna easy to be adjusted separately. This makes the antenna easy to design for practical applications. Details of the proposed printed monopole antenna for penta-band operation are presented.

2. DESIGN OF PROPOSED PRINTED MONOPOLE ANTENNA

Figure 1(a) shows the geometry of the proposed printed monopole antenna for GSM850/900/1800/1900/UMTS operation in the mobile phone, and the equivalent circuit of the high-pass matching network incorporated to the antenna is shown in Figure 1(b). The printed monopole consists of a driven strip and a coupled strip; both strips are in a folded configuration to achieve a compact size. The driven and coupled strips are printed on the small top no-

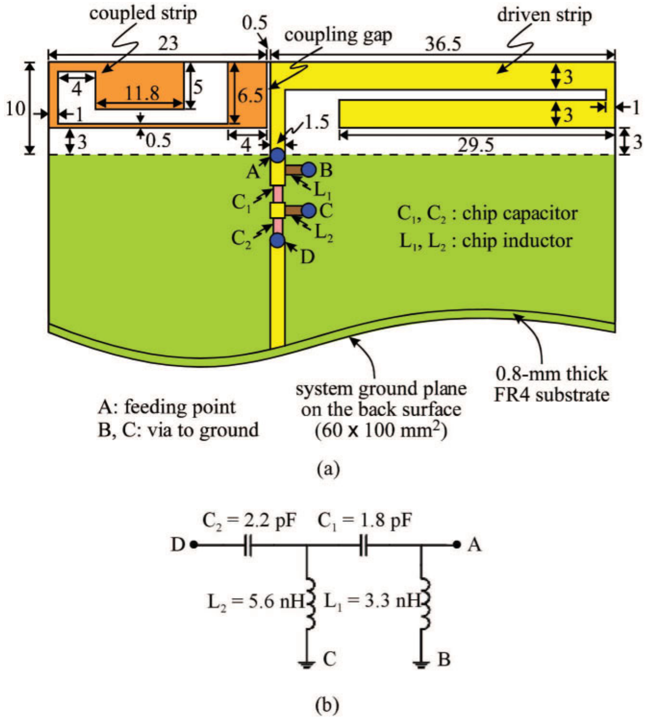

Figure 1 (a) Geometry of the proposed printed monopole antenna for GSM850/900/1800/1900/UMTS operation in the mobile phone. (b) The equivalent circuit of the high-pass matching network incorporated to the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

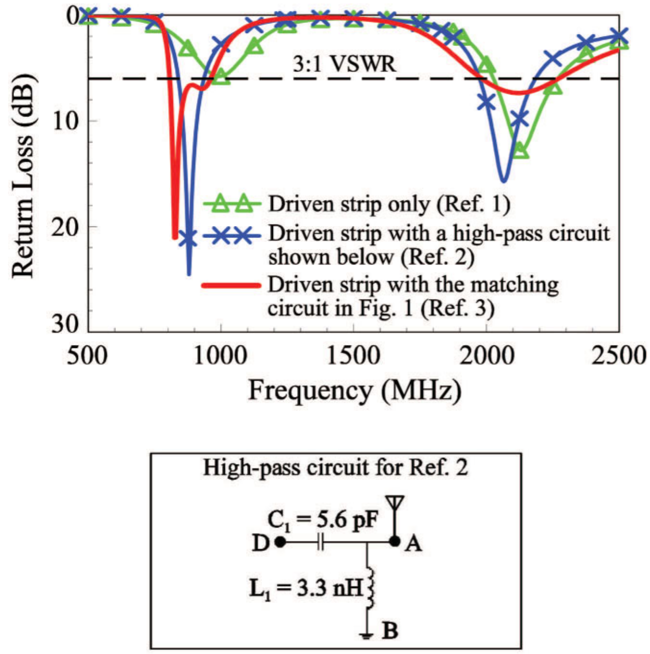

Figure 3 Simulated return loss for the driven strip only [1], the driven strip with a high-pass circuit only [2], and the driven strip with the matching network shown in Figure 1 [3]. All the three antennas are without the coupled strip. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

