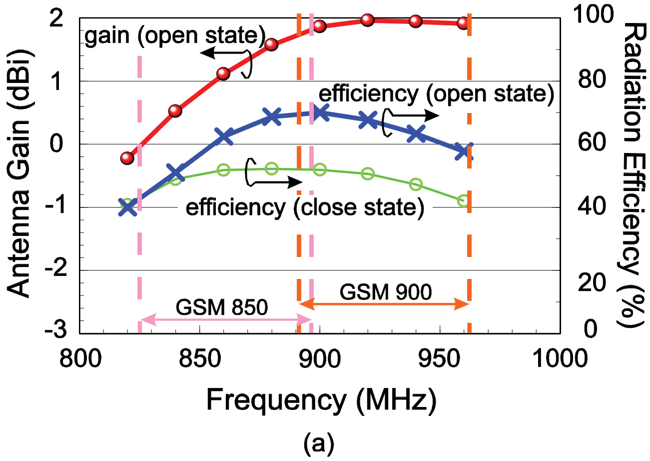


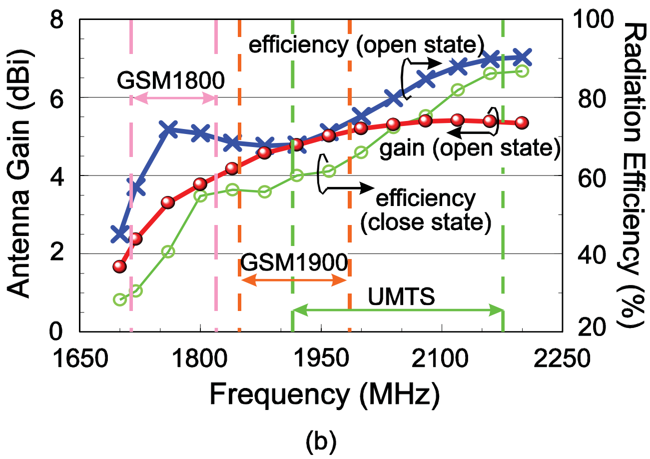


**Figure 11** Measured antenna gain and simulated radiation efficiency for the antenna. (a) The GSM850/900 bands. (b) The GSM1800/1900/UMTS bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

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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**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*

## 1. INTRODUCTION

Many of today's mobile communication devices are required to perform multipurpose functions for applications such as in the wireless local area network (WLAN) and wireless wide area network (WWAN). For WWAN operation, it mainly includes five operating bands of GSM850 (824–894 MHz), GSM900 (880–960 MHz), GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), and UMTS (1920–2170 MHz). To cover the five operating bands, several promising internal antennas for mobile phones have been reported [1–6]. However, it is noted that these antennas are generally with a system ground plane of length about or larger than 90 mm. When they are applied to a small-size mobile phone (for example, the groundplane length 60 mm in this study), it is usually a big challenge for the internal antenna to provide a wide operating band at about 900 MHz to cover the required bandwidth of GSM850/900 bands (824–960 MHz). This is because the achievable bandwidth of the antenna's lower band is greatly dominated by the groundplane length of the mobile phone [7–9]. On the other hand, in order to cover GSM1800/1900/UMTS operation and the 2.4 GHz band (2400–2484 MHz) for WLAN operation, a very wide upper band (1710–2484 MHz) is required, which is also a challenge for the internal antenna design in the mobile phones.

In this article, we propose a promising internal antenna capable of covering the five operating bands for WWAN operation and the 2.4 GHz band for WLAN operation in the mobile phone with a small groundplane length of 60 mm only, which is much smaller than that of the general mobile phones. With six-band operation achieved, the proposed antenna occupies a volume of 3.6 $cm^3$ only. The antenna uses three conventional monopole elements that have been applied in the general mobile phones [11] for achieving the desired six-band operation. Two longer monopoles are capacitively coupled together and incorporate an external parallel chip inductor at the antenna's feeding point, resulting in a dual-resonance lower band having a much widened bandwidth for GSM850/900 operation. In addition, the three monopoles together contribute to the excitation of a very wide upper band (bandwidth larger than 1 GHz) for the antenna to cover GSM1800/1900/UMTS/WLAN operation. That is, a six-band internal antenna suitable for small-size mobile phone application is achieved. Detailed design considerations of the proposed antenna are described and experimental and simulation results of the constructed prototype are presented.

