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A LOW-PROFILE MONOPOLE ANTENNA EMBEDDED WITH A RESONANT SLOT

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Abstract—A low profile dual-band mobile phone antenna with a very small volume of 0.768 cm^3 ($40 \times 4 \times 4.8$ mm^3) is presented. The antenna is formed by a monopole and an open-end slot embedded therein. The impedance bandwidths for the lower and upper bands with a definition of 3 : 1 VSWR (6 dB return loss) reach 215 MHz (815–1030 MHz) and 515 MHz (1660–2175 MHz) respectively. Furthermore, small excited surface current distributions on the ground plane of the antenna are achieved, and the ground plane length has smaller effect on the achievable bandwidths of the antenna compared with the conventional internal patch antennas for mobile phones, which make the antenna very attractive to be applied to the mobile phones with various possible ground plane lengths. Good radiation characteristics over the operating bands are obtained.

1. INTRODUCTION

Planar monopole antennas have been demonstrated to be promising for applications in mobile phone and reported in the open literature [1–3]. These monopole antennas show attractive features of broadband operation, low-profile and easy fabricate at low cost compared with the internal patch antennas that have been presented [4–6]. The antennas generally can cover GSM900 (880–960 MHz), DCS (1710–1880 MHz), PCS (1850–1990 MHz), and UMTS (1920–2170 MHz) bands. However, it is difficult for them to provide enough bandwidths to cover the desired GSM850 operation (824–894 MHz) in their lower operating band. Another promising antenna structure for mobile phone application is the slot antenna [7, 8]. This type of antenna is suitable to be printed on and integrated with the system circuit

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board of the mobile device, which makes it easy to fabricate at low cost. However, these antennas occupy much board space in the mobile phone.

In this paper, a small low profile antenna for mobile phone applications is presented. The proposed antenna is capable of dual-wideband operation to cover the GSM850/900/1800/1900, DCS, PCS, and UMTS operating bands. The antenna occupies a small area of $4.8 \times 40\,\text{mm}^2$. In addition, the antenna has a low profile of 4 mm, which is attractive for thin mobile phone applications. The occupied volume of $0.768\,\text{cm}^3$ ($40 \times 4 \times 4.8\,\text{mm}^3$) is among the smallest in the reported internal multiband mobile phone antennas [9, 10]. Design considerations of the antenna are described, and results for the fabricated prototype are presented and discussed.

2. DESIGN CONSIDERATIONS OF THE ANTENNA

The geometry and dimensions of the proposed antenna is shown in Figure 1. The antenna comprises of a L-shaped monopole and a resonant slot embedded therein. The dimensions of the ground plane are selected to be 80 mm in length and 40 mm in width. These selected dimensions are reasonable for general mobile phone antenna. There is a no-ground portion of size $7 \times 40\,\text{mm}^2$ between the monopole and the ground plane, which can be reused to accommodate the associated electronic components, such as the speaker [11].

The monopole is printed on a 0.8 mm thick FR4 substrate of relative permittivity 4.4, and tangent loss of 0.0245. The monopole is placed at the top edge of the system circuit board, with a small distance of 7 mm to the system ground plane. In order to reduce

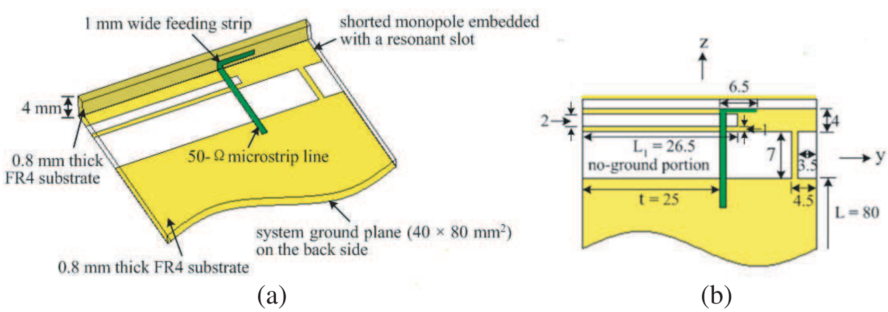


Figure 1. (a) Geometry of the proposed antenna. (b) Detail dimensions of the proposed antenna.

