anisotropic artificial absorber for truncating finite element meshes, IEEE Trans Antennas Propag 43(12) (1995) 1460–1463.
10. W.C. Chew and W.H. Weedon, A 3D perfectly matched medium from modified Maxwell's equations with stretched coordinates, Microwave Opt Technol Lett 7 (1994), 599–604.
11. S.D. Gedney, An anistropic perfectly matched layer—Absorbing medium for trunction of FDTD lattices, IEEE Trans Antennas Propag 44(12) (1996), 1630–1639.
12. M.D. Deshpande, C.R. Cockrell, and C.J. Reddy, Electromagnetic scattering analysis of arbitrarily shaped material cylinder by FEM-BEM method, NASA Technical Report (1996).
13. Q.H. Liu, An FDTD algorithm with perfectly matched layers for conductive media, Microwave Opt Technol Lett 14(2) (1997), 134–137.
14. M.W. Ali, T.H. Hubing, and J.L. Drewniak, A hybrid FEM/MoM technique for electromagnetic scattering and radiation from dielectric objects with attached wires, IEEE Trans Electromagn Compat 39(4) (1997).
15. J. Jin, The finite element method in electromagnetics, Wiley, New York, 1993.
16. J.L. Volakis, A. Chatterjee, and L.C. Kempel, Finite element method for electromagnetics, IEEE Press, 1998.
17. A.F. Peterson, A.L. Ray, and R. Mittra, Computational methods for electromagnetics, IEEE press, 1998, p. 43.
18. A. Musolino and M. Raugi, A hybrid FEM/MOM formulation for nonlinear electromagnetic analysis, IEEE Trans Magn 34(5) (1998), 3292–3295.
19. F.L. Teixeira and W.C. Chew, A general approach to extend Berenger's absorbing boundary condition to anisotropic and dispersive media, IEEE Trans Antennas Propag 46(9) (1998), 1386–1387.
20. J.A. Roden and S.D. Gedney, Convolution PML (CPML): An efficient FDTD implementation of the CFS-PML for arbitrary media, Microwave Opt Technol Lett 27(5) (2000), 334–339.
21. G.X. Fan and Q.H. Liu, A strongly well-posed PML in lossy media, IEEE Antennas Wireless Propag Lett 2(7) (2003), 97–100.
22. A. Musolino, Finite-element method/method of moments formulation for the analysis of current distribution in rail launchers, IEEE Trans Magn 41(1) (2005), 387–392.
23. J. Liu, and Q.H. Liu, A spectral integral method (SIM) for periodic and nonperiodic structures, IEEE Microwave Wireless Compon Lett 14(3) (2004), 97–99.
24. F. Q. Hu, A spectral boundary integral equation method for the 2D Helmholtz equation, J Comput Phys 120 (1995), 340–347.
25. A. Kirsch and P. Monk, An analysis of the coupling of finite-element and Nystrom methods in acoustic scattering, IMA J Numer Anal 14 (1994), 523–544.
26. E. Arvas and T. Sarkar, RCS of two-dimensional structures consisting of both dielectrics and conductors of arbitrary cross section, IEEE Trans Attennas Propog 30(5) (1989), 546–554.
27. A.F. Peterson and S.P. Castillo, A frequency-domain differential equation formulation for electromagnetic scattering from inhomogeneous cylinders, IEEE Trans Attennas Propag 30(5) (1989), 601–607.
28. M.J. Grote and J.B. Keller, Nonreflecting boundary conditions for Maxwell's equations, J Comput Phys 139(2) (1998), 327–342.

INTERNAL GSM/DCS PATCH ANTENNA MOUNTED ABOVE THE SYSTEM GROUND PLANE OF THE PDA PHONE

Kin-Lu Wong,[1] Chih-Hua Chang,[1] and Jeen-Sheen Row[2]
[1] Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 804, Taiwan, Republic of China
[2] Department of Electrical Engineering, National Changhua University of Education, Changhua 500, Taiwan

Received 15 January 2007

ABSTRACT: *This paper presents an internal dual-band patch antenna to be mounted above the system ground plane of the PDA (personal digital assistant) phone for GSM/DCS operation. The antenna is supported by conducting pins (5 mm long in this study) and mounted above the system ground plane of the PDA phone. In this case, the antenna does not directly occupy the system ground plane, and a usable space between the antenna ground portion and the system ground plane is provided for accommodating associated conducting elements or electronic components of the PDA phone. A design example is demonstrated, and obtained results are presented and discussed.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 2002–2006, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22593