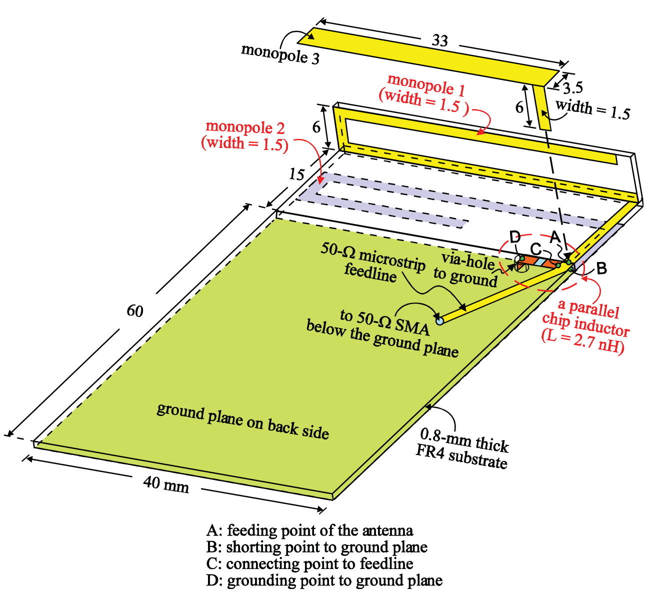



**Figure 1** Geometry of the proposed six-band internal antenna for the small-size mobile phone. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

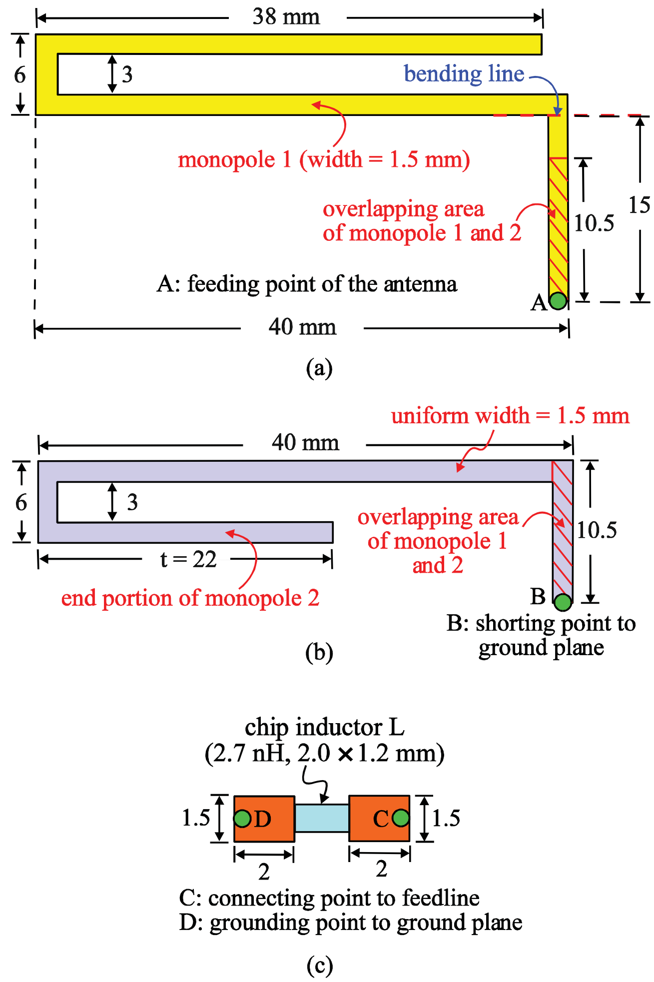



**Figure 2** Dimensions of (a) monopole 1 in the planar structure, (b) monopole 2, and (c) the external parallel chip inductor of $L = 2.7$ nH. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

