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COMPACT MULTIBAND PIFA WITH A COUPLING FEED FOR INTERNAL MOBILE PHONE ANTENNA

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ABSTRACT: *A compact multiband PIFA (planar inverted-F antenna) occupying a very small volume of less than 0.8 cm^3 in the mobile phone for GSM/DCS/PCS/UMTS operation is presented. The PIFA uses a single resonant path only, which is close to about one-eighth wavelength at 900 MHz. A coupling feed, different from the conventional direct feed, is proposed to excite the PIFA. In this case, the large input impedance at 900 and 1900 MHz can be greatly decreased, making it promising to excite two operating bands at about 900 and 1900 MHz to cover the desired multiband operation. Good radiation characteristics for frequencies over the operating bands are also obtained. The occupied volume of the proposed multiband PIFA is about the smallest among the reported internal multiband mobile phone antennas.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 2487–2491, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23727

Key words: *internal mobile phone antennas; PIFA (planar inverted-F antenna); multiband operation; coupling feed*

1. INTRODUCTION

Conventional planar inverted-F antennas (PIFAs) have been widely applied in the mobile phone as internal antennas for dual-band or multiband operation at about 900 and 1900 MHz [1]. These PIFAs generally use two separate resonant paths of different lengths operated at their quarter-wavelength modes to cover the operating bands at about 900 and 1900 MHz. It is also promising to use the first two resonant modes of a single resonant path operated at its quarter- and half-wavelength modes. These conventional PIFAs usually occupy a volume of larger than 2 cm^3 inside the mobile phone for 900/1900 MHz operation. In this article, we demonstrate a novel compact multiband PIFA with an occupied volume of less than 0.8 cm^3 in the mobile phone to cover GSM (890–960 MHz), DCS (1710–1880 MHz), PCS (1850–1990 MHz), and UMTS (1920–2170 MHz) operation. Such a small occupied volume is about the smallest among the conventional internal multiband mobile phone antennas [1].

The proposed PIFA comprises a single resonant path close to about one-eighth wavelength at 900 MHz only, and a coupling feed [2] is used, which is different from the use of a direct feed of the conventional PIFAs. With the coupling feed, the large input impedance at 900 and 1900 MHz can be greatly decreased to allow the proposed PIFA to generate two operating bands at about 900 and 1900 MHz to cover the desired multiband operation. The coupling feed in the proposed PIFA can also be considered as an internal matching circuitry, which does not increase the occupied volume of the antenna inside the mobile phone. This is different from the external matching circuitry that has been reported [3–6], which will occupy some valuable board space on the system circuit board of the mobile phone and increase some insertion loss also. Detailed design considerations of the proposed PIFA are described in the article. Experimental and simulation results for fabricated prototypes of the proposed PIFA are presented and discussed.

2 DESIGN CONSIDERATIONS OF PROPOSED PIFA

Figure 1(a) shows the configuration of the proposed PIFA with a coupling feed for mobile phone application. In this study, the PIFA is printed on a 0.4-mm thick FR4 substrate, which is then folded into a compact configuration to be mounted on the top no-ground portion (size 6 × 60 mm^2) of the system circuit board of the mobile phone. In this study, a 0.8-mm thick FR4 substrate of size 106 × 60 mm^2 is used as the system circuit board; on its back side, there is a printed system ground plane of length 100 mm and width 60 mm. The dimensions of the system circuit board and ground plane considered here are practical for general smart phones or PDA (personal digital assistant) phones [7, 8].

The total occupied volume of the PIFA is 0.78 cm^3 (5 × 6 × 26 mm^3) only. Owing to its small volume, the PIFA is flushed to the left side edge of the system circuit board in this study, leaving a large unoccupied portion in the top no-ground portion of the system circuit board, which can be used to accommodate other