ground region (size 10 mm × 60 mm) of the system circuit board of the mobile phone, which uses a 0.8-mm thick FR4 substrate of dimensions 100 mm × 60 mm in this study. On the back surface of the system circuit board, the system ground plane of width 60 mm and length 100 mm is printed. The dimensions of the system circuit board and ground plane studied here are reasonable for general smartphones or PDA (Personal Digital Assistant) phones [3, 15–18]. Also, note that the coupled strip is capacitively excited through a narrow coupling gap of width 0.5 mm by the driven strip. With this coupling structure, the inclusion of the coupled strip to the proposed antenna can have very small effects on the existing resonant modes generated by the driven strip. This feature can make it relatively easy for the design of the multiband internal mobile phone antenna to achieve wide operating bandwidths for its lower and upper bands and is advantageous for practical applications.

In the first step of the design, the driven strip is selected to have a length of about 80 mm, which makes it capable of generating a quarter-wavelength resonant modes at about 900 MHz and a half-wavelength resonant mode at about 2000 MHz. The two resonant modes, however, usually cannot provide wide operating bandwidths for the desired lower and upper bands to cover GSM850/900 and GSM1800/1900/UMTS operation.

In the second step, the bandwidth of the lower band is effectively enhanced by incorporating a high-pass matching network to the driven strip. The matching network consists of two high-pass

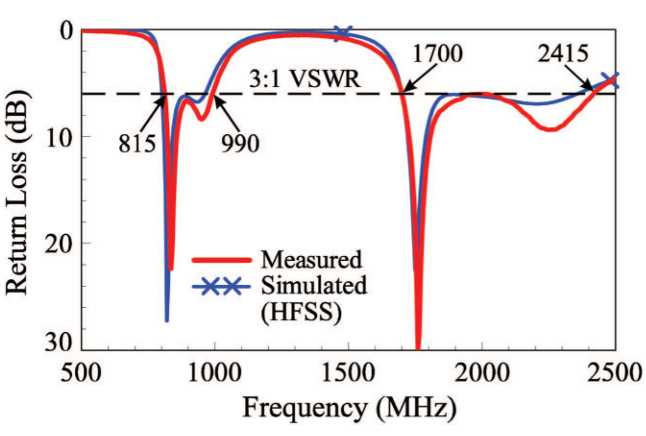

Figure 2 Measured and simulated return loss for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

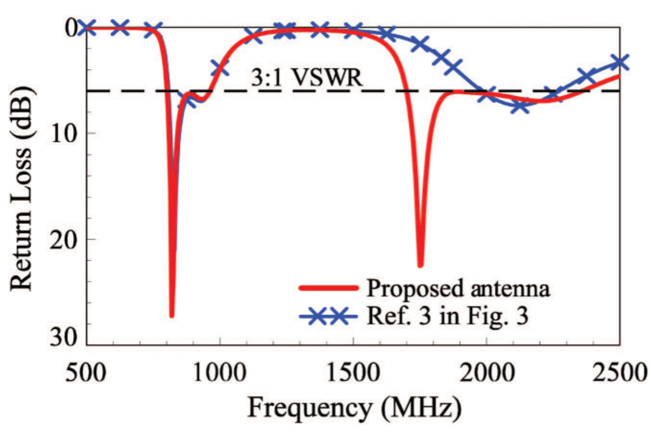

Figure 4 Simulated return loss for the proposed antenna and Ref. 3 in Figure 3. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