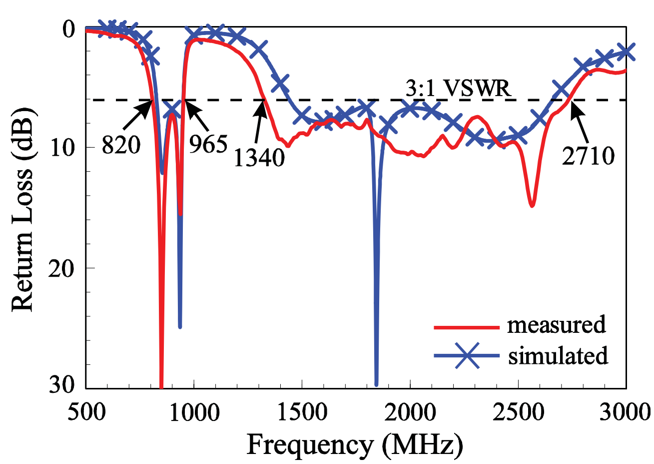



**Figure 3** Measured and simulated return loss for the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

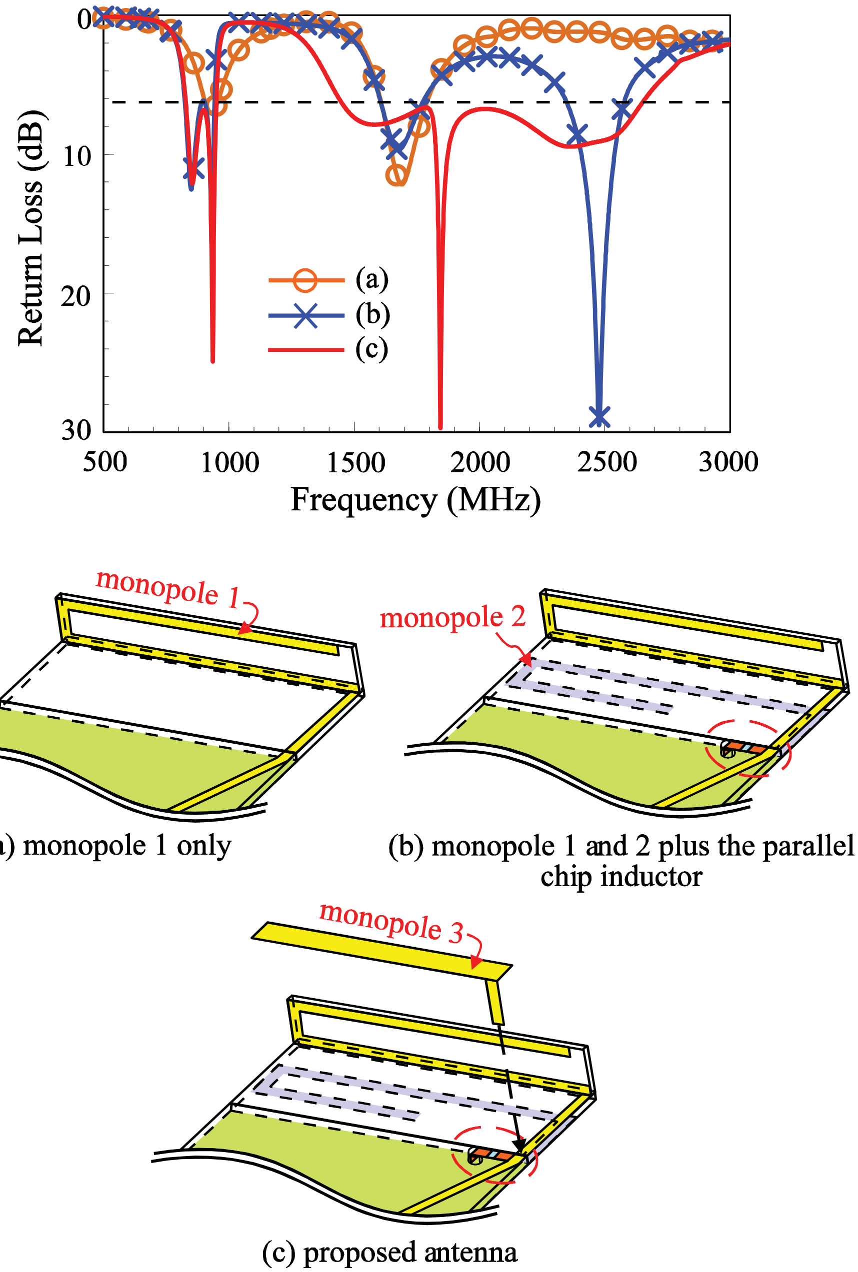



**Figure 4** Simulated return loss for (a) monopole 1 only, (b) monopoles 1 and 2 with the external parallel chip inductor, and (c) the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

## 2. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed six-band internal antenna for the small-size mobile phone. The antenna is placed at the top no-ground portion of a 0.8-mm thick FR4 substrate of relative permittivity 4.4, which is treated as the system circuit board of the small-size mobile phone. Note that the system ground plane printed on the back side of the FR4 substrate has a width of 40 mm and a length of 60 mm; the length is much smaller compared with the general mobile phones.