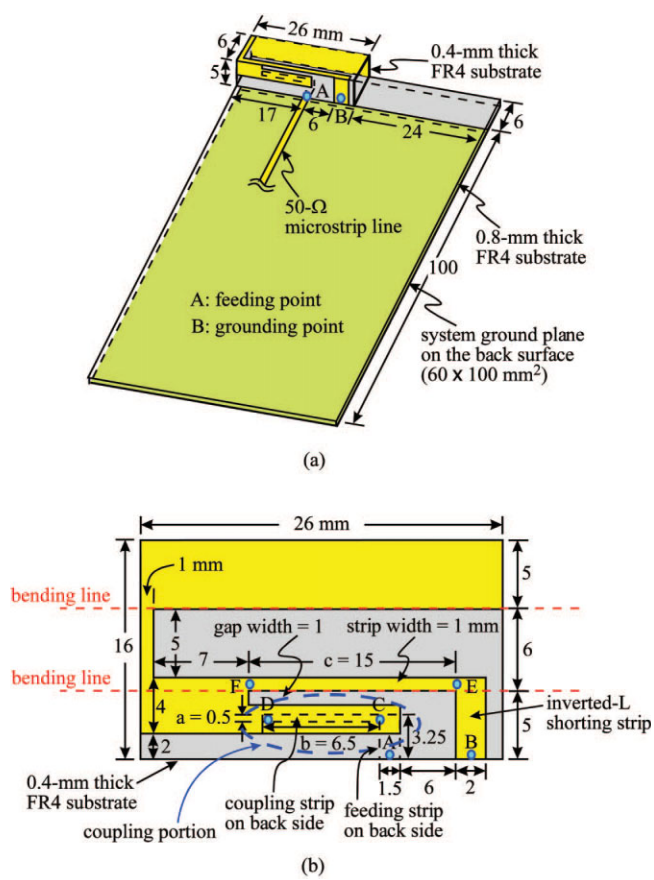

Figure 1 (a) Configuration of the compact multiband PIFA with a coupling feed for internal mobile phone antenna. (b) Dimensions of the metal pattern of the proposed PIFA unfolded into a planar structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

possible electronic components such as the speaker or lens of the embedded digital camera [9–11]. To feed the PIFA in the experiment, a 50-Ω microstrip feedline printed on the front side of the system circuit board is used. The microstrip feedline is connected to the PIFA at the feeding point, point A in the figure.

Figure 1(b) shows the dimensions of the metal pattern of the PIFA in its planar structure. The PIFA comprises a folded resonant path, a coupling feed, and an inverted-L shorting strip. The folded resonant path starting from point D to the open end has a length of about 43 mm, close to about one-eighth wavelength at 900 MHz. In this case, when the PIFA is excited using a conventional direct feed, large reactance is usually occurred at 900 MHz, making it difficult to generate an operating band for GSM operation. With the use of the proposed coupling feed, the large reactance at about 900 MHz can be decreased, making it possible for generating a desired operating band at 900 MHz.

The coupling feed consists of a coupling portion and a short feeding strip of length 3.25 mm and width 1.5 mm. One end of the feeding strip is the feeding point (point A) of the PIFA. The coupling portion further comprises a 2-mm long strip printed on the front side of the substrate and a coupling strip CD of width 0.5 mm (*a*) and length 6.5 mm (*b*) printed on the back side of the substrate. The coupling strip is further centered below the long strip, and by varying the dimensions (*a* and *b*) of the coupling strip, the coupling portion can contribute various coupling capacitances to the input impedance of the PIFA. This contributed capacitance can decrease the large input reactance of the PIFA seen at about 900 MHz. In addition, the capacitive coupling can also lead to the lowering of the input resistance of the PIFA at about 900 MHz, making it close to 50 Ω. This behavior allows it very promising for the proposed PIFA to generate an operating band at about 900 MHz.

Also note that, for the conventional feeding method of using a direct feed, the proposed PIFA can generate a quarter-wavelength resonant mode at frequencies close to 1800 MHz. However, with the presence of the coupling feed, the contributed capacitance of the coupling feed will also lower the reactance level around 1800 MHz. This will shift the resonant frequency (zero reactance) of the quarter-wavelength resonant mode to higher frequencies. In this case, it is found that the quarter-wavelength resonant mode of the proposed PIFA can occur at about 1900 MHz with a wide bandwidth. That is, in addition to a new operating band occurred at about 900 MHz as the antenna's lower band, a wide upper operating band at about 1900 MHz can also be obtained. The lower and upper bands can cover GSM and DCS/PCS/UMTS operations, respectively, resulting in a quad-band operation obtained for the proposed PIFA with a very small occupied volume of about 0.78 cm^3 only.