the volume, the monopole is bent into L shape. The monopole has a low profile of 4 mm and a length of 40 mm. The monopole can be successfully excited a quater-wavelength resonant mode at about 900 MHz for GSM850/900 operation and a half-wavelength mode at about 1900 MHz for GSM1900/PCS/UMTS operation. The resonant slot is of a simple straight shape of width 2 mm and length 26.5 mm, which is cut at the edge of the monopole antenna. The resonant slot can generate a 0.25-wavelength resonant mode at about 1700 MHz. When the 0.25-wavelength resonant mode of the slot and the 0.5-wavelength mode of the monopole are formed together, a wideband upper band for GSM1800/1900/DCS/PCS/UMTS operations can be obtained. Note that owing to the presence of the FR4 substrate, the lengths of the monopole and slot are smaller than one-quarter wavelength at 900 MHz and 1700 MHz respectively.

To excite both the monopole and resonant slot, a L-shaped feeding strip integrated with a 50-Ω microstrip line at the location of $t = 25$ mm away from the edge of the circuit board is used. For the location t, it has a large effect on the impedance matching over the lower and upper band of the antenna, and a parametric study on t is presented in the next section to describe in detail their respective effect on the impedance matching. In addition, the effect of the ground plane length L on the performance of the antenna are generally smaller than those of conventional internal mobile phone antennas [12, 13], and the results of the proposed antenna with various possible ground plane lengths are shown in Figure 7 and will be discussed in the next section.

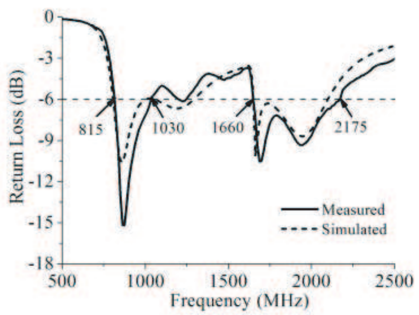


Figure 2. Measured and simulated return loss for the proposed antenna.

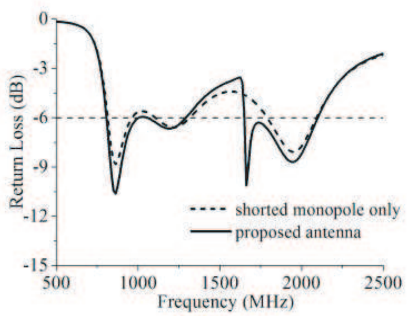
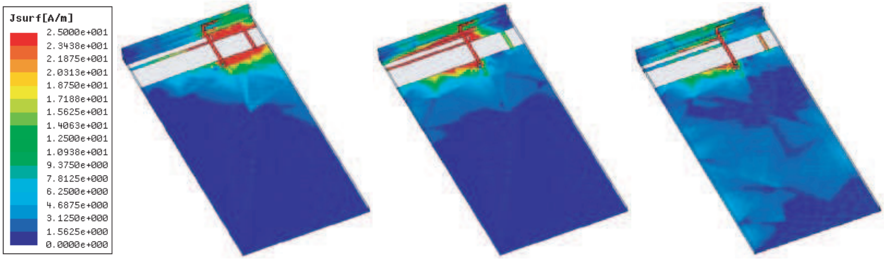


Figure 3. Comparison of simulated return loss for the proposed antenna and the case with the shorted planar monopole only; corresponding parameters are the same as given in Figure 1.



(a) (b) (c) (d)

Figure 4. Simulated current distributions of the proposed antenna at 900 MHz, 1700 MHz, and 1900 MHz.

3. RESULTS AND DISCUSSION

The proposed antenna described in Figure 1 was fabricated and tested. The measured and simulated return losses of the antenna are shown in Figure 2. The simulated result is obtained using the electromagnetic simulation software Ansoft HFSS. Good agreement between the measurement and simulation is seen. From the results, two wide operating bands centered at about 920 MHz and 1900 MHz are excited with good impedance matching. With the definition of 3 : 1 VSWR, which is usually used for mobile phone design, the measured bandwidths for the lower and upper bands reach 215 MHz (815–1030 MHz) and 515 MHz (1660–2175 MHz) respectively.

To demonstrate the effect of the monopole and the resonant slot on generating the antenna's lower and upper bands, Figure 3 presents the comparison of the simulated return loss for the proposed antenna and the case with the monopole only. A first (quarter-wavelength) resonant mode at about 900 MHz and a second (half-wavelength) mode at about 1900 MHz are obtained for the monopole only. When the resonant slot is embedded in the monopole, an additional fundamental (quarter-wavelength) resonant mode of the slot at about 1700 MHz is generated. A wide upper band is obtained when the 0.25-wavelength resonant mode of the slot and the 0.5-wavelength mode of the monopole are formed together.