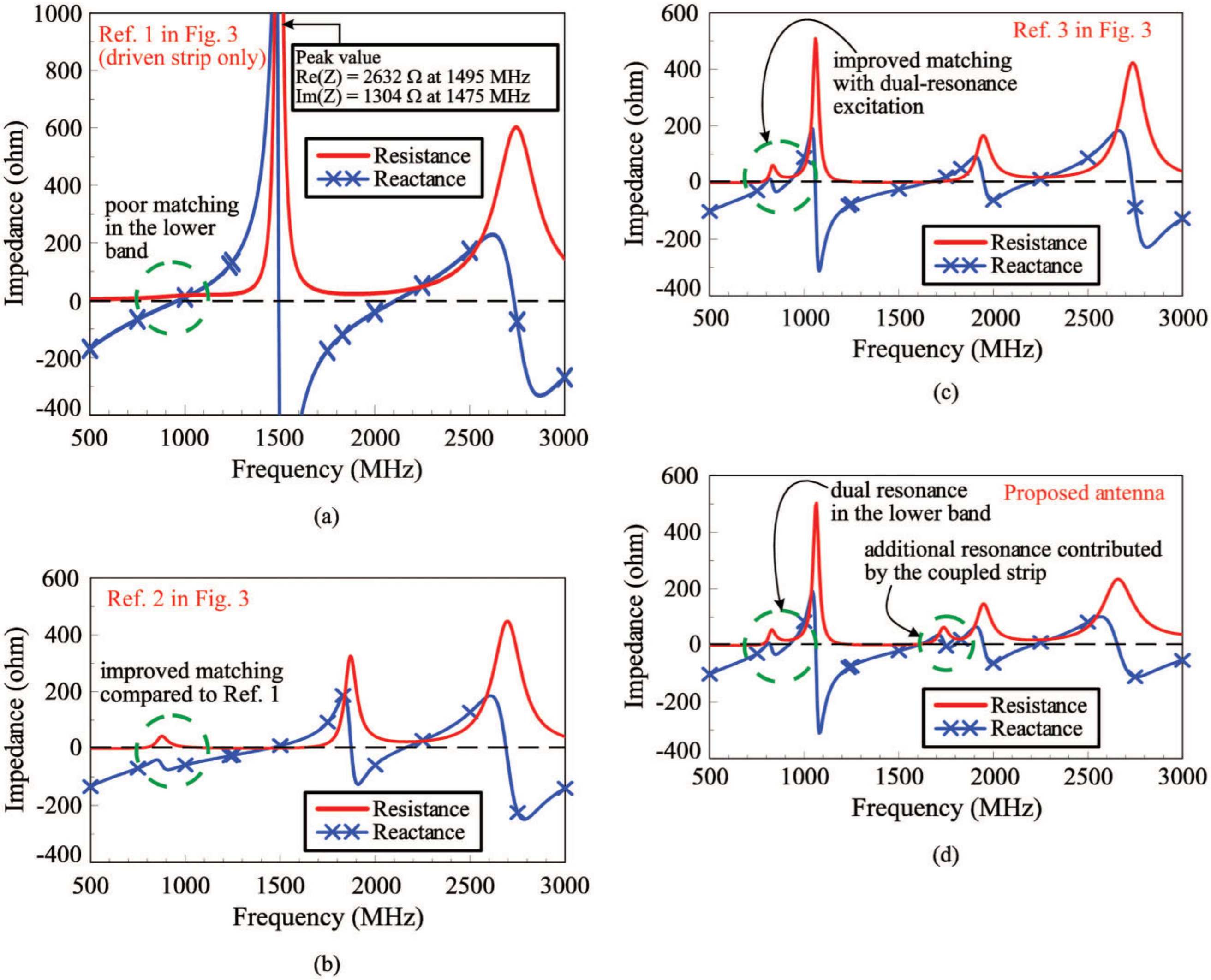

Figure 5 Simulated input impedance for (a) Ref. 1, (b) Ref. 2, and (c) Ref. 3 in Figure 3, and (d) the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

circuits in series, whose equivalent circuit is shown in Figure 1(b). Each circuit is formed by a chip inductor (L_1 or L_2) and a chip capacitor (C_1 or C_2) as shown in Figure 1(a). With the proper matching network incorporated, the excited quarter-wavelength mode of the driven strip can be tuned to have a dual-resonance behavior [19], thus resulting in a much widened lower-band bandwidth to easily cover GSM850/900 operation. In addition, the incorporated matching network in this study shows no degraded effects on the obtained bandwidth of the antenna's upper band, an advantage over the matching circuit applied in the antenna design in [5].

In the third step, the obtained bandwidth of the upper band is greatly increased by adding the coupled strip, which is to be capacitively excited through a narrow coupling gap of 0.5 mm by the driven strip. With a length of about 45 mm, the coupled strip can contribute a quarter-wavelength resonant mode at about 1800 MHz, which incorporates the half-wavelength resonant mode of the driven strip at about 2000 MHz to form a much widened upper-band bandwidth to easily cover GSM1800/1900/UMTS operation. Note that in comparison with the use of an additional resonant strip directly connected to the driven strip, the use of the coupled strip in this study can have very small degrading effects on the obtained bandwidth of the existing resonant modes of the driven strip. This behavior makes it easy to tune the antenna's lower band and upper band separately. By following the three design steps described earlier, it becomes an easy task for achieving GSM850/900/1800/1900/UMTS penta-band operation for an internal printed monopole antenna for mobile phone applications.

