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PRINTED COMPACT S-SHAPED MONOPOLE ANTENNA WITH A PERPENDICULAR FEED FOR PENTA-BAND MOBILE PHONE APPLICATION

Chih-Hsien Wu and Kin-Lu Wong
Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 804, Taiwan, Republic of China; Corresponding author: wuch@ema.ee.nsysu.edu.tw

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ABSTRACT: *A printed compact S-shaped monopole antenna for penta-band mobile phone application is presented. The S-shaped monopole antenna has a uniplanar structure and can be printed on an FR4 substrate of small size 10 × 45 mm^2 to achieve a compact configuration. By mounting the antenna above the top edge of the system ground plane of the mobile phone and feeding it using a perpendicular feed, the antenna occupies a small volume in the top portion of the mobile phone. This makes it especially suited for application in the thin mobile phone in which the embedded internal antenna is required to be small in occupied volume and narrow in width. In addition, the antenna can generate two wide operating bands at about 900 and 2000 MHz to cover the GSM850/900 and DCS/PCS/UMTS operation, respectively. Details of the proposed antenna are presented.* © 2007 Wiley Periodicals, Inc.
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Key words: *printed monopole antenna; mobile phone antenna; penta-band operation; perpendicular feed*

1. INTRODUCTION

Multiband operation such as quad-band or penta-band operation has recently become a general requirement for the mobile phone antenna design. For the penta-band operation, the required bandwidths of the mobile phone antenna for its lower and upper bands are about 136 MHz (824–894/890–960 MHz for GSM850/900 band) and 460 MHz (1710–1880/1850–1990/1920–2170 MHz for DCS/PCS/UMTS band), respectively. In addition, it is also required that such penta-band antennas occupy a small volume inside the mobile phone. When embedded in the thin mobile phone with a thickness of about 10 mm only [1, 2], which is becoming very attractive for many wireless users, the limitation in the occupied volume of the antenna is even more strict. This volume limitation makes the internal antenna design a big challenge for penta-band operation in the thin mobile phone. For this application, we present a promising printed compact S-shaped monopole antenna for penta-band operation. This antenna is a low-profile internal monopole antenna [3-9], and moreover, is uniplanar in structure, allowing it to fabricate at low cost, and also compact in its occupied volume inside the mobile phone. Detailed design considerations of the antenna are described, and results of the fabricated prototype are presented and discussed.

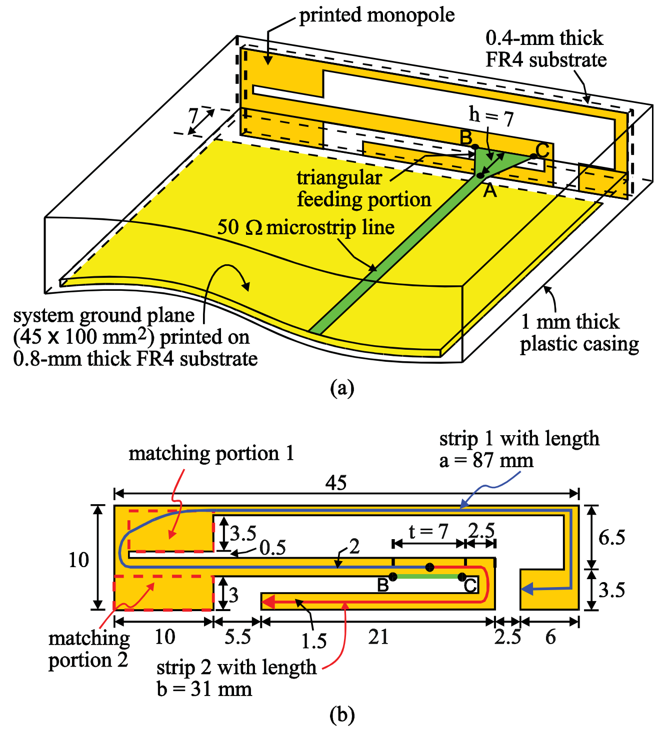

Figure 1 (a) Geometry of the printed S-shaped monopole antenna for penta-band operation; the antenna is enclosed by a 1-mm thick plastic housing. (b) Detailed dimensions of the antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

2. DESIGN CONSIDERATIONS OF PROPOSED ANTENNA

The geometry of the proposed antenna embedded in the top portion of a 1-mm thick plastic casing is shown in Figure 1(a). The plastic casing is treated as the casing of the practical mobile phone. The antenna is a uniplanar S-shaped monopole printed on a 0.4-mm thick FR4 substrate of small size 10 × 45 mm^2, whose dimensions are shown in Figure 1(b). The antenna is mounted above and perpendicular to the top edge of the 0.8-mm thick grounded FR4 substrate in the study, which is considered as the system circuit board of the mobile phone. With the width of the S-shaped monopole limited to be 10 mm only and its orthogonal orientation to the system circuit board, it is promising to place the monopole inside the casing of the thin mobile phone, which usually has a