For the inverted-L shorting strip, it comprises a horizontal section EF of length 15 mm (*c*) and a vertical section BE of length 6 mm. One end of the vertical section is the grounding point (point B), which short-circuits the PIFA to the top edge of the system ground plane through a via-hole (not shown in the figure) in the system circuit board. For the horizontal section, it is selected to have a narrow width of 1 mm. Thus, by varying the length *c,* it can effectively lead to some variations in the input inductance of the PIFA, that is, the input reactance of the PIFA can also be adjusted. The length *c* of the horizontal section can therefore be treated as an additional parameter for tuning the input impedance of the PIFA, in addition to the parameters *a* and *b* of the coupling feed. The inverted-L shorting strip and the coupling feed can hence be considered as an internal matching circuitry for the proposed PIFA. Detailed effects of the parameters *a, b,* and *c* on the impedance matching of the PIFA are studied in Figures 4 and 5 in the next section.

3. RESULTS AND DISCUSSION

The proposed PIFA with dimensions given in Figure 1 is fabricated and tested. Figure 2 shows the measured and simulated return loss for the fabricated PIFA. Although the proposed PIFA occupies a very small volume and its resonant length is only about one-eighth of the wavelength at 900 MHz, there are two operating bands generated and the lower band is excited around 900 MHz as designed. The lower band has a 3:1 VSWR (6-dB return loss) bandwidth of 90 MHz (880–970 MHz), which covers GSM operation. Note that the 3:1 VSWR bandwidth definition is generally accepted for practical applications. For the upper band, a much wider bandwidth is obtained, which reaches 475 MHz (1695–2170 MHz) and covers DCS/PCS/UMTS operation. Good agreement between the measured data and simulated results obtained from Ansoft HFSS (High Frequency Structure Simulator) [12] is seen.

For comparison, the simulated return loss and input impedance of the proposed PIFA and the reference PIFA are shown in Figure 3. The geometry of the reference PIFA is also shown in Figure 3, and it is a corresponding conventional PIFA with a direct feeding strip. The corresponding dimensions of the two PIFAs are the same, except that there is no coupling portion in the reference PIFA, making its feeding point A moved closer to the left side edge of the system circuit board. From Figure 3(a), it is clearly seen that there is only one resonant mode at about 1650 MHz excited for the reference PIFA. This is reasonable, since the reference PIFA has a resonant length close to a quarter-wavelength at that frequency.

From the input impedance shown in Figure 3(b), it is seen that the input resistance and reactance levels at about 900 MHz are very large for the reference PIFA. This can explain why there is no excited mode seen at 900 MHz for the reference PIFA. However, for the proposed PIFA, largely owing to the presence of the coupling feed, both the input resistance and reactance levels are decreased. At about 900 MHz, the input reactance has a zero value (that is, the PIFA is at resonance), and the input resistance is close to 50 Ω and its variation versus frequency is also smoother than that of the reference PIFA. A resonant mode with wide bandwidth to cover GSM operation can hence be excited at about 900 MHz for the proposed PIFA. On the other hand, the lowering of the input reactance level also makes the zero reactance at about 1650 MHz shifted to be at about 1900 MHz, making a second resonant

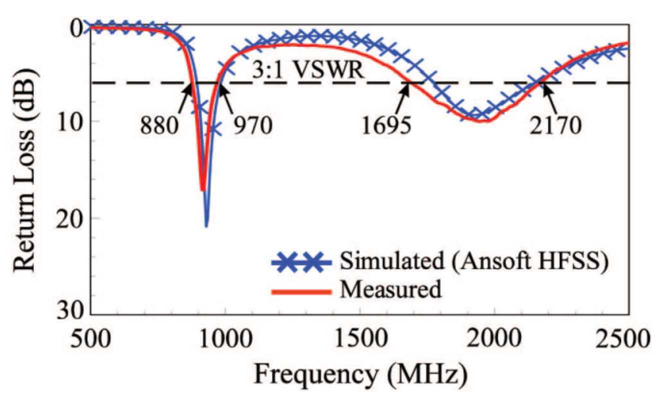

Figure 2 Measured and simulated return loss for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