3. RESULTS AND DISCUSSION

The proposed penta-band printed monopole antenna was constructed and tested. The results of the measured and simulated return loss of the constructed prototype are shown in Figure 2. Good agreement between the measured data and simulated results obtained using Ansoft HFSS [20] is obtained. Two wide operating bands for the antenna's lower and upper bands are obtained. For the lower band at about 900 MHz, the impedance bandwidth defined by 3:1 VSWR or 6-dB return loss (general standard for practical mobile phone applications) reaches 175 MHz (815~990 MHz), allowing the antenna to cover GSM850/900 (824~960 MHz) operation. For the upper band, a much wider bandwidth as large as 715 MHz (1700~2415 MHz) is obtained, which easily covers GSM1800/1900/UMTS (1710~2170 MHz) operation. From the results, penta-band operation for the proposed printed monopole antenna has been obtained.

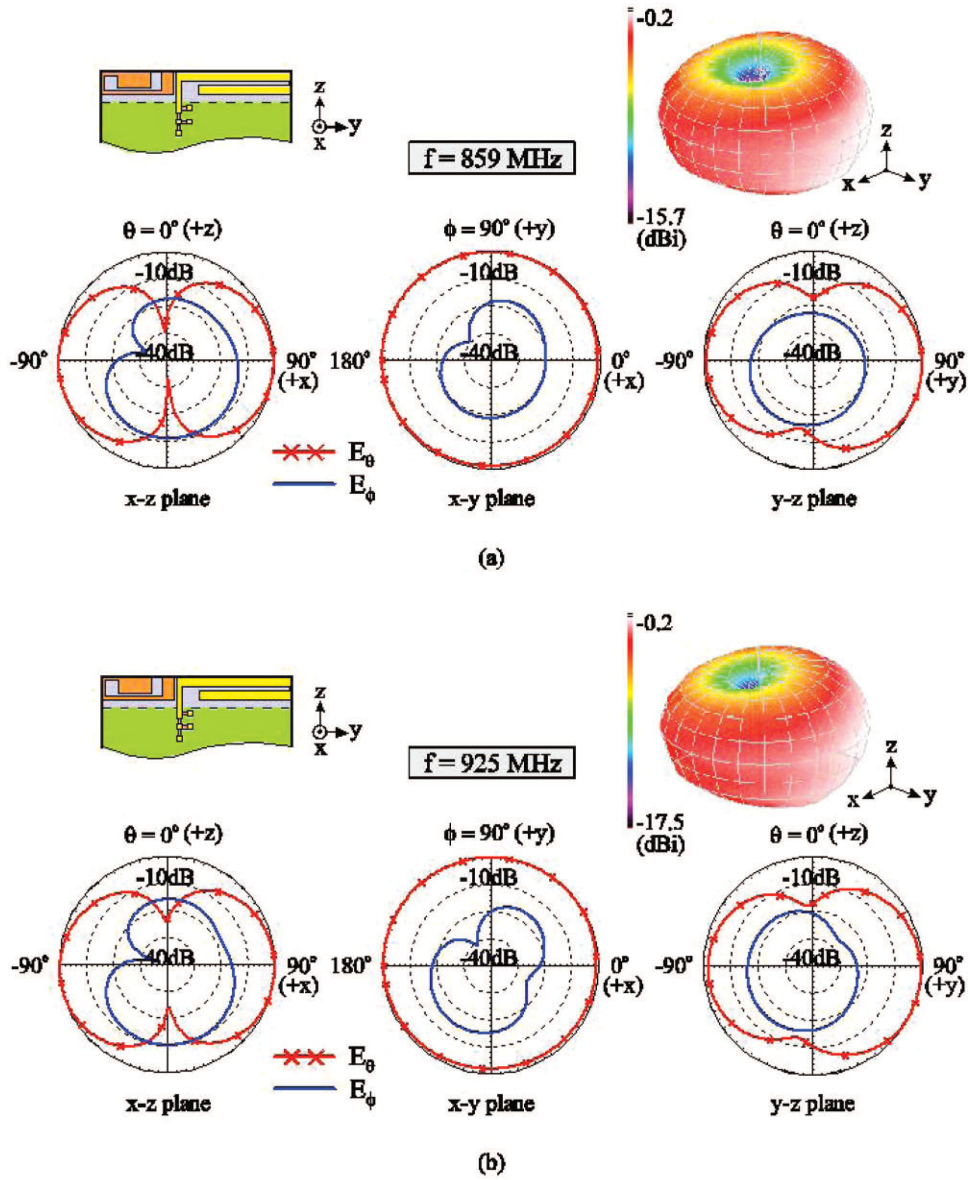

Figure 6 Measured 2-D and 3-D radiation patterns at 859 and 925 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

To study the effects of the high-pass matching network, a comparison of the simulated return loss for the driven strip only [1], the driven strip with a high-pass circuit only [2], and the driven strip with the matching network shown in Figure 1 [3] is presented in Figure 3. In this study, the three cases are without the coupled strip. From the results, it is seen that the driven strip alone [1] can generate two resonant modes at about 1000 and 2000 MHz; however, the obtained bandwidths are far from those required for penta-band operation. By adding a simple high-pass circuit as shown in the figure, improved impedance matching over the two resonant modes, especially