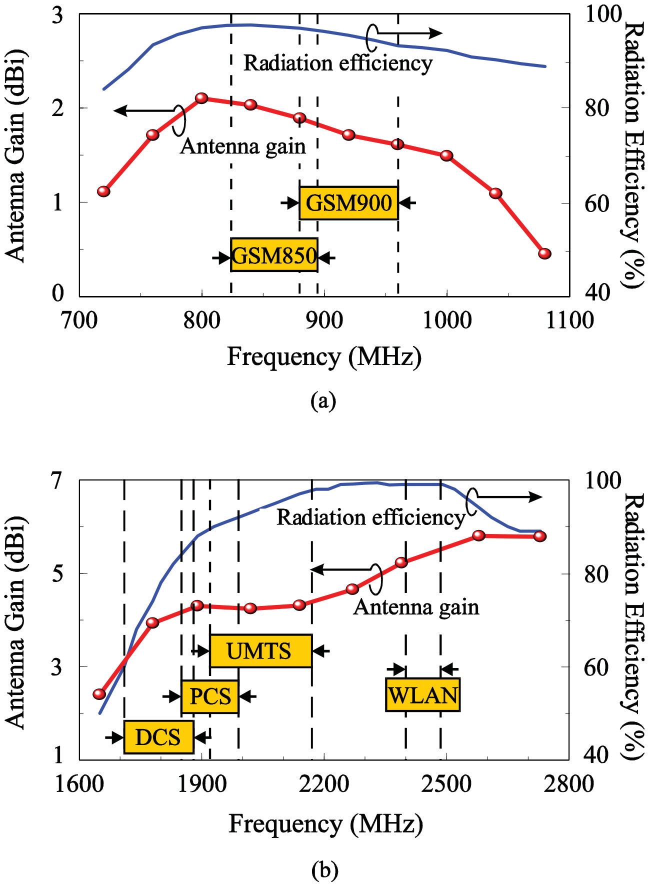

Figure 7 Measured antenna gain and simulated radiation efficiency for the proposed antenna. (a) The GSM850/900 bands. (b) The DCS/PCS/UMTS/WLAN bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

is about 4.2 and 5.3 dBi, respectively. For the radiation efficiency, it is all larger than 85% for PCS/UMTS/WLAN operation.

4. CONCLUSION

A novel internal printed slot antenna for hexa-band operation in the mobile phone has been proposed, constructed, and studied. The antenna has a planar structure and is easy to fabricate at low cost on the system circuit board of the mobile phone. With the compact integration of the C-shaped slot and the monopole slot, which are fed in series by using a simple 50-Ω microstrip feedline centered at the system circuit board, two wide operating bands for covering GSM850/900/DCS/PCS/UMTS/WLAN hexa-band operation have been generated. Good radiation characteristics for frequencies over the operating bands have also been obtained.

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INTERNAL HYBRID ANTENNA FOR MULTIBAND OPERATION IN THE MOBILE PHONE

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ABSTRACT: *A new internal hybrid antenna formed by a printed open-ended slot (monopole slot) and a T-shaped metal-strip monopole (monopole T-strip) for multiband operation in the mobile phone is presented. The monopole slot is printed near the top edge of the system circuit board of the mobile phone and can generate a quarter- wavelength resonant mode at about 900 MHz for GSM850/900 operation. The monopole T-strip is bent and mounted above the monopole slot and is used to excite a quarter-wavelength resonant mode at about 1900 MHz to cover DCS/PCS operation. The monopole slot and monopole T-strip are integrated to occupy a compact volume and can be fed using a simple 50 Ω microstrip line printed on the system circuit board. Obtained results indicate that it is promising to integrate two different types of antennas into an internal hybrid antenna for multiband operation in the mobile phone, and good performances of the hybrid antenna over the operating band can be achieved.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 38–42, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22980

Key words: *internal mobile phone antennas; internal hybrid antennas; monopole slot; antennas; quad-band operation*