The antenna mainly consists of two longer monopoles (monopoles 1 and 2), a shorter monopole (monopole 3), and an external parallel chip inductor; their detailed dimensions are given in Figures 1 and 2. Monopole 1 is a metal strip of uniform width 1.5 mm and length 96 mm; its front section is printed on the front side of the no-ground portion of the circuit board, and its end portion is also printed on a 0.8-mm thick FR4 substrate and mounted perpendicularly at the top edge of the no-ground portion to achieve a

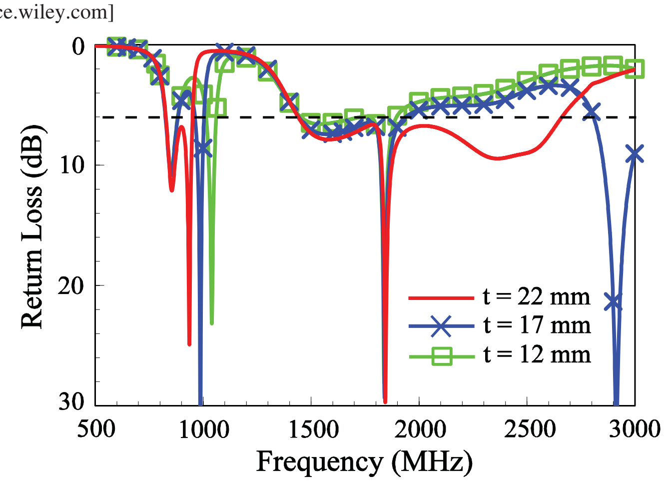



**Figure 5** Simulated return loss as a function of the length $t$ of the end section of monopole 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