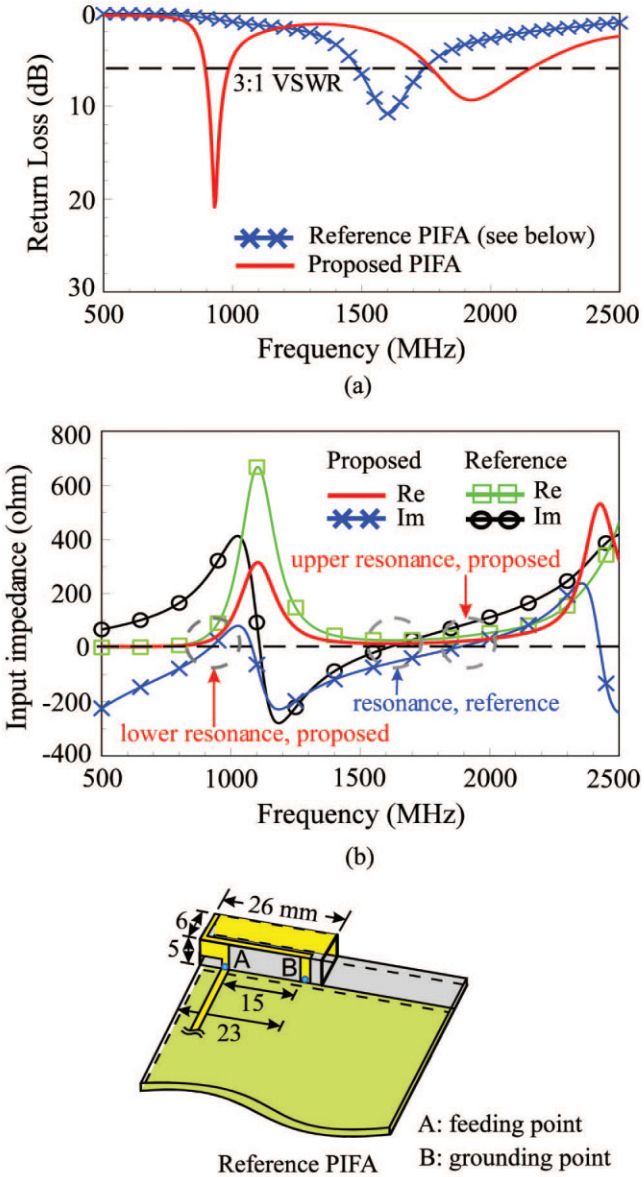

Figure 3 Simulated (a) return loss and (b) input impedance of the proposed PIFA and the reference PIFA (the corresponding conventional PIFA with a direct feeding strip). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

mode excited for the proposed PIFA to cover DCS/PCS/UMTS operation.

Since the coupling feed controls the excitation of the two operating bands for the proposed PIFA, the parameters *a* and *b* of the coupling strip in controlling the coupling capacitance of the coupling feed can affect the occurrence of the two excited bands. Figure 4(a) shows the simulated return loss as a function of the width *a* varied from 0.3 to 0.7 mm; other parameters fixed as shown in Figure 1. The simulated return loss as a function of the length *b* varied from 4.5 to 8.5 mm is presented in Figure 4(b). From the results, it is clearly seen that the proper selection of the parameters *a* and *b* can effectively fine-tune the excited two modes to occur at about 900 and 1900 MHz for the desired quad-band operation in this study.

Figure 5 shows the simulated return loss for the proposed PIFA as a function of the length *c* of the section EF in the inverted-L shorting strip. Since the length *c* can lead to some variations in the