1. INTRODUCTION

It has recently been shown that by cutting the printed slot at the edge of the ground plane, a quarter-wavelength, or monopole slot antenna can be obtained [1–4]. Such an open-ended monopole slot antenna, different from the traditional half-wavelength slot antenna [5–7], can be operated as a quarter-wavelength resonant structure with a large operating bandwidth. This property makes it very promising to achieve a wide operating band covering GSM850/900 (Global System for Mobile Communication, 824–894 MHz/890–960 MHz) operation with a compact antenna size. It is then found that by integrating a simple T-shaped metal-strip monopole (monopole T-strip) for generating a wide operating band at about 1900 MHz covering DCS/PCS (Digital Communication System, 1710–1880 MHz/Personal Communication System, 1850–1990 MHz) operation, a multiband hybrid antenna suitable for mobile phone application can be obtained. The multiband operation can allow the mobile users to roam in different areas or countries using one single mobile phone and has become a demand for the internal mobile phone antenna design. In this article, such a multiband hybrid antenna formed by one monopole slot and one monopole T-strip is demonstrated. Owing to the use of the two different antenna types studied here, the lower and upper bands of the antenna can generally be controlled separately. This property allows the antenna designer to easily adjust the excited lower and upper bands of the proposed antenna for GSM850/900/DCS/PCS multiband operation. Details of the proposed antenna are described, and results of the fabricated prototype are presented and discussed.

2. DESIGN OF THE PROPOSED HYBRID ANTENNA

Figure 1(a) shows the configuration of the proposed hybrid antenna enclosed by a 1-mm thick plastic mobile phone housing with a relative permittivity of 3.5. The antenna is mainly formed by two monopole elements. One is the printed monopole slot cut at the top portion of the system ground plane of the mobile phone, and the other is the monopole T-strip bent and mounted above the monopole slot with a height of 8 mm. The system ground plane having a length of 100 mm and a width of 60 mm is printed on the back side of a 0.8-mm thick FR4 substrate (relative permittivity 4.4 and loss tangent 0.0245), which is treated as the system circuit board of the mobile phone. Note that the dimensions of the ground plane or system circuit board in the study are selected for the possible applications of the proposed hybrid antenna in the general PDA (personal digital assistant) phone or smartphone. The dimensions of the monopole slot and monopole T-strip of the hybrid antenna are given in Figure 1(b).

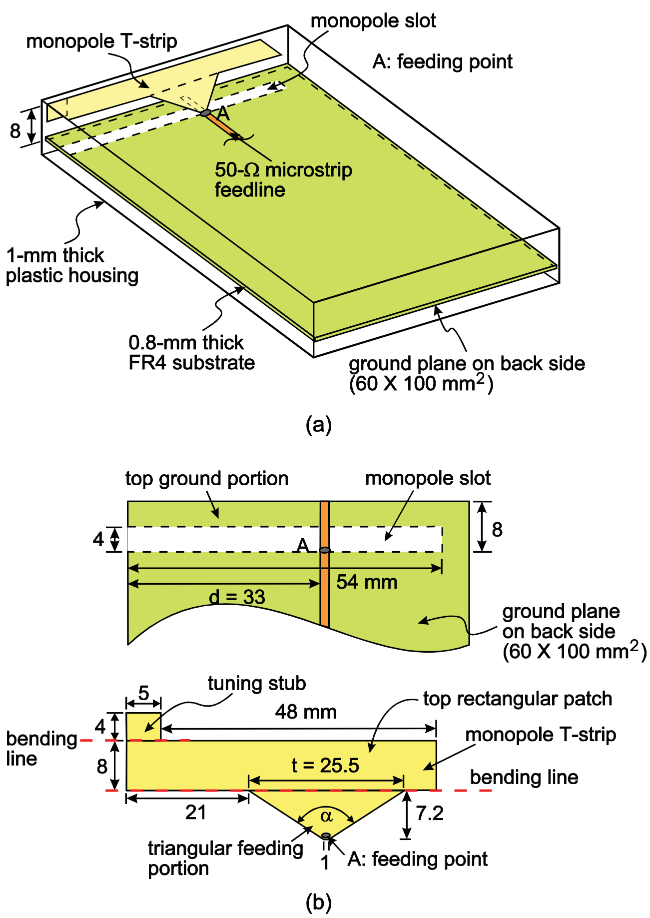

Figure 1 (a) Configuration of the proposed internal multiband hybrid antenna enclosed by a 1-mm thick plastic mobile phone housing. (b) Dimensions of the monopole slot and monopole T-strip of the hybrid antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