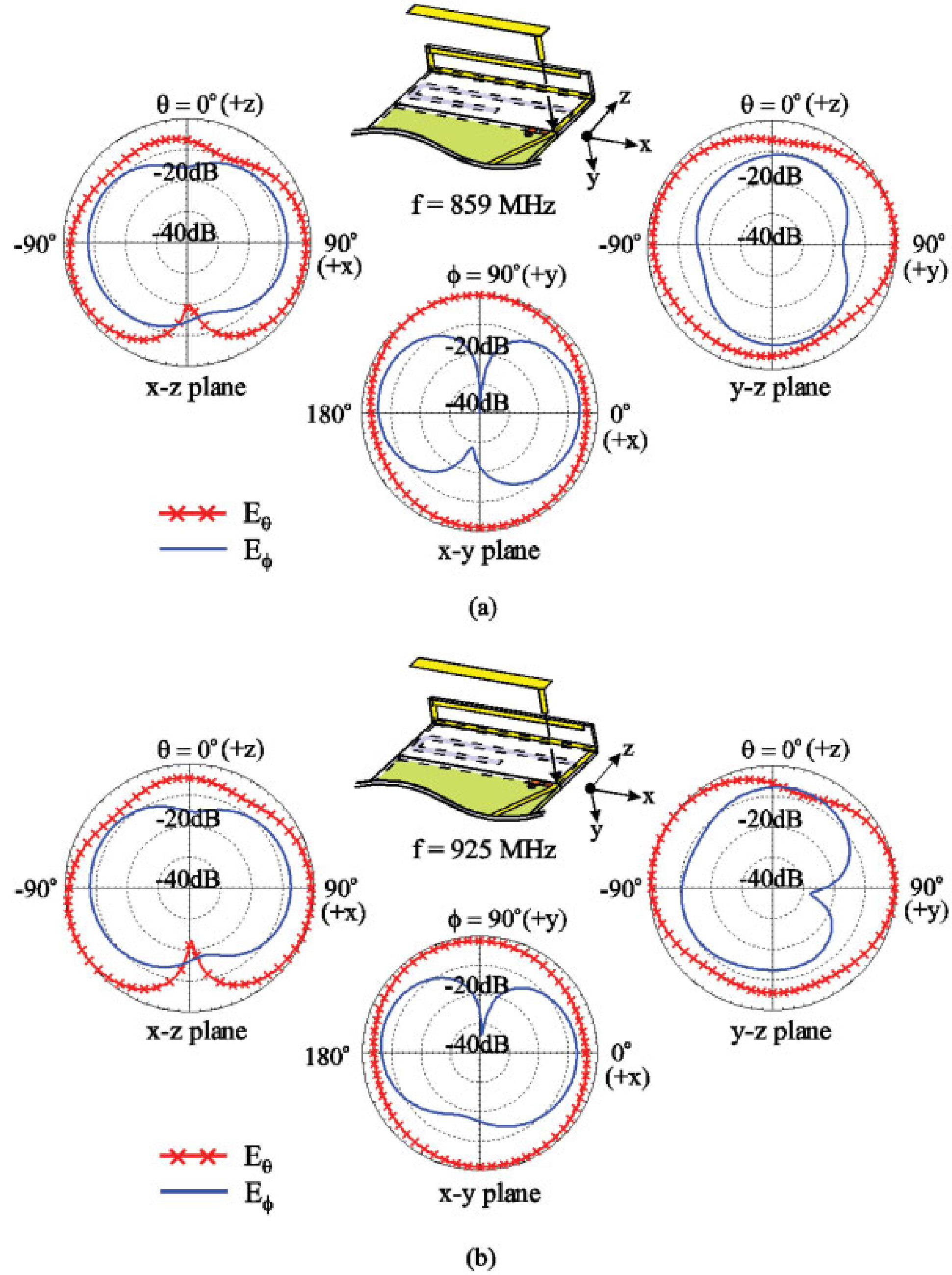



**Figure 6** Measured radiation patterns at (a) 859 MHz and (b) 925 MHz for the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

compact configuration. The front end (point A) of monopole 1 is the feeding point of the antenna and is connected to a 50-Ω microstrip feedline printed on the front side of the circuit board.

Monopole 2 is printed on the back side of the no-ground portion with its front end (point B) short-circuited to the ground plane. Further, monopole 2 having a uniform width 1.5 mm and a length 77 mm is excited by monopole 1 through the capacitive coupling in-between the overlapping section of area 10.5 × 1.5 mm$^2$. Monopoles 1 and 2 are operated as quarter-wavelength structures and can generate two adjacent resonant modes around 900 MHz. By incorporating an external parallel chip inductor near the antenna's feeding point, good impedance matching of the two excited quarter-wavelength resonant modes of monopoles 1 and 2 can be achieved and further formed into a wide lower band for the antenna to cover GSM850/900 operation from 824 to 960 MHz. The distributed capacitance contributed from the capacitive coupling between monopoles 1 and 2 and the lumped inductance contributed by the parallel chip inductor function like a matching circuitry for the input impedance of the antenna. Since this matching circuitry uses only one external element (the chip inductor of $L$ = 2.7 nH used here), which is simpler than many of the reported matching circuitry for the internal antenna in the mobile phones [10–13]. Also note that the matching circuitry used here has the high-pass property [10] and will not cause large effects on the impedance characteristics of the frequencies over the antenna's upper band. This behavior is an advantage and can make it easier for the antenna engineer to adjust the impedance matching of the antenna's lower band, without large effects on the impedance matching of the upper band. Further, the end section (length $t$) of monopole 2 can provide an effective parameter to adjust the