the lower resonant mode, is obtained (see Ref. 2 in the figure). The obtained bandwidth of the lower band, however, is still not enough for the desired GSM850/900 operation. With the use of two high-pass circuit in series (the matching network shown in Fig. 1), a dual-resonance excitation for the lower resonant mode of the driven strip alone is obtained (see Ref. 3 in the figure), which greatly increases the lower-band bandwidth for covering GSM850/900 operation. Note that for Ref. 3, the upper-band bandwidth is also increased with the presence of the matching network shown in Figure 1, although the bandwidth is still far from that required for GSM1800/1900/UMTS operation.

By further including the coupled strip to Ref. 3, the upper-band bandwidth of the proposed antenna can be effectively enhanced, allowing the antenna to easily cover GSM1800/1900/UMTS operation. The results are presented in Figure 4 for comparison. It is also seen that the lower-band bandwidth is almost not affected when the coupled strip is added.

Simulated input impedances for Refs. 1–3, and the proposed antenna are also shown in Figure 5 for comparison. Figure 5(a) shows the real part (Re or Resistance in the figure) and imaginary part (Im or Reactance in the figure) of the case with the driven strip alone [1], while those for Refs. 2 and 3, and the proposed antenna are given in Figures 5(b)–5(d), respectively. It is seen in Figure 5(b) that Ref. 2 shows improved matching for frequencies in the lower band, when compared with Ref. 1. For the results of Ref. 3 shown in Figure 5(c), dual-resonance excitation is obtained at about 900 MHz. Finally, for the results of the proposed antenna shown in Figure 5(d), an additional resonance contributed by the