The monopole slot has a simple linear shape of length 54 mm and uniform width 4 mm. The monopole slot can generate a quarter-wavelength resonant mode at about 900 MHz to cover GSM850/900 operation, and the presence of the top ground portion of width 4 mm between the monopole slot and the top edge of the system ground plane is required for achieving good excitation of the quarter-wavelength resonant mode. A 50-Ω microstrip feedline printed on the front surface of the system circuit board is used to feed the monopole slot at point A, and the location d of the microstrip feedline is an important factor to obtain good impedance matching of the excited resonant mode. From the study, the optimal location d is determined to be 33 mm, which is about 60% of the length (54 mm) of the monopole slot. Detailed effects of the location d on the impedance matching of the antenna will be discussed with the aid of Figure 4 in the next section. Also note that the monopole slot and monopole T-strip are fed in parallel by the microstrip feedline at point A.

The monopole T-strip is easily made of a metal plate and is bent to be mounted above the monopole slot. The monopole T-strip can generate a quarter-wavelength resonant mode covering DCS/PCS operation, and it comprises a triangular feeding portion, a top rectangular patch of size 8 × 53 mm^2, and a small tuning stub of size 4 × 5 mm^2. The top rectangular patch is in parallel to the monopole slot with a height of 8 mm, while the triangular feeding portion and tuning stub are orthogonal to the system ground plane. The monopole T-strip unbent into a planar structure is shown in Figure 1(b), and the tuning stub is added at the far end of the top rectangular patch away from the triangular feeding portion. With the adding of the tuning stub, the effective resonant length of the monopole T-strip can be lengthened, without increasing the occupied volume of the antenna, and the excited resonant mode can thus be shifted to lower frequencies. This result can lead to a compact size of the proposed hybrid antenna (8 × 8 × 54 mm^3 here).

The triangular feeding portion has a flare angle of α facing an edge of length 25.5 mm (t). By selecting a suitable flare angle α or length t, the impedance matching of the antenna's upper band controlled by the monopole T-strip can be greatly improved. This behavior is mainly because the triangular feeding portion can provide as a smooth transition region [8, 9] between the microstrip feedline and the top rectangular patch. Results of the impedance matching of the antenna as a function of the length t are presented in Figure 5, and its effects will be discussed in Section 3. In addition, it is noted that the monopole T-strip is asymmetric with respect to point A, which is also helpful in achieving an enhanced bandwidth of the antenna's upper band controlled by the monopole T-strip [10].

3. RESULTS AND DISCUSSION

The proposed hybrid antenna was fabricated and studied. Figure 2 shows the measured and simulated return loss of the fabricated prototype. The simulated results are obtained using Ansoft HFSS (high frequency structure simulator) [11], and agreement between the measurement and simulation is seen. Two wide operating bands at about 900 and 1900 MHz are excited with good impedance matching. The impedance bandwidth of the lower band defined by 3:1 VSWR, which is generally adopted for practical

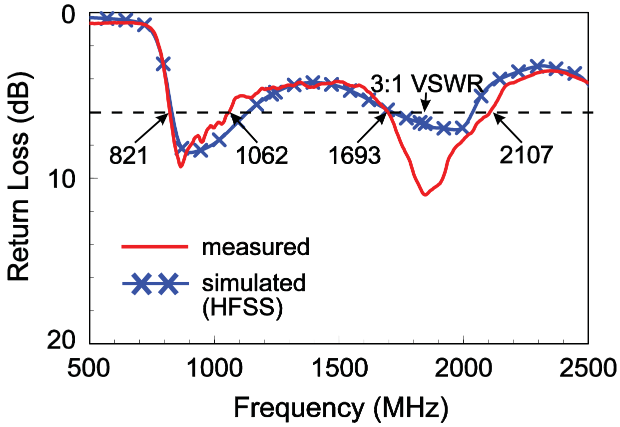

Figure 2 Measured and simulated return loss for the proposed hybrid antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