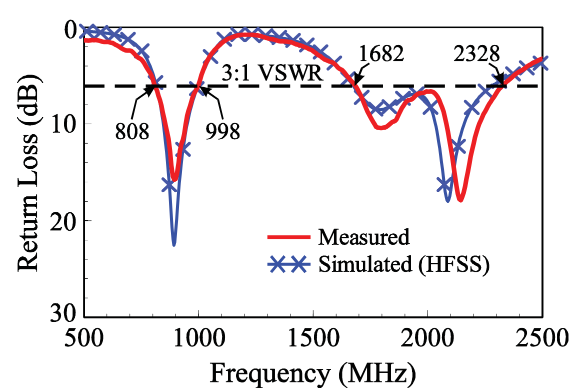

Figure 2 Measured and simulated return loss for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

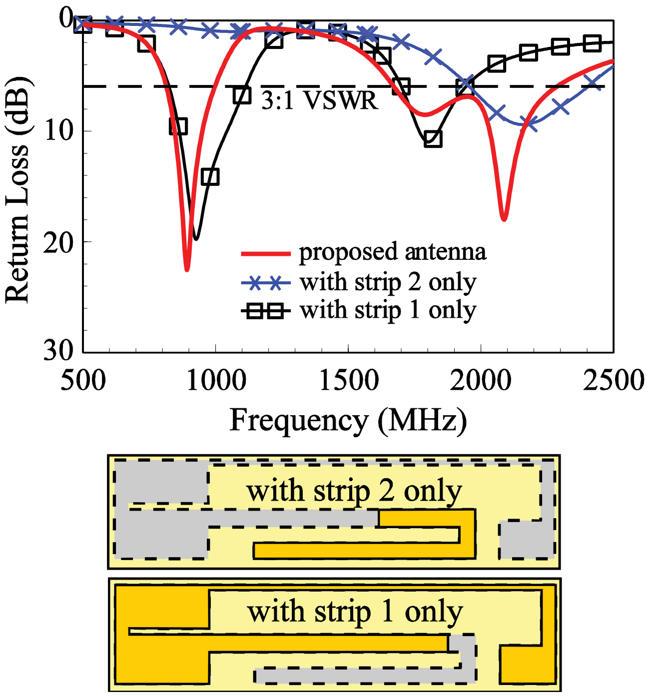

Figure 3 Comparison of the simulated return loss for the proposed antenna, the case with Strip 2 only, and the case with Strip 1 only; related parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

thickness of about 10 mm only, to result in a small occupied volume inside the mobile phone.

On the back surface of the FR4 substrate the system ground plane of width 45 mm and length 100 mm (L) is printed. The groundplane length L is first chosen to be 100 mm, which is a reasonable length for general mobile phones. The length L is expected to have large effects on the achievable operating bandwidths of the internal mobile phone antennas [10], and its detailed effects on the lower and upper bands of the proposed antenna are discussed in Figure 7 in the next section. Also note that the two FR4 substrates used in the study have a relative permittivity of 4.4, and their conductivity is 0.0055 S/m at 900 MHz and 0.013 S/m at 2000 MHz. For the plastic casing, it has a relative permittivity of 3.5, and its conductivity is 0.01 S/m at 900 MHz and 0.025 S/m at 2000 MHz.

Through a triangular feeding portion printed on the top no-ground portion (7×40 mm^2) of the system circuit board, the S-shaped monopole is fed by a 50-Ω microstrip line printed on the