In order to explain in more detail the excited resonant modes of the proposed antenna, the simulated surface current distributions on the proposed antenna at the resonant frequencies (900 MHz, 1700 MHz, and 1900 MHz) of the first three excited modes are shown in Figure 4. For the 900 MHz excitation, a larger surface current distribution is observed for the longer path along the monopole, and the 0.25-

wavelength resonant mode at 900 MHz of the monopole is excited. This indicates that the monopole is the major radiating element for the proposed antenna at the 900 MHz band. For the 1700 MHz operation, it is observed that the surface current distribution around the resonant slot gradually increases, indicates that the 0.25-wavelength of the sot antenna is generated. On the other hand, strong surface current distribution around the monopole at 1900 MHz is also seen, which demonstrate that the 0.5-wavelength resonant mode of the monopole is excited. These results indicate that the L-shaped monopole and the resonant slot are the major radiating elements for the antenna at the upper band.

Effects of the resonant slot length L_1 on impedance matching are shown in Figure 5. Effects of the length L_1 on the impedance matching of the second resonant mode are seen to be larger than those on the first and third resonant modes. Results show that the second resonant mode is shifted to lower frequencies, when the length L_1 is increased from 25 to 28 mm. The result clearly indicates that the second resonant mode can be effectively controlled by adjusting the length of the resonant slot.

Effects of the location t of the microstrip feedline are studied in Figure 6. Large effects on the lower and upper bands of the antenna are seen. When the location t is selected to be 25 mm, good impedance matching for the lower and upper bands are achieved. This analysis indicates that a proper selection of t is important to achieve good excitation for the lower and upper bands.

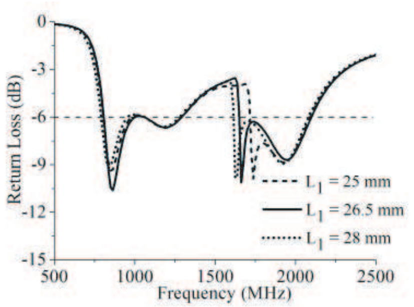


Figure 5. Simulated return loss for the proposed antenna as a function of L_1, the length of the resonant slot; other parameters are the same as given in Figure 1.

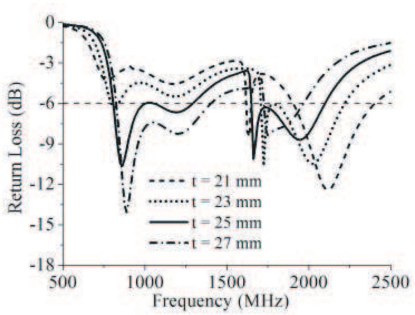


Figure 6. Simulated return loss for the proposed antenna as a function of t, the location of the microstrip feedline; other parameters are the same as given in Figure 1.

Effects of the ground-plane length L on the impedance matching are also studied. Figure 7 presents the simulated return loss with the ground-plane length L varied from 80 mm to 110 mm. For a larger value of L, enhanced impedance matching over the lower and upper bands are obtained. The bandwidths of the lower and upper bands can cover the GSM850/900/1800/1900/DCS/PCS/UMTS bands with L varied from 80 mm to 110 mm. The result indicates that the ground plane length L has smaller effects on the bandwidths compared with those observed for the conventional internal patch antenna for mobile phones [12, 13]. With this attractive feature, the antenna can be applied to the mobile phone with various possible ground plane lengths.

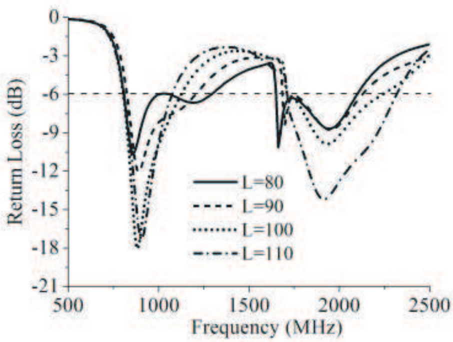


Figure 7. Simulated return loss for the proposed antenna as a function of the gound-plane length L; other parameters are the same as in Figure 1.