Key words: *antennas; mobile antennas; internal mobile phone antennas; dual-band antennas; GSM/DCS antennas*

1. INTRODUCTION

The conventional planar inverted-F antenna (PIFA) has been widely applied in mobile devices as an internal antenna for GSM (global system for mobile communication, 890–960 MHz) and DCS (digital communication system, 1710–1880 MHz) operation [1]. This kind of conventional PIFA, however, mainly occupies a certain portion of the system circuit board or ground plane of the mobile device, and uses it as the antenna ground plane. Hence, when such a conventional PIFA is employed in the mobile device, valuable board space is occupied. This limits the efficient integration of the employed internal antenna and the electronic components in the mobile device.

In this paper, we present a novel internal patch antenna suitable to be mounted above the system ground plane of the mobile device, without occupying the valuable space of the system ground plane. The proposed antenna mainly comprises a bottom antenna ground portion and a top radiating portion. When applied in the mobile device, the antenna ground portion, which encircles the top radiating portion in this design, is supported by conducting pins and mounted above the system ground plane. This configuration makes the portion of the system ground plane below the antenna reusable for accommodating the associated conducting elements or electronic components of the mobile device. Note that the antenna ground portion has a three-dimensional structure consisting of a planar ground plane and a vertical ground wall. The latter is expected to function as an effective shielding wall to suppress the antenna's possible fringing electromagnetic (EM) fields from entering the interiors of the mobile device [2–6]. In this case, the possible coupling between the proposed antenna and the conducting elements or electronic components mounted on the portion of the system ground plane below the antenna can be eliminated or greatly suppressed, thus resulting in very slight or no variations in the antenna performances.

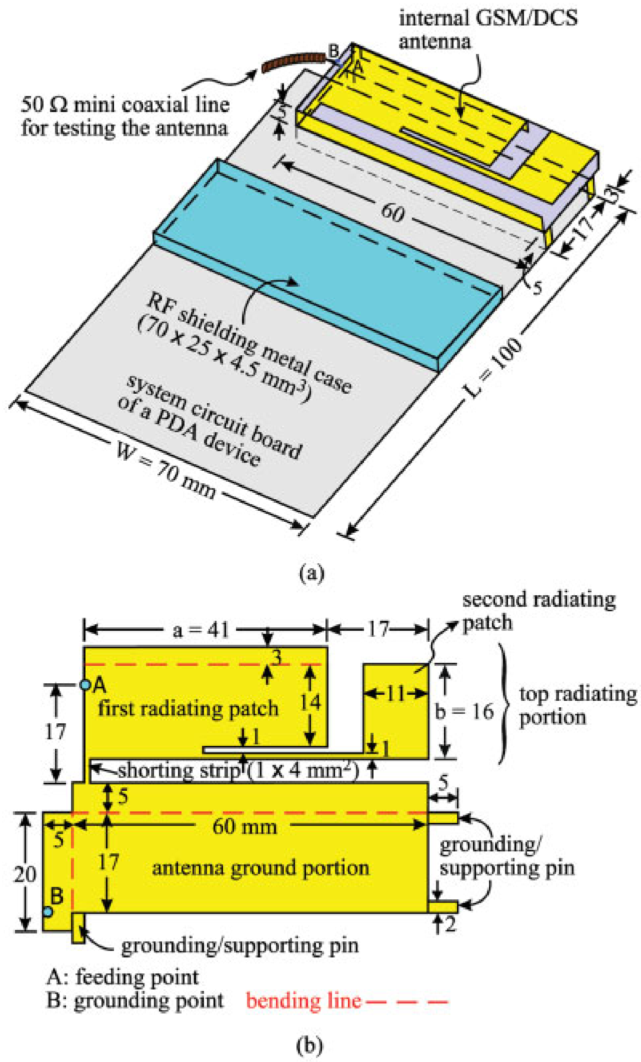


Figure 1 (a) Configuration of the proposed internal GSM/DCS patch antenna mounted above the system ground plane of the PDA phone. (b) Detailed dimensions of the metal pattern of the antenna unfolded into a planar structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