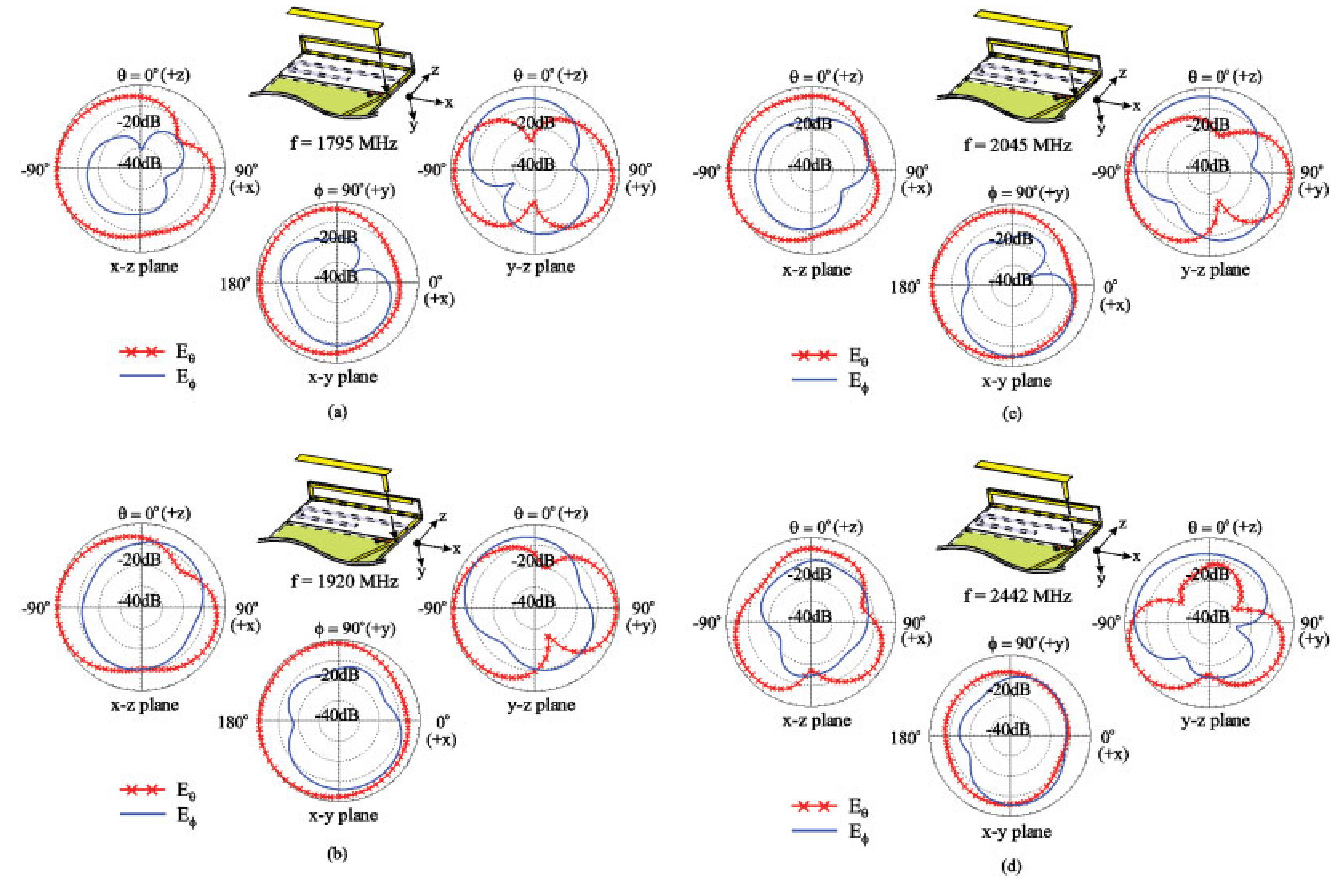



**Figure 7** Measured radiation patterns at (a) 1795 MHz, (b) 1920 MHz, (c) 2045 MHz, and (d) 2442 MHz for the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