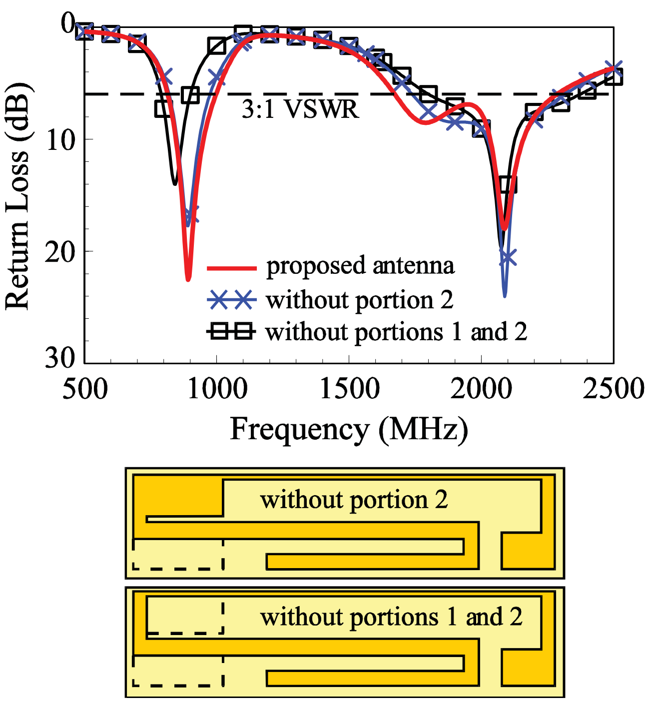

Figure 4 Comparison of the simulated return loss for the proposed antenna, the case without Portion 2, and the case without Portions 1 and 2; related parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

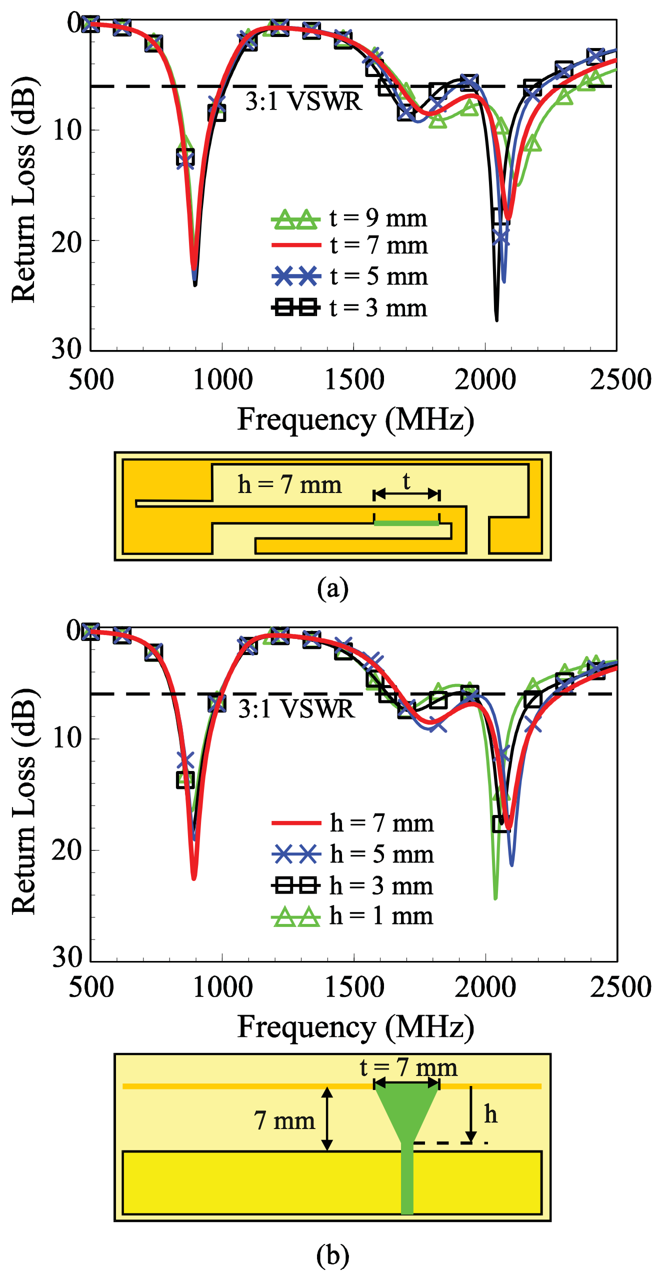

Figure 5 Simulated return loss (a) as a function of the width t and (b) as a function of the height h of the triangular feeding portion; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