Radiation characteristics of the constructed prototype were measured, and the results at 900 MHz, 1800 MHz and 2000 MHz are presented in Figure 8. At 900 MHz, monopole-like radiation patterns are seen, which are similar to the radiation patterns of the conventional mobile phone antenna for GSM operation [1, 8]. For the frequencies of 1800 MHz and 2000 MHz, the radiation patterns are also generally similar to those of the conventional mobile phone antenna. Figure 9 and Figure 10 present the measured antenna gain and simulated radiation efficiency over the lower and upper bands respectively. For the lower band, the antenna gain is varied in a small range of 1–2 dBi, and the radiation efficiency is all better than 70%. For the upper band, the antenna gain is varied from 3 to 5.3 dBi, while the radiation efficiency is larger than 74%. The obtained antenna gain and radiation frequency are acceptable for practical mobile phone applications.

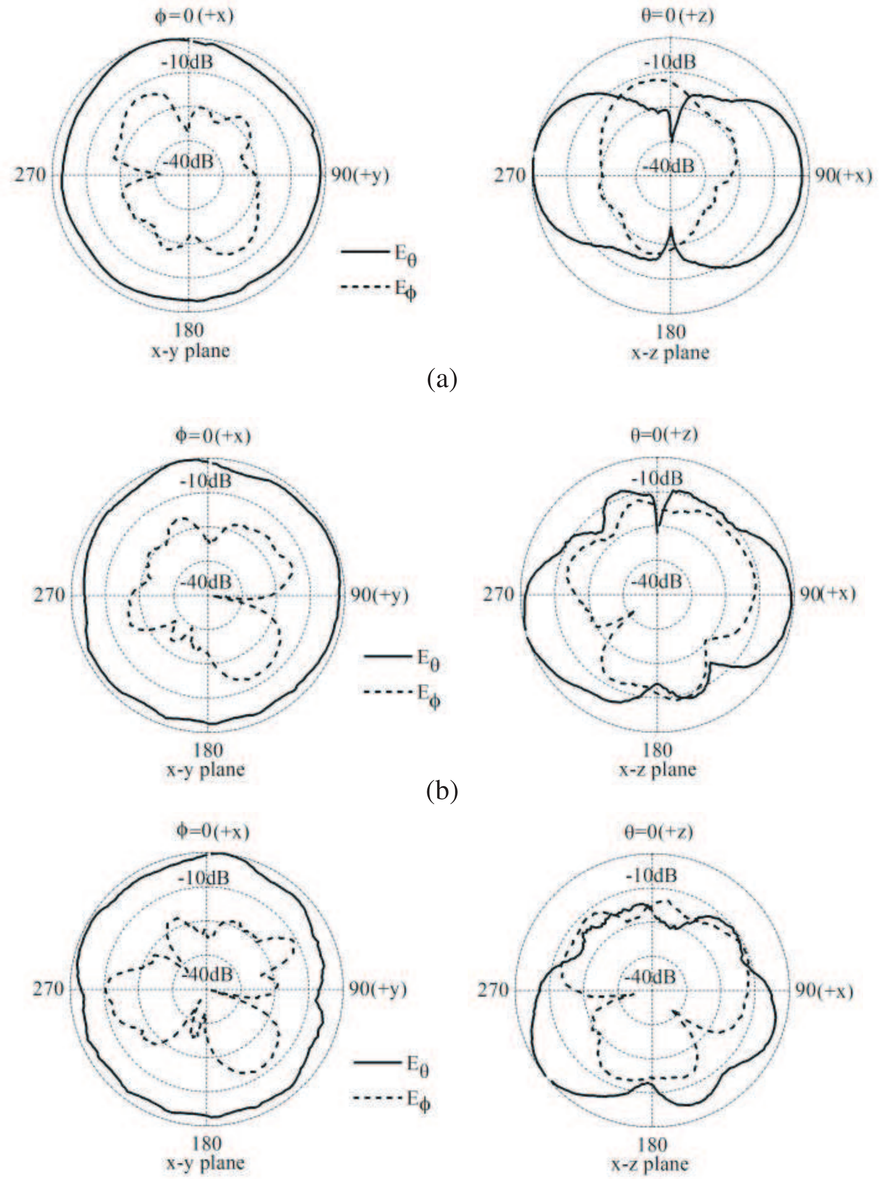


Figure 8. Measured radiation patterns at (a) 900 MHz, (b) 1800 MHz and (c) 2000 MHz of the antenna.