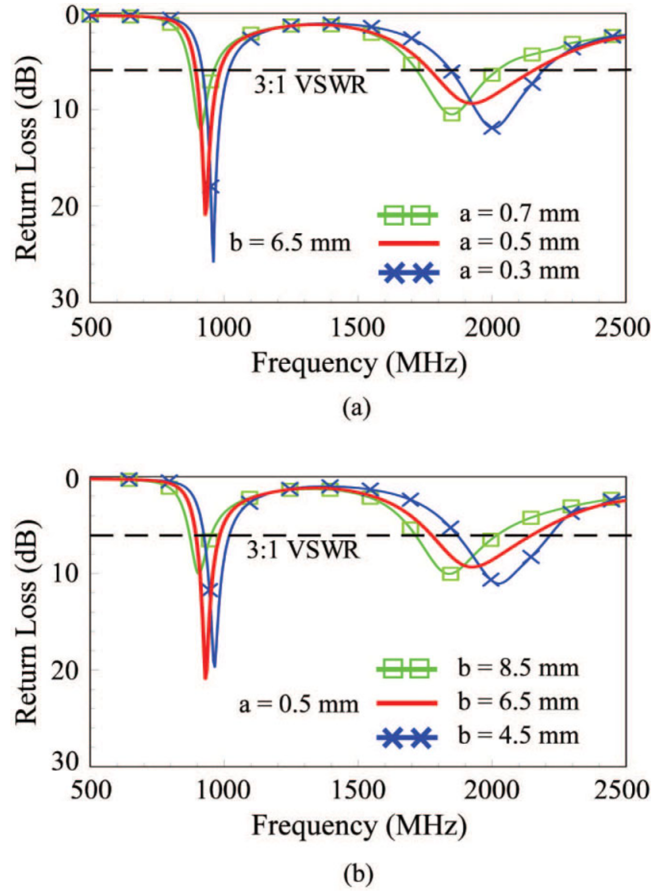

Figure 4 Simulated return loss for the proposed PIFA as a function of (a) the width *a* and (b) the length *b* of the coupling strip in the coupling feed; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

contributed inductance to the input impedance of the PIFA, the resonant frequencies with null input reactance can be varied, hence leading to some shifting in the excited two resonant modes of the proposed PIFA. This behavior is similar to those observed in Figure 4 for the parameters *a* and *b*.

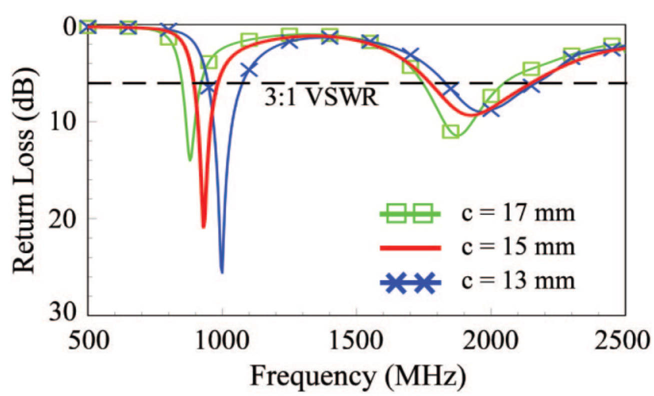

Figure 5 Simulated return loss for the proposed PIFA as a function of the length *c* of the section EF in the inverted-L shorting strip; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

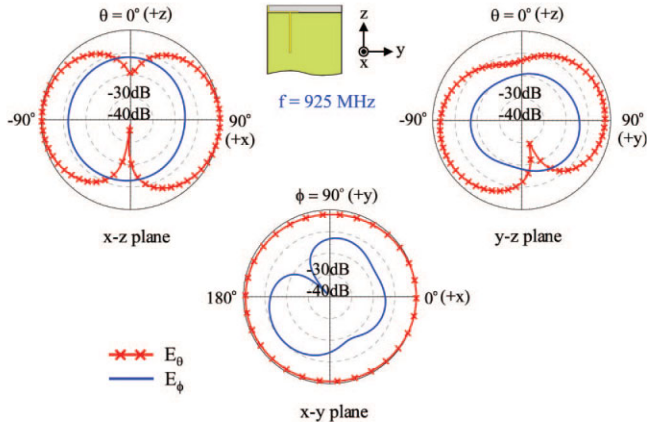

Figure 6 Measured radiation patterns at 925 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

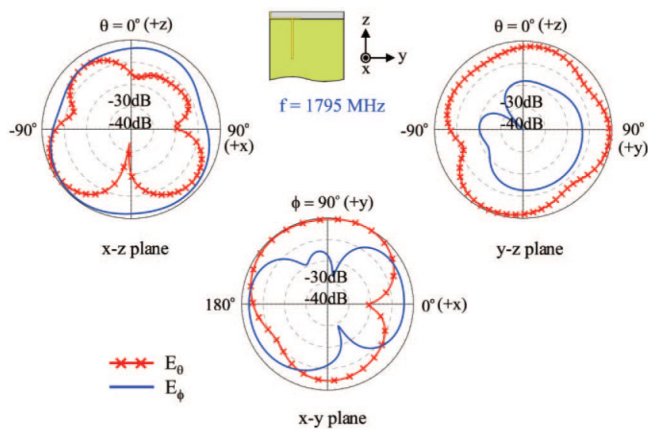

Figure 7 Measured radiation patterns at 1795 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