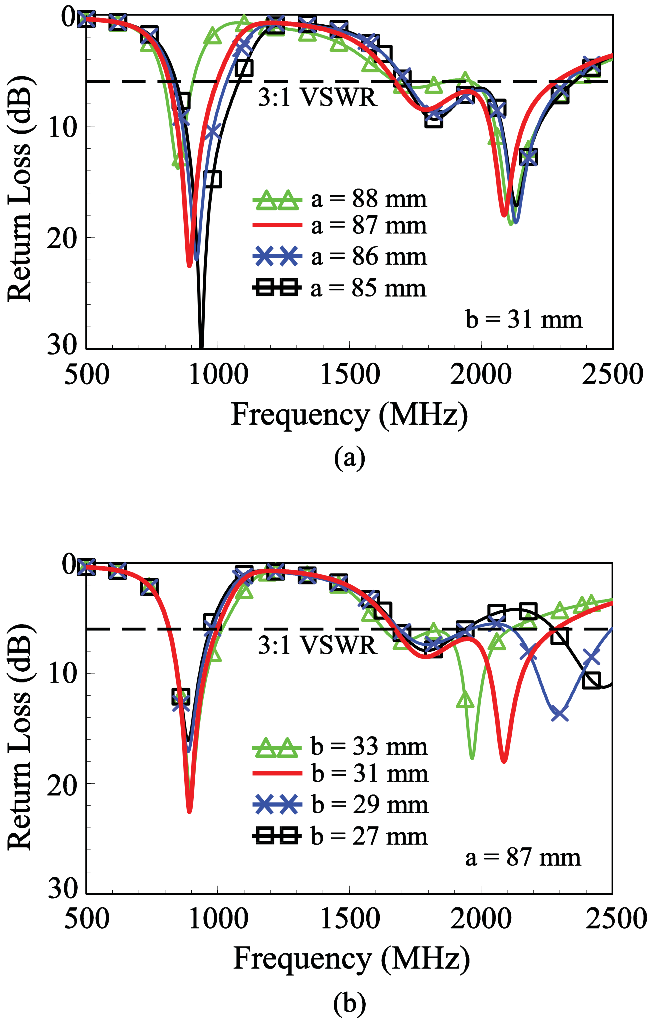

Figure 6 Simulated return loss (a) as a function of the Strip-1 length *a* and (b) as a function of the Strip-2 length *b*; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

front surface of the circuit board. The triangular feeding portion has a height of 7 mm (h) and a widened connecting edge of 7 mm (t or $\overline{BC}$) to the S-shaped monopole. The tip (Point A) of the triangular feeding point is connected to the microstrip feedline. By varying the height h and width t, the impedance matching of the antenna can be effectively adjusted. Related results are presented in Figure 5 for discussion in the next section.

The S-shaped monopole is separated into a longer resonant strip (Strip 1) and a shorter resonant strip (Strip 2), which provide two wide operating bands for covering penta-band operation. The two strips are separated by the triangular feeding portion, and Strip 1 and Strip 2 are on the front and back sides of the system circuit board, respectively. Strip 1 has a length a of about 87 mm (about 0.26 wavelength at 900 MHz) and controls the excitation of a fundamental (quarter-wavelength) mode at about 900 MHz and a second (half-wavelength) mode at about 1800 MHz. The lower band of the antenna is formed by the fundamental mode of Strip 1, which has a wide bandwidth to cover GSM850/900 operation.

Strip 2 has a length b of about 31 mm (about 0.22 wavelength at 2100 MHz) and controls the excitation of a quarter-wavelength mode at about 2100 MHz, which incorporates the second mode of Strip 1 to form a wide operating band for DCS/PCS/UMTS oper-

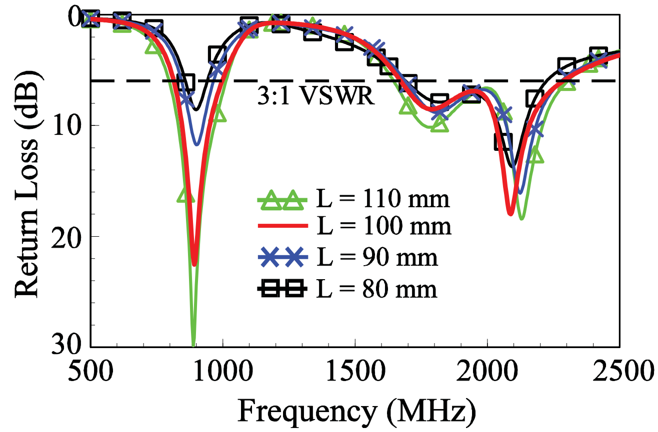

Figure 7 Simulated return loss as a function of the groundplane length *L*; other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

ation. More detailed effects of the lengths of Strip 1 and Strip 2 on the performance of the antenna will be analyzed with the aid of Figure 6 in Section 3.

Also note that there are two important matching portions (Portion 1 and Portion 2 in Fig. 1) added around the first bent corner of Strip 1. Portion 1 can smooth the excited surface current distribution around the corner on Strip 1, hence leading to an enhanced bandwidth for the lower band of the antenna. On the other hand, Portion 2 can result in improved impedance matching for the second mode of Strip 1, thus leading to a widened bandwidth of the upper band of the antenna. Detailed effects of Portion 1 and Portion 2 on the impedance matching of the antenna will be discussed with the aid of Figure 4 in the next section.