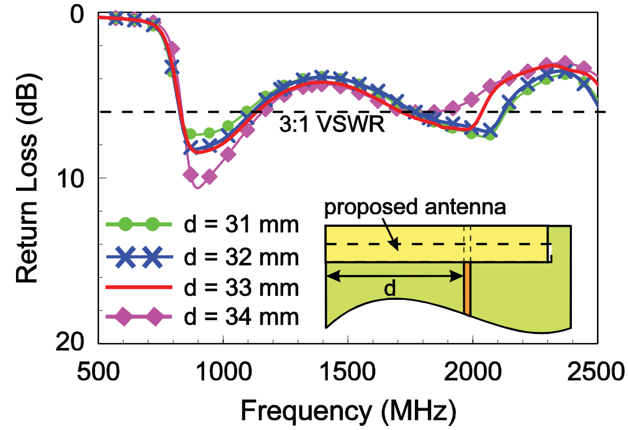

Figure 4 Simulated return loss as a function of the feedline location *d*; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

mobile phone antenna design, is as large as 241 MHz or about 26% with respect to 900 MHz. This wide lower band allows the antenna to easily cover GSM850/900 operation. A large operating band centered at 1900 MHz is also obtained. The bandwidth reaches 414 MHz or about 22% with respect to 1900 MHz and satisfies the required bandwidth of DCS/PCS operation. From the results, quad-band operation is obtained for the proposed hybrid antenna.

Figure 3 shows a comparison of the simulated return loss for the proposed hybrid antenna, the case with the monopole slot only, and the case with the monopole T-strip only. All the corresponding dimensions are the same for the three antennas. Results clearly show that the lower and upper bands of the antenna are mainly controlled by the monopole slot and the monopole T-strip, respectively. The presence of the monopole T-strip also leads to the bandwidth enhancement of the lower band controlled by the monopole slot, and vice versa. This indicates that the monopole slot and the monopole T-strip are two promising antenna elements for forming the proposed hybrid antenna for multiband operation in the mobile phone.

Effects of the location *t* of the microstrip feedline are studied in Figure 4, in which results of the simulated return loss for the location *t* varied from 31 to 34 mm are shown. It is seen that a proper selection of the location *t* is important for achieving good impedance for frequencies over the antenna's lower and upper bands. For covering the desired GSM850/900/DCS/PCS quad-band operation, the location *t* is selected to be 33 mm in this study.

Figure 5 shows the results of the simulated return loss as a function of the length *t* of the triangular feeding portion, and results of the length *t* varied from 9.5 to 33.5 mm are presented. As expected, the triangular feeding portion shows small effects on the lower band, which is mainly controlled by the monopole slot, but causes large variations in the impedance matching over the upper band controlled by the monopole T-strip. Results show that when the length *t* is chosen to be 25.5 mm, corresponding to a flare angle α of 118°, good impedance matching over the antenna's lower and upper bands for GSM850/900/DCS/PCS operation is obtained for the proposed hybrid antenna.

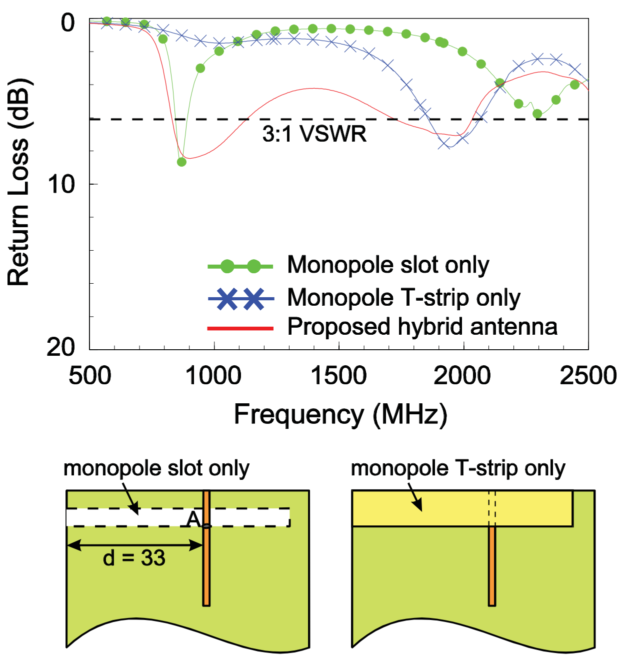

Figure 3 Comparison of the simulated return loss for the proposed hybrid antenna, the case with the monopole slot only, and the case with the monopole T-strip only. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