1.1. Design Considerations of Proposed Antenna

A design example of the proposed antenna for GSM/DCS operation in the personal digital assistant (PDA) phone or smart phone is demonstrated. Figure 1(a) shows the configuration of the antenna mounted above the system ground plane of the PDA phone with a height of 5 mm, and detailed dimensions of the metal pattern of the antenna unfolded into a planar structure is given in Figure 1(b); the configuration indicates that the antenna can be fabricated from a single metal plate. The antenna has two major portions: a bottom antenna ground portion and a top radiating portion. The antenna ground portion is supported by three conducting/grounding pins of length 5 mm and mounted above the system ground plane. This configuration allows the space in between the antenna and the system ground plane reusable for accommodating associated components of the PDA phone. The antenna is also protruded over the top edge of the system ground plane with a small length of 3 mm, and the antenna ground portion is flushed to the top edge of the system ground plane. This small protrusion can effectively improve the operating bandwidths of the antenna [7, 8]; in this case, although the thickness of the antenna is 5 mm only, which is smaller than that of general PIFAs for mobile phones [1], the obtained bandwidths of the antenna can cover the GSM and DCS operations.

In the study, the dimensions of the system ground plane are selected to be 70×100 mm^2, which are reasonable dimensions of general PDA phones. Other possible lengths and widths of the system ground plane are also studied, and their detailed effects will be discussed in the next section. For the top radiating portion, it consists of a first radiating patch and a second radiating patch. Their detailed dimensions are given in Figure 1(b). The two radiating patches share a common shorting strip of length 4 mm and width 2 mm, which short-circuits the two patches to the antenna ground portion. The two patches can generate a lower band at about 900 MHz and an upper band at about 1800 MHz for GSM/DCS operation. The first radiating patch mainly controls the upper band, while the second radiating patch mainly controls the lower band. In the design, the length *b* of the open end of the second radiating patch is first adjusted to let the antenna's lower band occurred at about 900 MHz for GSM operation. Then, the length *a* of the first radiating patch is adjusted to let the antenna's upper band occurred at about 1800 MHz for DCS operation. This design rule allows the antenna easy to implement. Also notice that the outer part of the first radiating patch is bent downward to achieve a compact structure of the antenna.

The antenna ground portion has a three-dimensional structure consisting of a major ground plane (size, 17×60 mm^2) parallel to the top radiating portion and two vertical ground planes (sizes, 5×20 and 5×60 mm^2) parallel to the side surfaces of the antenna. The two vertical ground planes are used to shield the antenna's EM fringing fields from entering the interiors of the PDA phone. In this case, when there are conducting elements placed below the antenna, small effects on the performances of the antenna can be obtained. Related results of placing an RF shielding metal case [shown in Fig. 1(a) with a volume of $70 \times 25 \times 4.5$ mm^3] below the antenna will be discussed in the next section. This metal case can provide a coupling-free space for accommodating the associated electronic components of the PDA phone.

2. RESULTS AND DISCUSSION

The antenna was fabricated and tested. In the experiment, a 50 Ω mini coaxial line is used to feed the antenna across the feeding point (Point A) and the grounding point (Point B) shown in Figure 1. Figure 2 shows the measured and simulated return loss for the fabricated prototype without the presence of the shielding metal case. The simulated results are obtained using Ansoft simulation

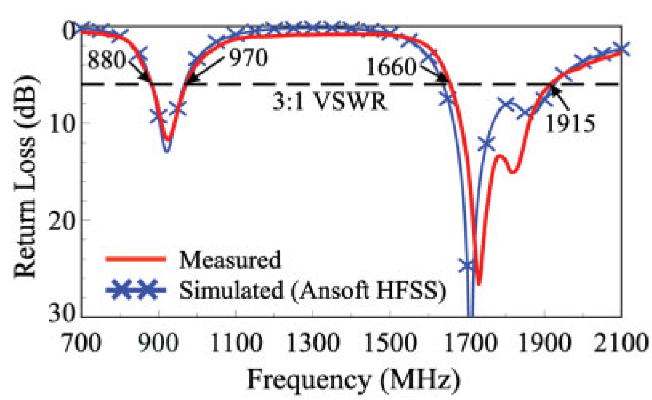
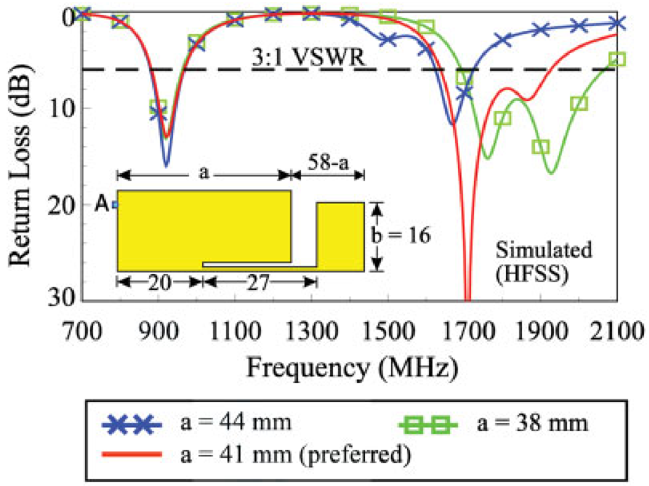
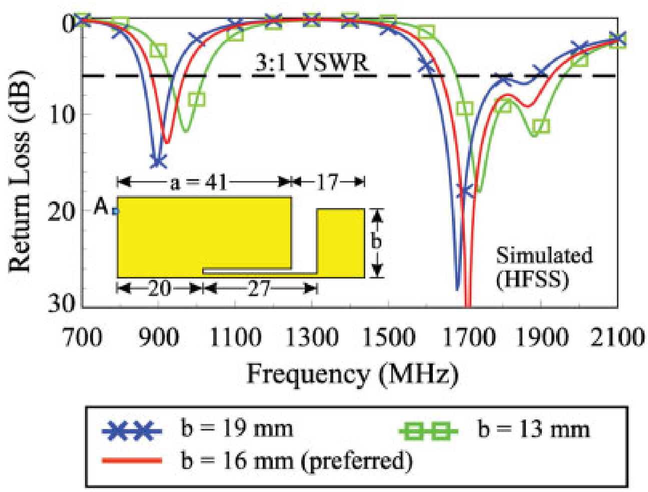