3. RESULTS AND DISCUSSION

A prototype of the proposed antenna shown in Figure 1 was constructed and tested. Figure 2 shows the measured and simulated return loss for the antenna. The simulated results are obtained using Ansoft simulation software HFSS (High Frequency Structure Simulator) [11], and an agreement between the measurement and simulation is observed. With a definition of 3:1 VSWR (6 dB return loss), which is generally used for mobile phone antenna design, the impedance bandwidths of the lower and upper bands

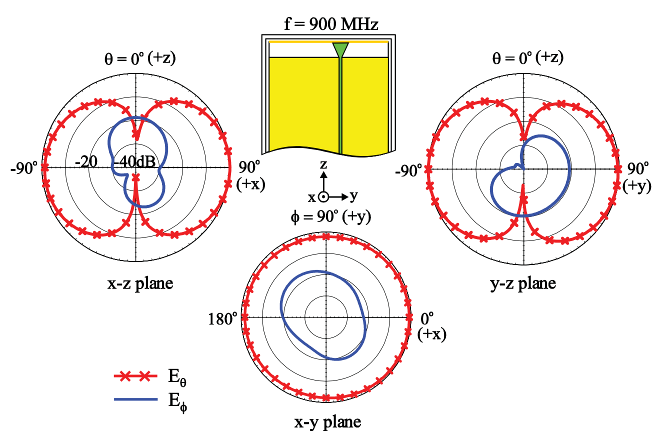

Figure 8 Measured radiation patterns for the proposed antenna at 900 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

reach 190 MHz (808–998 MHz) and 646 MHz (1682–2328 MHz), respectively, which cover the desired penta-band operation.

Figure 3 demonstrates the effects of Strip 1 and Strip 2 on the antenna performance. The simulated results of the return loss for the proposed antenna, the case with Strip 2 only, and the case with Strip 1 only are shown for comparison. It is seen that Strip 1 generates a fundamental mode at about 900 MHz and a second mode at about 1800 MHz, whereas Strip 2 generates a resonant mode at about 2100 MHz. The obtained results are expected as described in Section 2. It also indicates that the three excited resonant modes of the antenna mainly controlled by Strip 1 and Strip 2 of the S-shaped monopole.

Figure 4 shows the simulated return loss for the proposed antenna, the case without Portion 2, and the case without Portions 1 and 2. The case without Portion 2 is seen to have a wider bandwidth for the lower band compared to the case without Portions 1 and 2. This indicates that Portion 1 leads to the bandwidth enhancement for the lower band of the antenna. When Portion 2 is also added, the impedance matching of the second mode of Strip 1 is further improved. This behavior leads to a wider bandwidth for the upper band of the antenna.

Figures 5–7 show a parametric study of the triangular feeding portion, Strips 1 and 2, and groundplane length on the impedance characteristics of the proposed antenna. Effects of the width *t* and height *h* of the triangular feeding portion are presented in Figure 5. When the width *t* is varied from 3 to 9 mm [see Fig. 5(a), *h* fixed as 7 mm], the impedance matching for the upper band is varied and the obtained bandwidth for the upper band can be adjusted, while