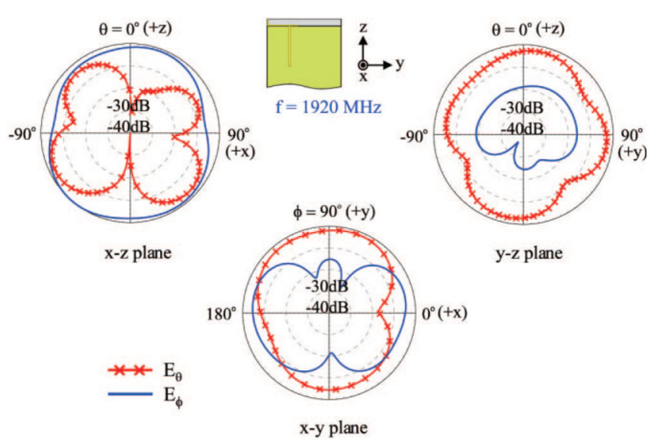

Figure 8 Measured radiation patterns at 1920 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

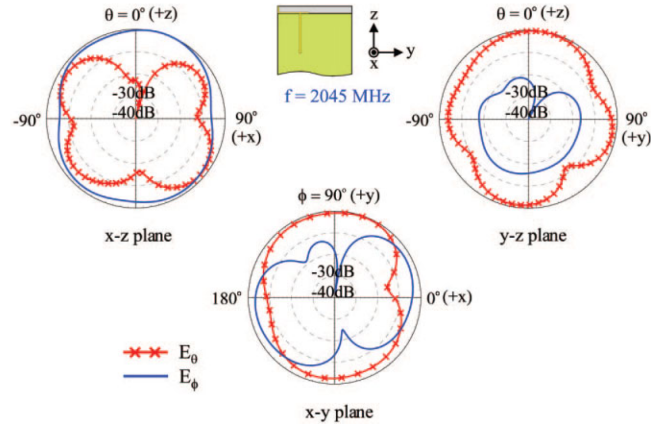

Figure 9 Measured radiation patterns at 2045 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

The radiation patterns of the proposed PIFA are also studied. Figure 6 plots the measured radiation patterns at 925 MHz, center frequency of the GSM band. Dipole-like radiation patterns are seen at 925 MHz, and omnidirectional radiation in the *x-y* plane (azimuthal plane) is obtained. Results at other frequencies are also measured, and very similar patterns as plotted here are obtained, indicating that stable radiation patterns are achieved. For the

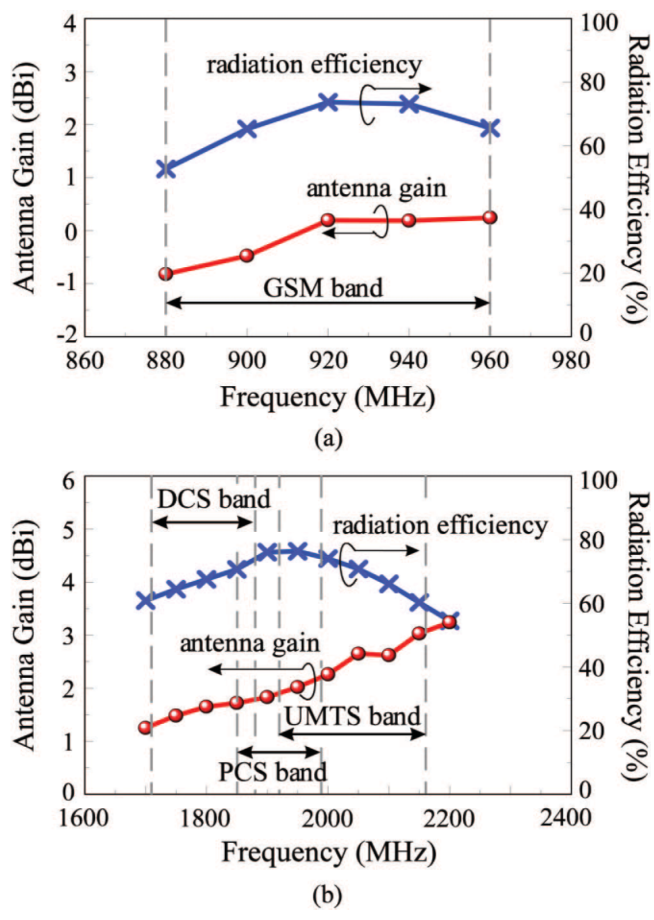

Figure 10 Measured antenna gain and simulated radiation efficiency of the proposed PIFA. (a) The lower band for GSM operation. (b) The upper band for DCS/PCS/UMTS operation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