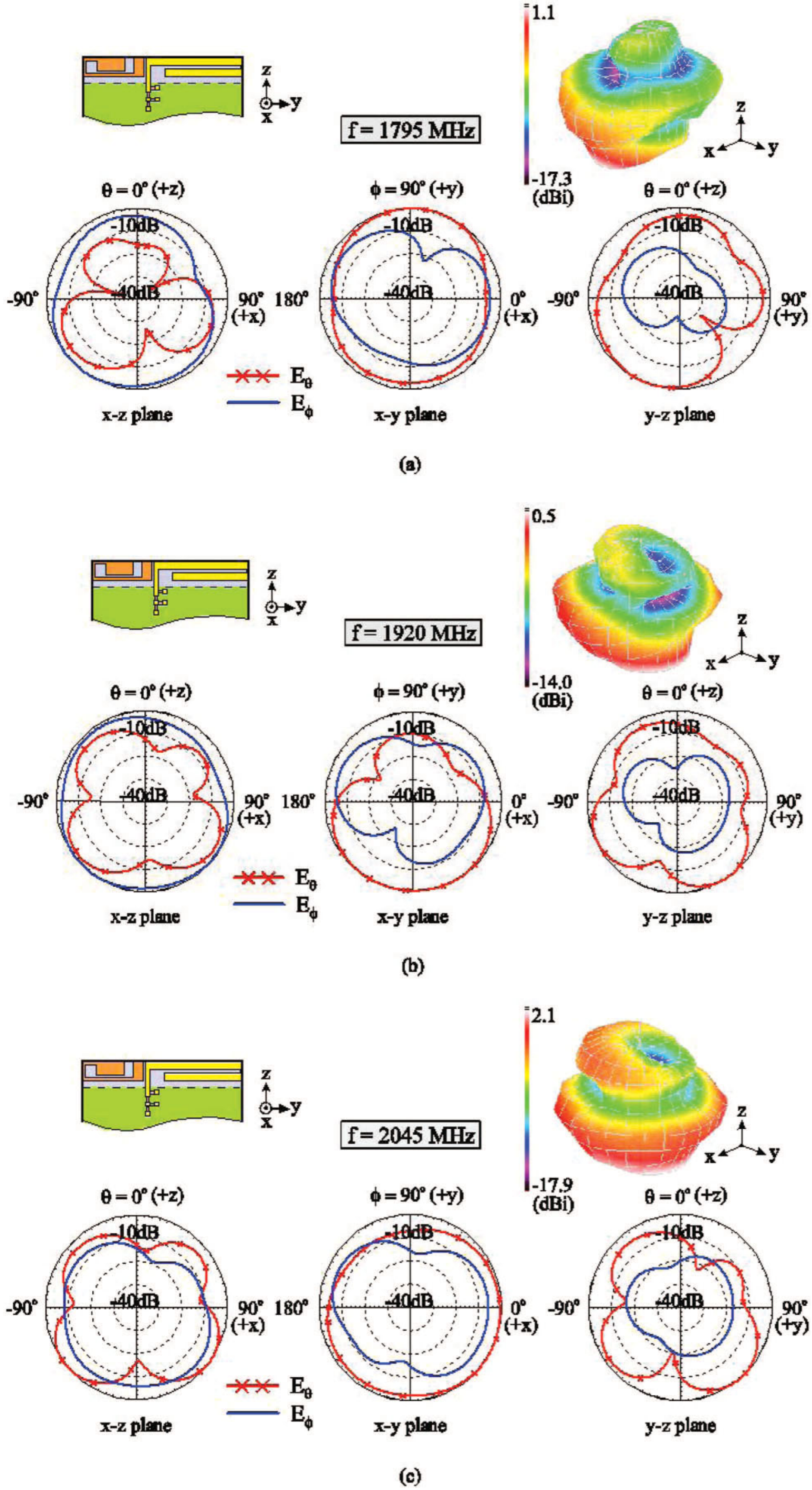

Figure 7 Measured 2-D and 3-D radiation patterns at 1795, 1920, and 2045 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

coupled strip at about 1700 MHz is seen, whereas the impedance matching of the existing resonant modes of Ref. 3 is almost not affected. The simulated input impedances shown in Figure 5 confirm the results obtained in Figure 4.

Figure 6 plots the measured two-dimensional and three-dimensional radiation patterns at 859 and 925 MHz (center frequencies of GSM850/900 systems) for the proposed antenna. The peak gain at 859 and 925 MHz is all about −0.2 dBi, and similar monopole-like radiation patterns are seen. Good omnidirectional radiation in the *x–y* plane (azimuthal plane) is also obtained. Results of the measured radiation patterns at 1795, 1920, and 2045 MHz (center frequencies of GSM1800/1900/UMTS systems) for the proposed antenna are plotted in Figure 7. The peak gain at 1795, 1920, and 2045 MHz is 1.1, 0.5, and 2.1 dBi, respectively. More variations in the radiation patterns compared with those in Figure 6 are observed. This is in part owing to the nulls of the excited surface currents on the system ground plane at higher frequencies. The obtained patterns are similar to those of the traditional internal mobile phone antennas such as the PIFAs [21] and are acceptable for practical applications. Figure 8 presents the measured antenna gain and simulated radiation efficiency for the proposed antenna. Over the GSM850/900 band shown in Figure 8(a), small variations in the antenna gain is seen (about −0.2 ∼ −0.5 dBi), and the radiation efficiency is still larger than 50%. Although over the GSM1800/1900/UMTS band shown in Figure 8(b), the antenna gain is varied from about 0 to 3.2 dBi, and the radiation efficiency is also larger than 50%.