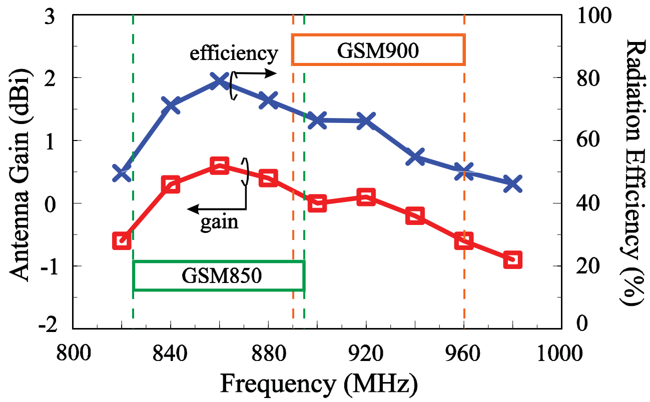
resonant frequency of monopole 2 such that the two quarter-wavelength modes excited by monopoles 1 and 2 are easier to be formed into a wide lower band for the antenna. In this study, the proper length *t* is selected to be 22 mm for monopole 2.

Monopole 3 is a metal strip of length about 39 mm and can provide a quarter-wavelength mode at about 1800 MHz. It can also improve the impedance matching of two higher-order modes contributed by monopoles 1 and 2 at about 1500 and 2500 MHz. A very wide upper band for the antenna is hence obtained, which easily covers the desired GSM1800/1900/UMTS/WLAN operation from 1710 to 2484 MHz. In addition, the adding of monopole 3 does not cause large effects on the impedance matching of the lower band, which is also an advantage for practical applications of the antenna. The front end of monopole 3 is connected to point A and then it is bent to be mounted above the no-ground portion of the circuit board with a height of 6 mm. With the arranged configuration, the three monopoles together occupy a volume of $6 \times 15 \times 40$ mm$^3$ or about 3.6 cm$^3$, and can generate two wide bands at about 900 and 2000 MHz for six-band operation for WWAN and WLAN dual-network communications.

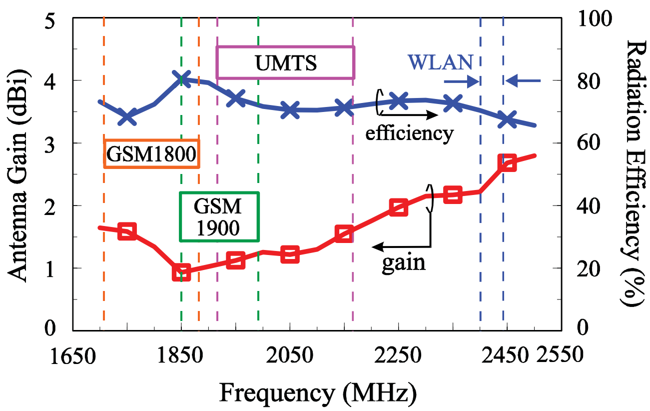
## 3. RESULTS AND DISCUSSION

The proposed antenna with dimensions given in Figures 1 and 2 was constructed and tested. Figure 3 shows the measured and simulated return loss for the constructed prototype. The obtained results indicate that good agreement between the measurement and simulation is obtained. The simulated results are obtained using Ansoft HFSS (High Frequency Structure Simulator) [14]. The lower band is formed by two adjacent resonant modes, which are contributed by monopoles 1 and 2 as discussed in Section 2. The lower band has an impedance bandwidth of 3:1 VSWR ranging from 820 to 965 MHz, large enough for covering GSM850/900 operation. For the upper band, it is formed by three resonant modes contributed by monopoles 1–3, and shows a wide bandwidth of 1370 MHz (1340–2710 MHz) to easily cover GSM1800/1900/UMTS/WLAN operation. Note that the impedance matching for frequencies over the 2.4 GHz band (2400–2484 MHz) for WLAN operation is around 2:1 VSWR or 9.6-dB return loss, while the impedance matching over GSM850/900/1800/1900/UMTS bands for WWAN operation is better than 3:1 VSWR or 6-dB return loss. The impedance matching levels obtained here for WWAN and WLAN operations are generally accepted for practical applications.