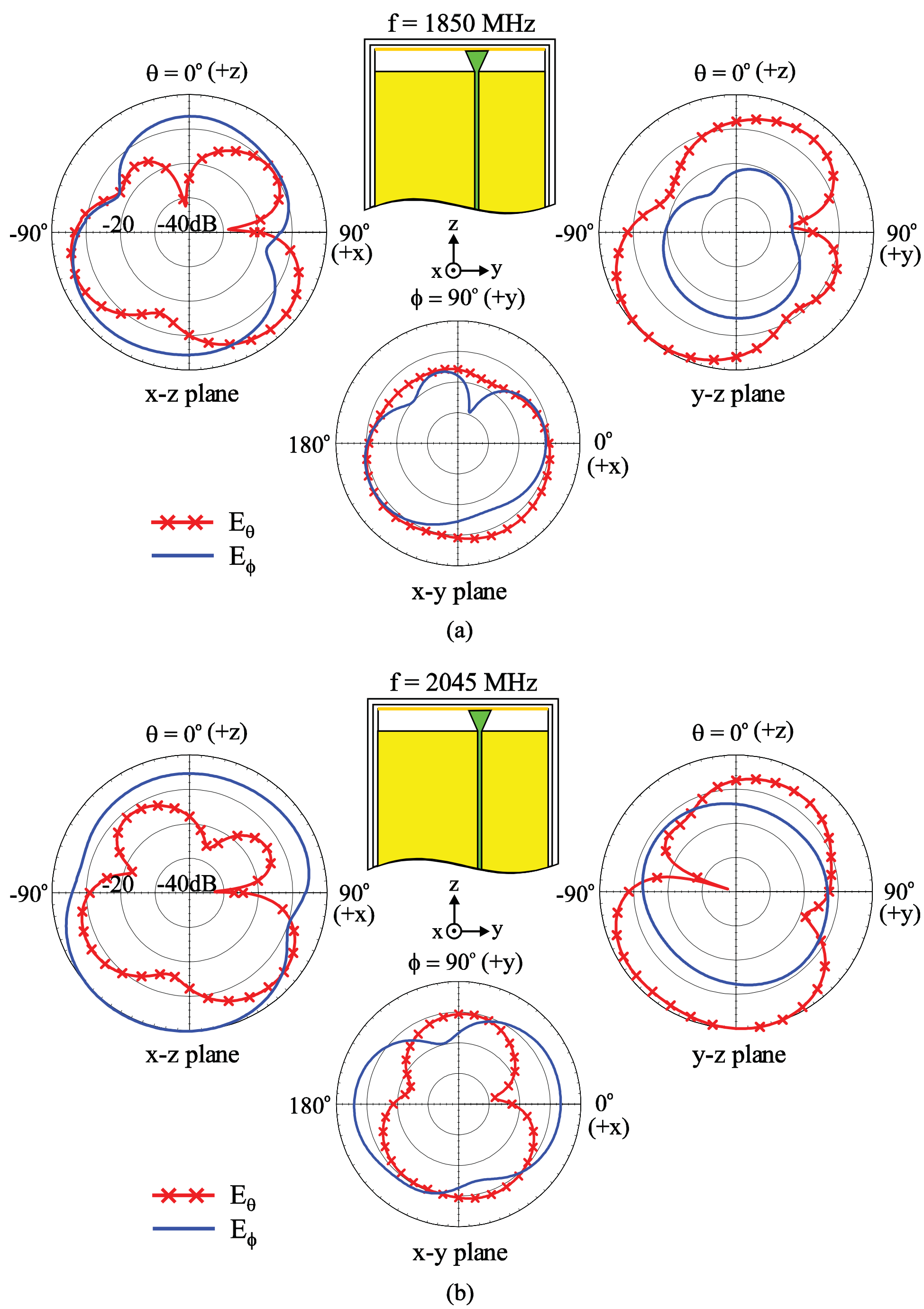

Figure 9 Measured radiation patterns for the proposed antenna at 1850 and 2045 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

that for the lower band is almost unchanged. Effects of the height h varied from 1 to 7 mm are shown in Figure 5(b). In this case, the width t is fixed as 7 mm, and a decreased height indicates that the triangular feeding portion has an increased flare angle facing the wide connecting edge to the antenna. Still, it can be seen that the height h is helpful in enhancing the impedance bandwidth of the upper band. These results suggest that the enhanced impedance bandwidth of the upper band can be obtained by adjusting the dimensions of the triangular feeding portion.

Effects of the Strip-1 length a and Strip-2 length b are studied in Figure 6. Results of the simulated return loss for the length a varied from 85 to 88 mm are shown in Figure 6(a). With a variation in the length a, major effects are seen for the excited resonant mode for the lower band and the first mode for the upper band. This confirms that the excitation of the resonant mode for the lower band and the first mode for the upper band are mainly controlled by Strip 1. In Figure 6(b), the results of the simulated return loss for the Strip-2 length b varied from 27 to 33 mm are presented. When the length b is decreased, it is seen that the second mode of the upper band is shifted to higher frequencies, with the other two modes very slightly affected. The obtained results shown in Figures 6(a) and 6(b) indicate that the resonant modes for the lower and upper bands of the antenna can be effectively controlled by adjusting the lengths of Strip 1 and Strip 2. For achieving the desired penta-band operation, the lengths of Strip 1 and Strip 2 in the study are selected to be 88 and 31 mm, respectively.