Figure 2 Measured and simulated return loss; the RF shielding metal case shown in Figure 1 is not present. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



(a)



(b)

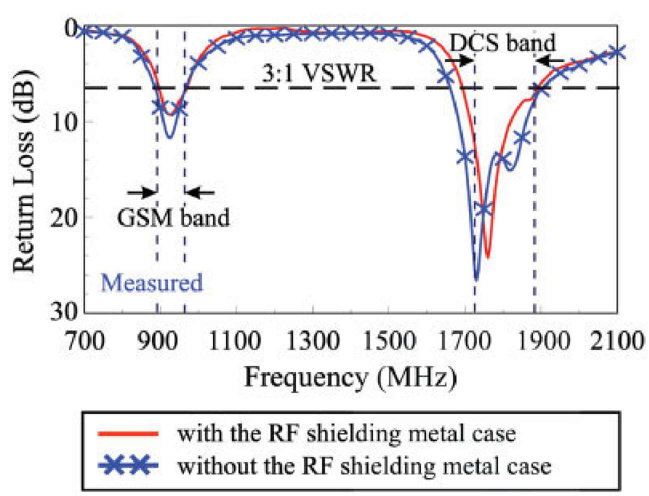
Figure 3 (a) Simulated return loss for the antenna studied in Figure 2(a) as a function of *a,* the length of the first radiating patch, and (b) as a function of *b,* the length of the end portion of the second radiating patch. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

software HFSS (high frequency structure simulator) [9], and agreement between the measurement and simulation is seen. Two operating bands of the antenna are excited with good impedance matching. The lower band is formed by the quarter-wavelength resonant mode generated by the second radiating patch and has an impedance bandwidth, defined by 3:1 VSWR or 6 dB return loss, of 90 MHz (880–970 MHz), which allows the antenna to easily cover the GSM operation. Note that the bandwidth definition of 3:1 VSWR is generally used for mobile phone antennas for practical applications. The upper band shows an impedance bandwidth of 255 MHz (1660–1915 MHz), allowing it to easily cover the DCS operation. The upper band is formed by two adjacent resonant modes. The one at about 1700 MHz is a quarter-wavelength mode generated by the first radiating patch and the other one at about 1900 MHz is the higher-order mode generated by the second radiating patch.

Dependence of the excited lower and upper bands on the antenna's first and second radiating patches is studied in Figure 3, in which results of the simulated return loss as a function of *a* and *b* are presented. In Figure 3(a), the length *a* is varied from 38 to 44 mm, with the length *b* fixed to be 16 mm. Results indicate that the lower band is almost not affected, while the upper band is strongly controlled by the length *a.* That is, the upper band is controlled by the first radiating patch; with the length *a* selected to be 41 mm (the preferred dimension in this design), wider bandwidth for the upper band centered at about 1800 MHz is achieved. Conversely, in Figure 3(b), the length *b* is varied from 13 to 19 mm, with the length *a* fixed to be 41 mm. The results indicate that the lower band can be effectively controlled by the length *b,* although the upper band is also affected by the variation in *b.* From the results, the design rule for adjusting the antenna's lower and upper bands for GSM/DCS operation as given in Section 2 is verified.