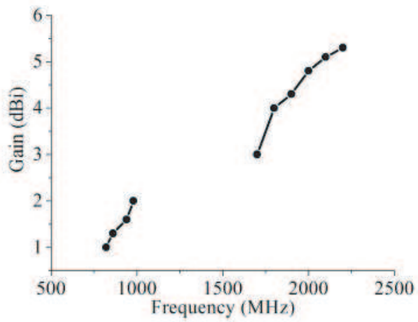


Figure 9. Measured gain of the proposed antenna.

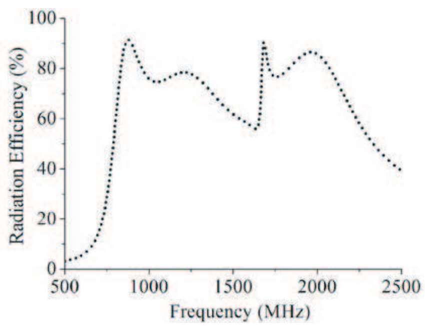


Figure 10. Simulated radiation efficiency of the proposed antenna.

4. CONCLUSION

In this paper, a compact antenna suitable for thin mobile phone applications has been proposed. The antenna consists of a L-shaped monopole and a resonant slot embedded therein, which can generate three modes to form two wide bands centered at about 920 MHz and 1900 MHz for GSM850/900/1800/1900/DCS/PCS/UMTS operations. The occupied volume of the antenna is 0.768 cm^3 only, which is among the smallest in the reported internal multiband mobile phone antennas. Good radiation characteristics of the antenna over the operating bands have also been observed.

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REFERENCES

1. Wong, K. L., *Planar Antennas for Wireless Communications*, Wiley, New York, USA, 2003.
2. Lin, S. Y., "Multiband folded planar monopole antenna for mobile handsets," *IEEE Trans. Antennas Propag.*, Vol. 52, 1790–1794, 2004.
3. Shin, Y. S., S. O. Park, and M. Lee, "A broadband interior antenna of planar monopole type in handsets," *IEEE Antennas Wireless Propag.*, Vol. 4, 9–12, 2005.

4. Geyi, W., Q. Rao, S. Ali, and D. Wang, "Handset antenna design: Practice and theory," *Progress In Electromagnetics Research*, PIER 80, 123–160, 2008.
5. Wang, Y. J., "Design of dual-frequency microstrip patch antennas and application for IMT-2000 mobile handsets," *Progress In Electromagnetics Research*, PIER 36, 265–278, 2002.
6. Wang, F. J. and J. S. Zhang, "wide band cavity-backed patch antenna for PCS/IMI2000/2.4 GHz WLAN," *Progress In Electromagnetics Research*, PIER 74, 39–46, 2007.
7. Wong, K. L., Y. W. Chi, and S. Y. Tu, "Internal multiband printed folded slot antenna for mobile phone application," *Microwave Opt. Technol. Lett.*, Vol. 49, 1833–1837, 2007.
8. Lin, C. I. and K. L. Wong, "Printed monopole slot antenna for internal multiband mobile phone antenna," *IEEE Trans. Antennas Propag.*, Vol. 55, 3690–3697, 2007.
9. Guo, Y. X., M. Y. W. Chia, and Z. N. Chen, "Miniature built-in multiband antennas for mobile handsets," *IEEE Trans. Antennas Propag.*, Vol. 52, 1936–1944, 2004.
10. Azad, M. Z. and M. Ali, "A miniaturized hilbert PIFA for dual-band mobile wireless applications," *IEEE Trans. Antennas Propag.*, Vol. 4, 59–62, 2005.
11. Chang, C. H., K. L. Wong, and J. S. Row, "Multiband surface-mount chip antenna integrated with the speaker in the mobile phone," *Microwave Opt. Technol. Lett.*, Vol. 50, 1126–1132, 2008.
12. Wu, T. Y. and K. L. Wong, "On the impedance bandwidth of a planar inverted-F antenna for mobile handsets," *Microwave Opt. Technol. Lett.*, Vol. 42, 249–251, 2002.
13. Vainikainen, P., J. Ollikainen, O. Kivekas, and I. Kelander, "Resonator-based analysis of the combination of mobile handset antenna and chassis," *IEEE Trans. Antennas Propag.*, Vol. 50, 1433–1444, 2002.