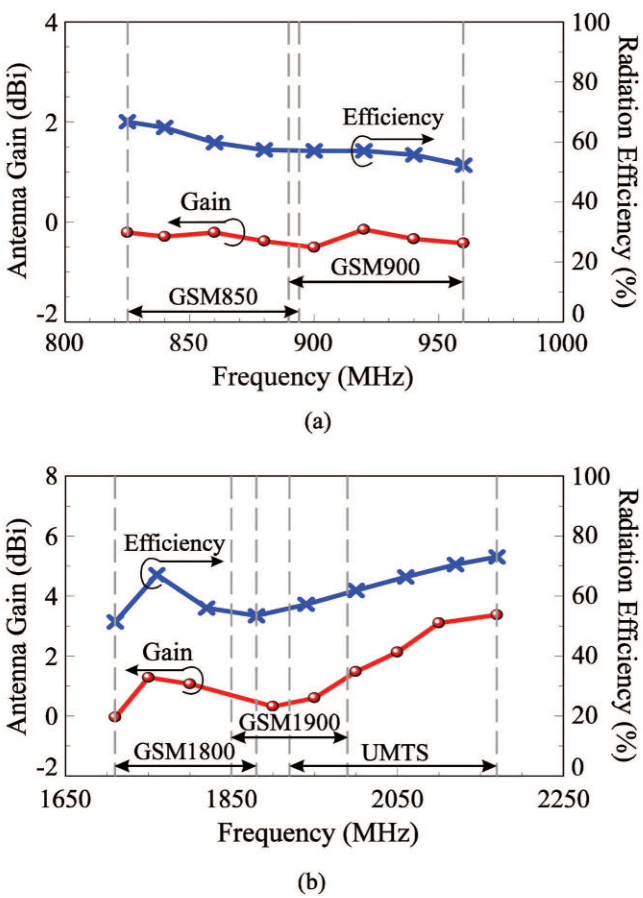

Figure 8 Measured antenna gain and simulated radiation efficiency for the proposed antenna. (a) GSM850/900 band. (b) GSM1800/1900/UMTS band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

4. CONCLUSION

A penta-band printed monopole antenna easily fabricated on the system circuit board of the mobile phone for covering GSM850/900/1800/1900/UMTS operation has been proposed. The design steps for the printed monopole antenna to achieve two wide operating bands at about 900 and 1900 MHz have been given in the article. With wide operating bands obtained, the printed monopole antenna also occupies a small area of 10 mm × 60 mm only. The design techniques used in the proposed antenna include the use of a high-pass matching network and a coupled strip to be capacitively excited by the driven strip of the antenna. The former effectively enhances the lower-band bandwidth of the antenna by introducing a dual-resonance excitation to the lower band, whereas the latter contributes an additional resonant mode to the antenna's upper band to enhance the bandwidth. Furthermore, the two design techniques can be applied at the same time, with very small effects on each other. That is, when the lower-band bandwidth is effectively enhanced by the high-pass matching network, the upper-band performances are generally not affected, and vice versa for the added coupled strip for enhancing the upper-band bandwidth. This allows the antenna's lower and upper bands to be adjusted separately, without affecting each other. This feature makes it very convenient and attractive for the proposed penta-band printed monopole antenna for practical applications in the mobile phones.