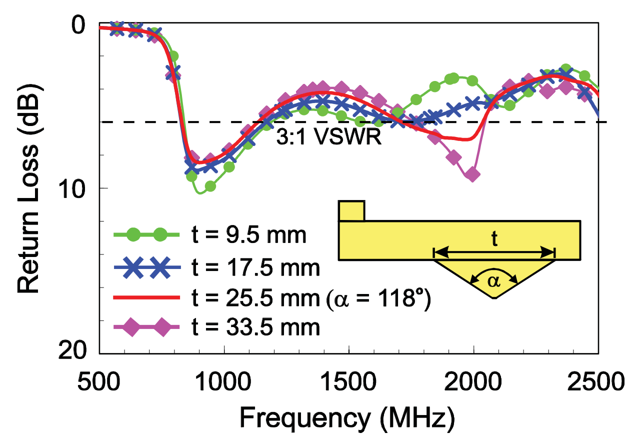

Figure 5 Simulated return loss as a function of the length *t* of the triangular feeding portion; other dimensions are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

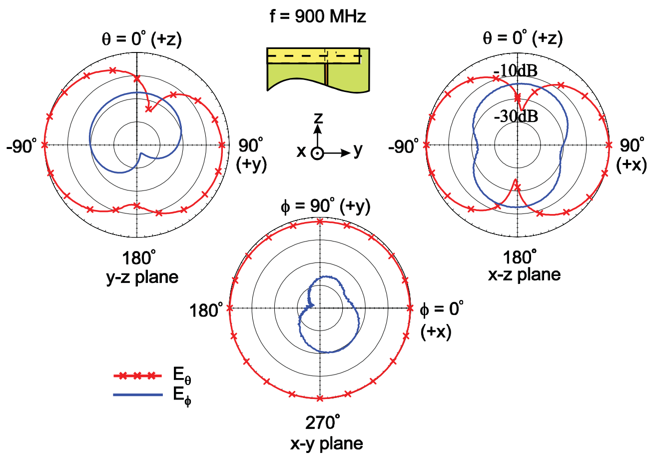

Figure 6 Measured radiation patterns at 900 MHz for the hybrid antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Radiation characteristics of the fabricated prototype studied in Figure 1 are also studied. Figure 6 plots the radiation patterns at 900 MHz, and similar patterns at other frequencies over the lower band as plotted here are also observed. This indicates that stable patterns are obtained over the GSM850/900 bands, and monopole-like radiation patterns are seen, which are similar to those of the conventional internal mobile phone antennas [12]. Figures 7 and 8 plot the radiation patterns at 1795 and 1920 MHz, center frequencies of the DCS and PCS bands. Comparable E_θ and E_ϕ components in the three principal planes are seen, and the radiation patterns also show no special distinction compared to those of the conventional internal mobile phone antennas [12]. Figure 9 shows the measured antenna gain and simulated radiation efficiency. As shown in Figure 9(a), the efficiency is varied from 42 to 70% and the antenna gain is in the range of −0.4 to 1.4 dBi for the GSM850 band. While for GSM900 band, a stable efficiency of about 70% is seen and the antenna gain is varied from 1.3 to 1.8 dBi. For the DCS/PCS bands shown in Figure 9(b), the efficiency is all larger than 62% and the antenna gain is about 3.8 dBi over the DCS band and about 3.2–3.8 dBi over the PCS band. From the results, the efficiency and antenna gain of the proposed hybrid antenna are good for practical quad-band operation in the mobile phones.

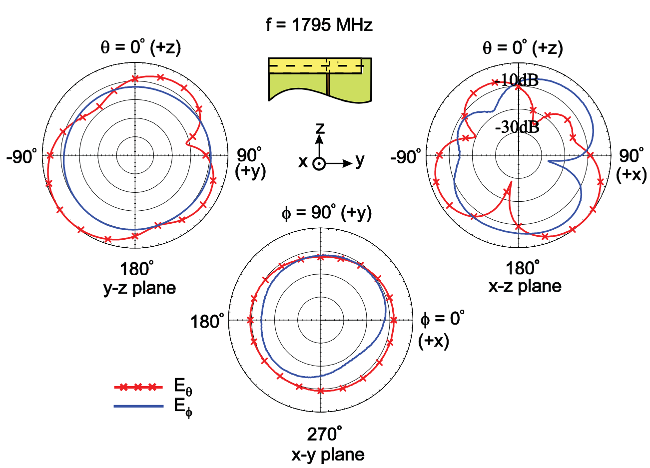

Figure 7 Measured radiation patterns at 1795 MHz for the hybrid antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