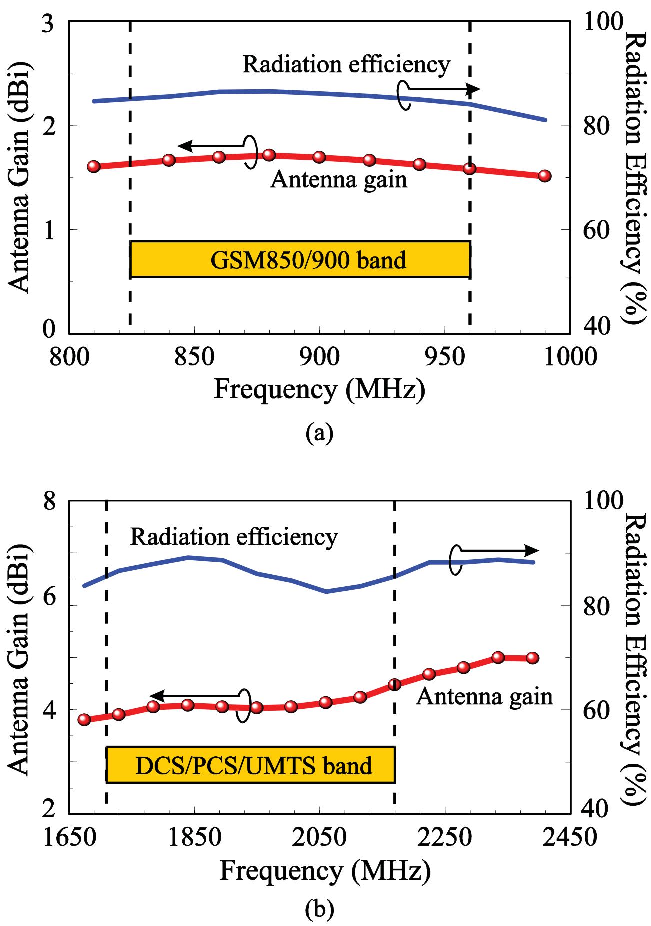

Figure 10 Measured antenna gain and simulated radiation efficiency for the proposed antenna. (a) GSM850/900 band. (b) DCS/PCS/UMTS band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Effects of the groundplane length L are studied in Figure 7. Results of the simulated return loss for the length L varied from 80 to 110 mm are shown in the figure, and large effects on the achievable bandwidth of the lower band are seen. On the other hand, the obtained bandwidths are about the same for the upper band. This behavior is mainly because the groundplane plays a more important role as a radiator in the lower band at about 900 MHz than in the upper band around 2000 MHz [10], and thus the variation in the groundplane length L will cause a more significant effect on the impedance bandwidth of the lower band. In this study, the groundplane length L is selected to be 100 mm, which is reasonable for general mobile phones and allows the lower band of the antenna to cover the GSM850/900 operation.

Radiation characteristics of the fabricated prototype are also measured. Figure 8 plots the measured radiation patterns at 900 MHz, the center frequency of the GSM850/900 band. Monopole-like radiation patterns are observed, which is similar to those of the conventional internal mobile phone antennas for GSM operation [6]. Figure 9 presents the measured radiation patterns at 1850 and 2045 MHz, the center frequencies of the DCS/PCS and UMTS bands. Large variations on the radiation patterns are seen, and similar radiation patterns compared to those of the conventional internal mobile phone antennas operated at the corresponding frequencies are observed. The measured antenna gain and simulated radiation efficiency are shown in Figure 10. Over the GSM850/900 band shown in Figure 10(a), a stable antenna gain of about 1.5 dBi is obtained, and the radiation efficiency is all larger than 80%. For the DCS/PCS/UMTS band [see the results in Fig. 10(b)], the antenna gain is varied from about 4.0 to 4.5 dBi, and the radiation efficiency is also all larger than 80%.

4. CONCLUSION

A compact printed monopole antenna with a perpendicular feed for penta-band operation in the mobile phone has been proposed and studied. The antenna is of a uniplanar S shape and occupies a small area of 10×45 mm^2 on an inexpensive FR4 substrate, yet generating two wide operating bands at about 900 and 2000 MHz to cover the GSM850/900/DCS/PCS/UMTS operation. Good radiation characteristics of the antenna over the operating bands have also been observed. A parametric study has been conducted, and the results indicate that it is easy to adjust the impedance matching over the operating bands of the antenna. In addition, with the perpendicular feed and the small distance (7 mm here) required between the antenna and the system ground plane, the antenna will occupy a small volume in the top portion of the mobile phone. Further, the narrow width (10 mm only) of the antenna makes it very promising for application in the thin mobile phone as an internal antenna for penta-band operation.