Figure 4 shows the simulated return loss for three cases of monopole 1 only, monopoles 1 and 2 with the parallel chip inductor only, and the proposed antenna. It is first seen that for the case of monopole 1 only, there are two resonant modes excited at about 900 and 1700 MHz. When monopole 2 and the external parallel chip inductor are added, two additional resonant modes at about 900 and 2450 MHz are generated, without affecting the excitation of the two modes contributed by monopole 1. Note that the original mode at about 900 MHz contributed by monopole 1 is shifted to be at about 850 MHz. Further, the two modes at about 850 and 900 MHz contributed by monopoles 1 and 2 are formed into a wide lower band for the antenna. On the other hand, the two modes at about 1700 and 2045 MHz are the higher-order modes of monopoles 1 and 2. Finally, by adding monopole 3, a quarter-wavelength mode at about 1850 MHz is generated, and the lower band formed by the two modes at about 850 and 900 MHz is very slightly affected. Moreover, the three resonant modes at about




(a)




(b)

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

1700, 1850, and 2045 MHz contributed by monopoles 1–3 are formed into a very wide upper band for the antenna.

Figure 5 shows the effect of the length *t* of the end section of monopole 2 on the obtained impedance bandwidths. The results for the length *t* varied from 12 to 17 mm are presented. When a proper length *t* is selected, the two excited modes at about 900 MHz can be formed into a wide operating band. Also, the higher-order mode controlled by monopole 2 is shifted from about 2900–2450 MHz when the length *t* is increased from 12 to 22 mm, and a wide operating band is hence formed.

The radiation characteristics of the constructed prototype are also studied. Figure 6 plots the measured radiation patterns at 859 and 925 MHz. Both the two radiation patterns show monopole-like patterns and are similar to each other, indicating that stable radiation characteristics are obtained over the antenna's lower band. This behavior is similar to those of the conventional internal antennas for the general mobile phones [11]. Figure 7 plots the measured radiation patterns at 1795, 1920, 2045, and 2442 MHz. Similar omnidirectional radiation characteristics in the azimuthal plane (*x-y* plane) can still be obtained over the antenna's upper band. There are generally no radiation nulls in the azimuthal plane, which is advantageous for practical applications. Figure 8 shows the measured maximum antenna gain and simulated radiation efficiency. Over the GSM850/900 bands shown in Figure 8(a), the measured antenna gain is about −0.5 to 0.5 dBi, and the efficiency is about 50–80%. Over the GSM1800/1900/UMTS/WLAN bands shown in Figure 8(b), the measured antenna gain is about 1.0–2.6 dBi, and the efficiency is about 65–80%.

## 4. CONCLUSION

A promising internal six-band antenna suitable for small-size mobile phone application has been proposed. Three conventional monopole elements are used for the proposed antenna. By applying the technique of using capacitive coupling between two longer monopoles of the antenna and further incorporating an external parallel chip inductor, a dual-resonance wide operating band at about 900 MHz for the antenna's lower band has been achieved. In this case, although the system ground plane of the mobile phone is with a short length of 60 mm only, the obtained bandwidth of the antenna's lower band can easily cover the desired GSM850/900 operation. Moreover, the three monopoles can contribute three resonant modes to form into a wide operating band for the antenna's upper band, allowing it to easily cover the desired GSM1800/1900/UMTS/WLAN operation. Over the obtained six operating bands, good radiation characteristics have also been obtained, and there are generally no radiation nulls in the azimuthal plane of the mobile phone. With the six-band operation obtained, the proposed antenna is promising for application in the small-size mobile phone for WWAN and WLAN dual-network communications.

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