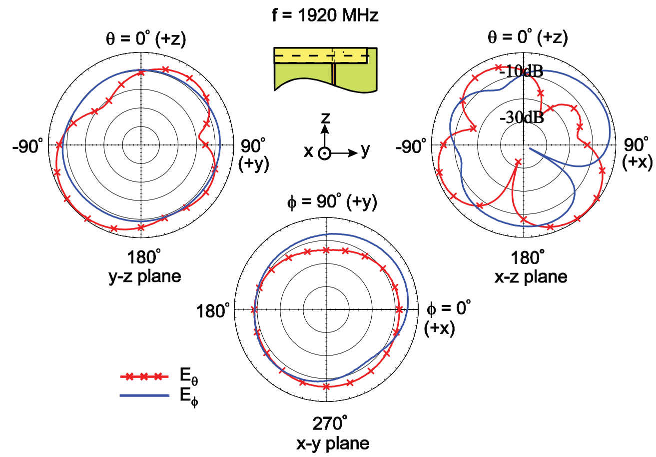

Figure 8 Measured radiation patterns at 1920 MHz for the hybrid antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

4. CONCLUSION

A promising quad-band internal hybrid mobile phone antenna formed by a monopole slot and a monopole T-strip has been

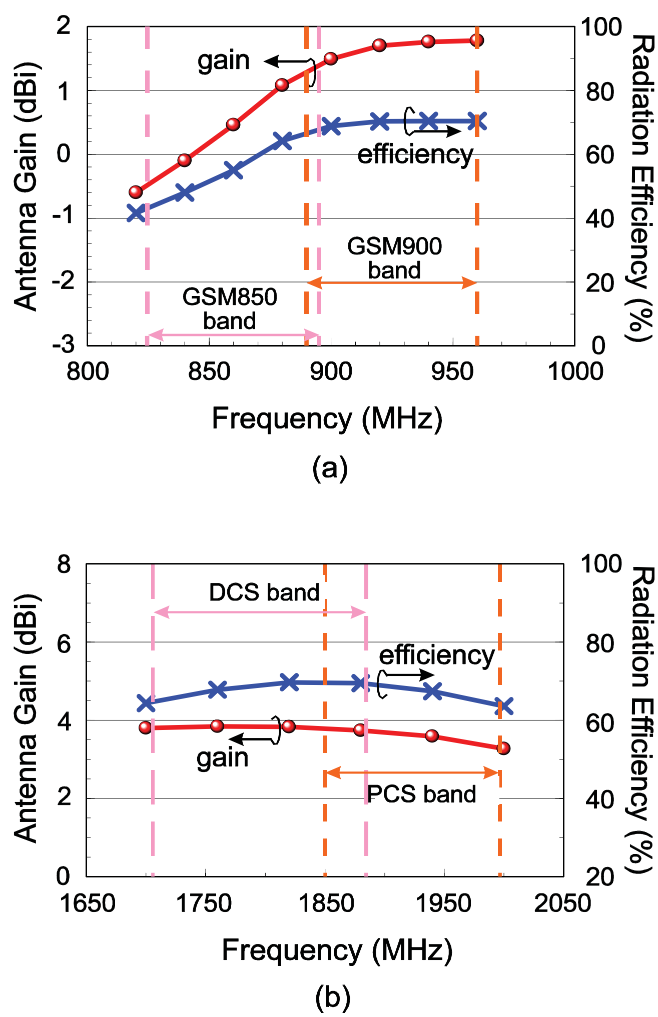

Figure 9 Measured antenna gain and simulated radiation efficiency for the hybrid antenna. (a) The GSM850/900 bands. (b) The DCS/PCS bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

proposed and studied. The hybrid antenna can generate two wide operating bands at about 900 and 1900 MHz to cover the GSM850/900 and DCS/PCS operation, respectively. The hybrid antenna also shows an attractive feature that the obtained two wide operating bands are mainly controlled by the monopole slot and the monopole T-strip, respectively. This feature makes the fine-adjustment of the antenna's lower and upper bands easy to achieve. Although formed by two different monopole elements, the antenna occupies a reasonable volume of $8 \times 8 \times 54$ mm^3 and is easy to fabricate at low cost. In addition, the hybrid antenna shows good radiation characteristics for frequencies over the desired GSM850/900/DCS/PCS bands, making the antenna a very promising candidate for internal quad-band mobile phone antennas.