ACKNOWLEDGMENTS

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OPTIMAL DESIGN OF ULTRA WIDEBAND ANTENNAS USING A MIXED MODEL OF 2-D GENETIC ALGORITHM AND FINITE-DIFFERENCE TIME-DOMAIN

Min Ding, Ronghong Jin, and Junping Geng
Department of Electronic Engineering, Shanghai Jiaotong University, Shanghai, China 200240; Corresponding author: dingmin@sjtu.edu.cn

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ABSTRACT: *A mixed model of two-dimensional (2-D) genetic algorithm and finite-difference time-domain is applied to the automatic design of ultra wideband (UWB) planar antennas in a finite size. The results illustrate that the method is valid and a new UWB antenna is designed successfully in the small size.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 3177–3180, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22928

Key words: *ultra wideband antennas; genetic algorithm; finite-difference time-domain*

1. INTRODUCTION

The ultra wideband (UWB) antenna has become an intensive topic in the field of the antenna research because of some of its unique features such as transmitting and/or receiving very short time durations of electromagnetic energy and avoiding frequency dispersion and space dispersion. Recently, many methods are developed to realize conventional UWB antennas [1–3] for commercial applications, the frequency range of which is between 3.1 GHz and 10.6 GHz meeting with FCC standard. Genetic algorithm (GA) is also applied to the design of UWB antennas because of its robust global stochastic search ability [4, 5]. However, when traditional GA [6] is used to design UWB antennas, the structure of the antenna must be foreseen before the optimization process starts. The design of UWB antennas greatly depends on the designers' experience. In other words, the automatic design of UWB antennas will become difficult. Therefore, it is important that the antenna is designed by algorithms themselves rather than by persons, and the best characteristic is achieved in the fitted size. The 2-D GA is reported in [7–9], in which the coding "1" represents a cell with metal and "0" represents a cell without metal. The arbitrary structure can be designed by the method and the performance can be improved without increasing the overall volume or manufacturing cost [7]. However, when the method is applied to the design of UWB antennas, some shortcomings such as premature will happen because of the unique characteristic of UWB antennas.

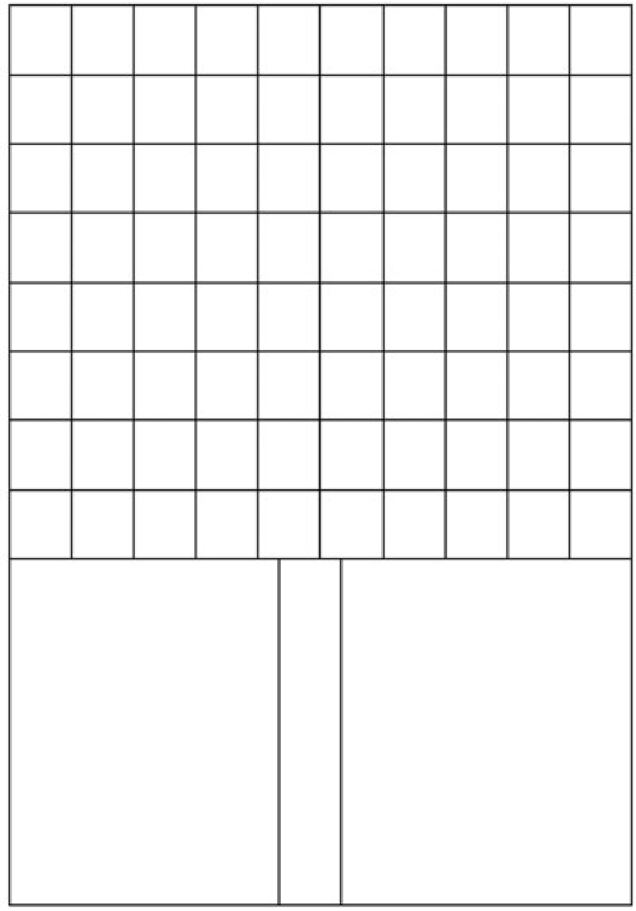

Figure 1 Division of the design area

In this letter, to avoid the premature phenomena, all chromosomes in parents are mated according to Best-Mate-Worst (BMW) [10] rather than only elitist chromosomes are mated. The 2-D GA that is encoded into a 2-D chromosome is adopted to optimize the geometric shape of UWB antennas automatically, and finite-difference time-domain (FDTD) method is used to evaluate fitness function in GA. A small UWB antenna is designed in fitted sizes by the method. The bandwidth is covering a frequency range from 3.1 GHz to above 12 GHz, and the size of patch is utilized adequately.

2. ANTENNA OPTIMIZATION PROCEDURE

Recently, GA has been widely applied to search for optimization designs of antennas. In this letter, a 2-D GA is adopted to design the UWB antenna. The algorithm starts with dividing the design area (21.2 mm × 23.85 mm) into 8 × 10 grids (as shown in Fig. 1). An initial 2-D chromosome population is produced randomly. The size of population is 100. In the 2-D chromosome, ones represent the metallized areas and zeros represent the areas without metal. To avoid the discontinuity of the structure, the filter code is necessary: when all cells around "0" are "1," replace "1" to "0";