radiation patterns for frequencies over the upper band, Figures 7–9 plot the measured radiation patterns at 1795, 1920, and 2045 MHz, which are center frequencies of the DCS, PCS, and UMTS bands, respectively. Again, similar radiation patterns are seen, that is, stable patterns are also obtained over the upper band. These radiation patterns show no special distinctions compared with those of the conventional PIFA for DCS, PCS, or UMTS operation [1]. The measured antenna gain and simulated radiation efficiency are presented in Figure 10. Over the GSM band shown in Figure 10(a), the antenna gain is varied from about −0.8 to 0.1 dBi, and the radiation efficiency is all larger than 52%. Over the DCS/PCS/UMTS bands shown in Figure 10(b), the antenna gain is varied from about 1.3–3.1 dBi, and the radiation efficiency is all better than 60%.

4. CONCLUSION

An internal PIFA with a volume as small as 0.78 cm^3 for quad-band operation in the mobile phone has been proposed and studied. The small volume of the proposed PIFA is owing to the use of the coupling feed replacing the direct feed for the conventional PIFA. The coupling feed makes it possible for the excitation of a one-eighth-wavelength resonant mode at about 900 MHz, and moreover, a wide quarter-wavelength resonant mode at about 1900 MHz can also be excited. The two excited resonant modes cover GSM and DCS/PCS/UMTS operations for the proposed PIFA in the study. Good radiation characteristics for frequencies over the operating bands have also been observed. The proposed PIFA is very promising for practical applications as a compact quad-band internal mobile phone antenna.

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A DUAL-BAND REJECTED CROSS MONOPOLE ANTENNA MAINTAINING OMNIDIRECTION RADIATION

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ABSTRACT: *UWB cross semi-elliptic monopole antenna with a dual-band rejected characteristic is presented and experimentally studied. The proposed cross bevel-rectangular monopole antenna is embedded with four small h-shaped slots; it produces a design of dual-band rejected characteristics and maintains omnidirection radiation. This technique is suitable for creating multiwideband antenna or ultrawideband (UWB) antenna with dual-rejected band. And the proposed antenna with good omnidirection characteristic is also maintained. Details of the results for the proposed antenna are presented and discussed in this study.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 2491–2493, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23712

Key words: *cross monopole antenna; bevel-rectangular monopole; dual-band-rejected operation; omnidirectional radiation; UWB antennas*

1. INTRODUCTION

Recently, the monopole antenna has been renewal of interest about to create ultra-wideband (UWB) antenna, it is because of which has very wide impedance bandwidth, omnidirectional radiation pattern, and simple structure [1–4]. However, the planar monopole antenna has non-omnidirectional radiation pattern at higher frequency. The cross monopole antennas [5–7] have received more attention due to its omnidirectional radiation. On the other hand, a wideband system normally overlaps several narrowband wireless technologies such as wireless local area network (WLAN) system about 5.15- to 5.825-GHz bands. It leads to that the UWB devices are required to provide filtering in those bands to avoid interference between the UWB and WLAN systems. But the UWB system uses a filter which increases the complexity of the UWB system. An UWB antenna having band-rejected operation can be a substitute for filter to overcome this problem. Several papers had been devoted to study band-rejected antennas [8–12]. The one band-rejected on planar monopole antenna in [8] and on cross monopole antenna in [9]. But, one band-rejected operation is insufficient for modern or future wireless communication. Thus the multi-wideband antennas or the antennas with dual (even above) band-rejected operation and having good omnidirectional radiation pattern become an important issue [10–12].

In this article, a dual-band rejected design for cross monopole antenna is proposed and experimentally studied. The proposed antenna consists of a UWB cross monopole antenna and the small h-shaped slots, producing dual band-rejected characteristics; moreover, it has good omnidirectional radiation pattern better than [12]. Details of the results for the proposed antenna are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed antenna, which consists of a cross bevel-rectangular monopole antenna and small h-shaped slots. Prototypes of cross monopole antenna were fabricated and vertically mounted on a 120 × 120 mm^2 finite square ground plane at spacing $G = 1$ mm. Antenna element and ground