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COMPACT DUAL FREQUENCY DUAL POLARIZED CROSS PATCH ANTENNA WITH AN X-SLOT

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ABSTRACT: *A new design of a compact single-feed dual frequency dual polarized microstrip antenna with an X-slot is presented. The proposed antenna generates two orthogonally polarized radiations with center frequencies at 1.42 GHz and 1.79 GHz, respectively. For fixed dual frequency operation, the antenna has an area reduction of 74% and 59% for the respective frequencies compared to standard rectangular patches. The antenna exhibits broadside radiation pattern and has sufficient gain for the two bands.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 3198–3201, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23903

Key words: *dual frequency; dual polarization; compact microstrip antenna*

1. INTRODUCTION

In applications such as broadcasting, personal communication, and radar systems, considerable efforts are given to the development of dual frequency patch antennas [1, 2]. For the case of dual frequencies with orthogonal polarizations, typical designs of rectangular microstrip antenna excited through an inclined slot [3], a square patch with a symmetric slot [4], and a hexagonal slot [5] have been reported. In these designs, the slots are embedded in the patch to decrease the resonant frequencies of the first two resonant modes of TM_{01} and TM_{10}, respectively. A broad band dual polarized antenna [6] uses two orthogonal feeds which creates complexities in transmitter design.

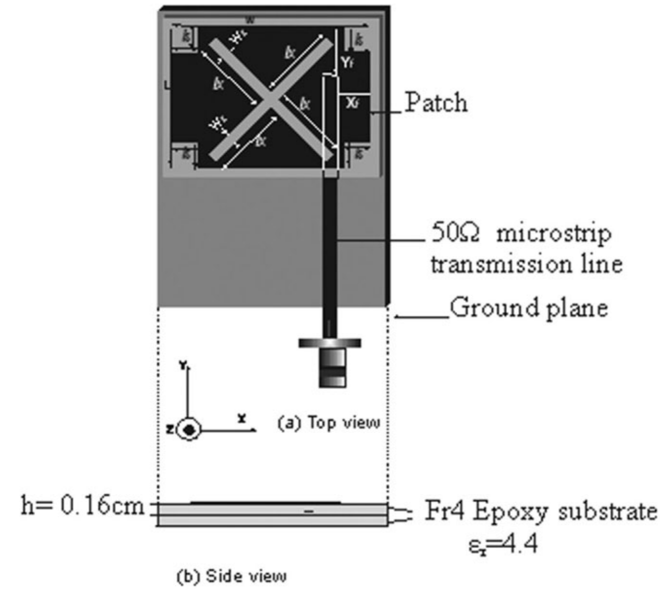

Figure 1 Geometry of the proposed antenna with dimensions: $L = 3.8$ cm, $W = 2.7$ cm, $l_s = 0.5$ cm, $l_x = 1.5$ cm, $w_x = 0.2$ cm, $X_f = 0.06$ cm, and $Y_f = 0.1$ cm

In this article, we present a technique for obtaining a compact dual frequency dual polarized microstrip antenna design. Initially, four square regions are cut off from the corners of a rectangular patch resulting in a cross-shaped patch, giving a dual frequency dual polarized antenna. To the abovementioned cross-shaped patch, an X shaped slot is inserted to obtain greater area reduction. The X shape is chosen to induce symmetric current distributions for the two modes of TM_{01} and TM_{10}. In this design, a single proximity feed is used to obtain impedance matching for the two frequencies with orthogonal polarization. The resulting antenna gives greater area reduction with good cross polarization levels and low frequency ratio. The design has been successfully implemented and the experimental results are in good agreement with the simulations.

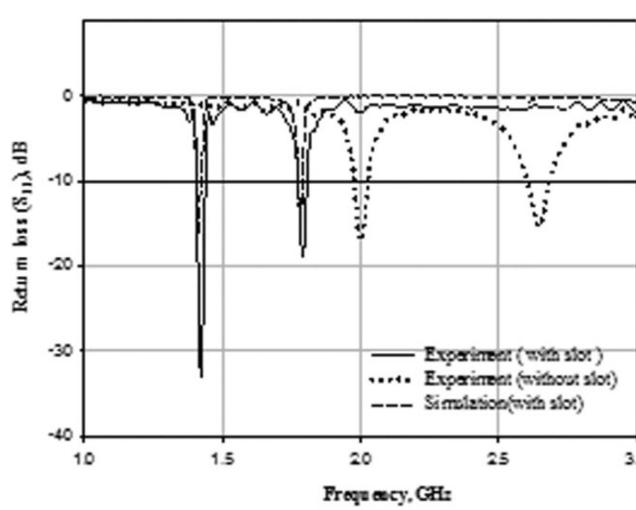

Figure 2 Measured return loss (S_{11}) of the antenna and without X-slot