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DESIGN OF ASYMMETRICAL COMPACT MICROSTRIP RESONATOR FILTER WITH FOUR CONTROLLABLE TRANSMISSION ZEROS

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ABSTRACT: *This article presents a method of synthesizing a microwave filter consisting of asymmetrical compact microstrip resonators. This filter is compact in size and exhibits a third-order characteristic in the passband and four controllable transmission zeros on the stop bands to enhance the desired signal rejection. A filter synthesizing method is developed to obtain the appropriate values of filter elements. Then the practical layout of filter is determined with the help of a commercial EM simulator. The efficiency of proposed design concept is verified through the design and measurement of an experimental Ku-band filter. A prototype is fabricated on the commercial Teflon PCB board with 3% bandwidth. The measured results show about 2 dB insertion loss and greater than 20 dB return loss in the passband.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 42–45, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22977

Key words: *microstrip filter; transmission zeros; asymmetrical compact microstrip resonator*

1. INTRODUCTION

High performance filters are important components in wireless communication systems to reject the unwanted signals. To achieve low-loss, high selectivity, and compact size properties of the modern microwave filter, various filter configurations such as hairpin resonators, ring resonators, and λ/8 resonators have been reported [1–4]. For obtaining more rejection on stop-band, three kinds of filter features, which are the trisection coupled-resonator filters, the dual-behavior resonator filters, and the compact microstrip resonator cells filter, also have been reported recently to achieve the characteristics with more than one transmission zeros to enhance the signal rejection [4–9]. One of these filters, which is consisting of asymmetrical compact microstrip resonator (ACMR) as that enclosed by dotted line in Figure 1, was proposed to realize a Ku-band filter with very compact size and having fast roll-offs in the edges of pass band by placing two controllable transmission zeros at the neighbor of corner frequencies. Although the fast roll-offs are exhibited by the ACMR filter in [9], but the existences of stop-band ripples on the stop bands limit maximum stop-band attenuation that might not satisfy the request of system. Another drawback of design method in [9] is not suitable for implementing the filter with narrow band performance; because the fast variation of the impedance caused by the ACMR in pass band results the elements of the filter are unable to be practically implemented. In this article, a new method of synthesizing the ACMR filter is proposed, which places two transmission zeros of each ACMR at either lower or upper stop bands to let the impedance of the ACMR to be inductive or capacitive in the passband; so that the conven-

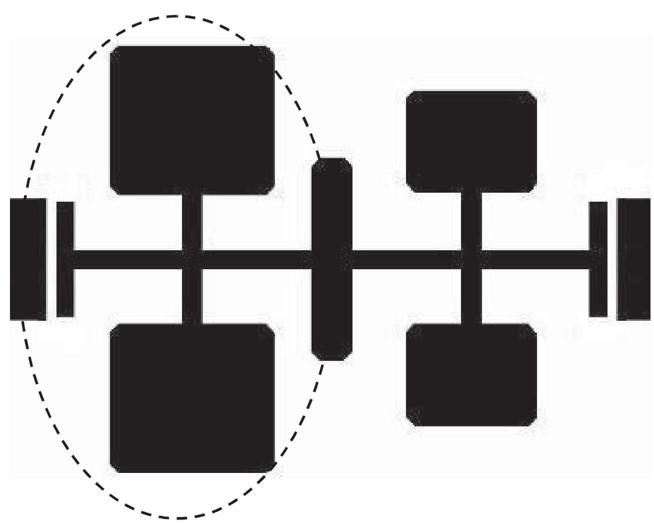

Figure 1 Geometry of a third-order bandpass filter consisted of ACMR