Effects of a nearby conducting element on the performances of the antenna are studied. Figure 4(a) shows the experimental photo of the antenna with the shielding metal case (size $70 \times 25 \times 4.5$ mm^3) placed below it. The measured return loss for the antenna with and without the shielding metal case is presented in Figure 4(b). Small effects on the measured return loss are obtained. This behavior can be explained from the simulated surface current distributions on the antenna and the system ground plane shown in Figure 5 for the proposed antenna and the reference antenna (the case without the presence of the antenna ground portion). On the portion of the system ground plane near the antenna the surface

(a)



(b)

Figure 4 (a) Experimental photo of the antenna with the RF shielding metal case located below the antenna ground portion. (b) Measured return loss for the antenna with and without the RF shielding metal case. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

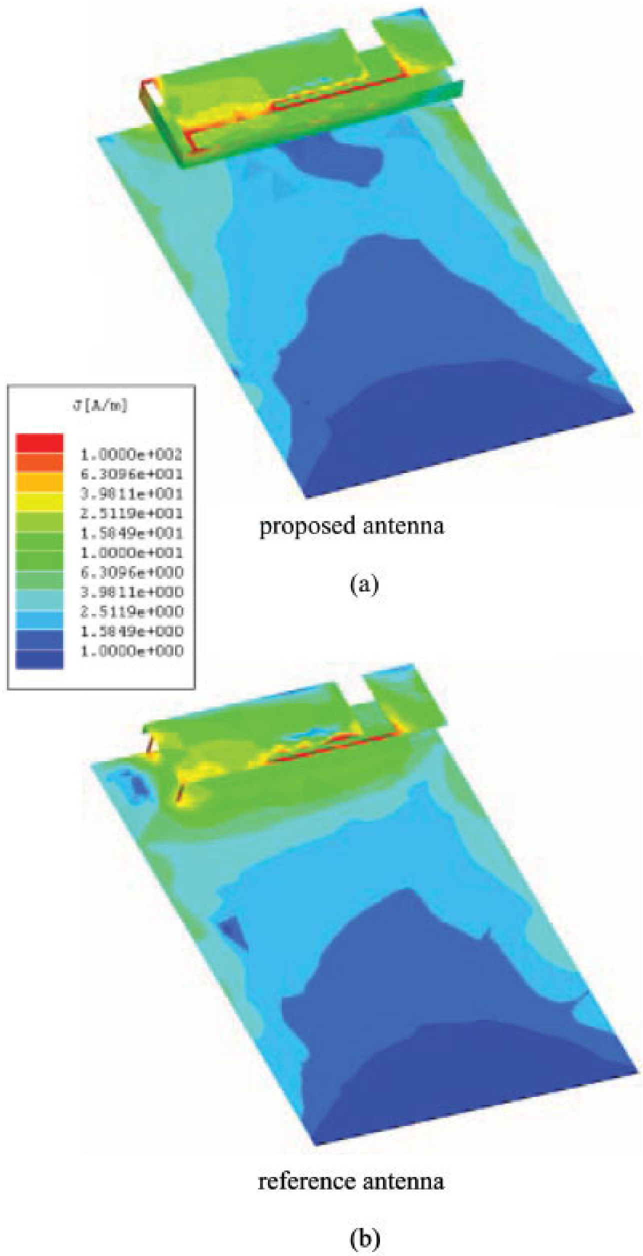


Figure 5 Simulated surface current distributions on the antenna and the system ground plane at 925 MHz for the case studied in Figure 2. (a) The antenna with $h = 5$ mm studied in Figure 2. (b) The top radiating portion directly mounted above the system ground plane with a height of 8 mm (the antenna ground portion not present). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

current distribution is seen to be much smaller for the proposed antenna than for the reference antenna. Thus, with the metal case placed below the proposed antenna, small effects on the antenna performances can be expected [10]. That is, the space below the antenna is usable for accommodating the related conducting elements or electronic components in the PDA phone.

Effects of the length and width of the system ground plane are studied in Figure 6. In Figure 6(a), results of the measured return loss for the ground-plane length L varied from 90 to 110 mm are presented. Very slight variations in the measured return loss are seen. This behavior is different from those observed for the conventional mobile phone antennas, whose impedance bandwidths are usually

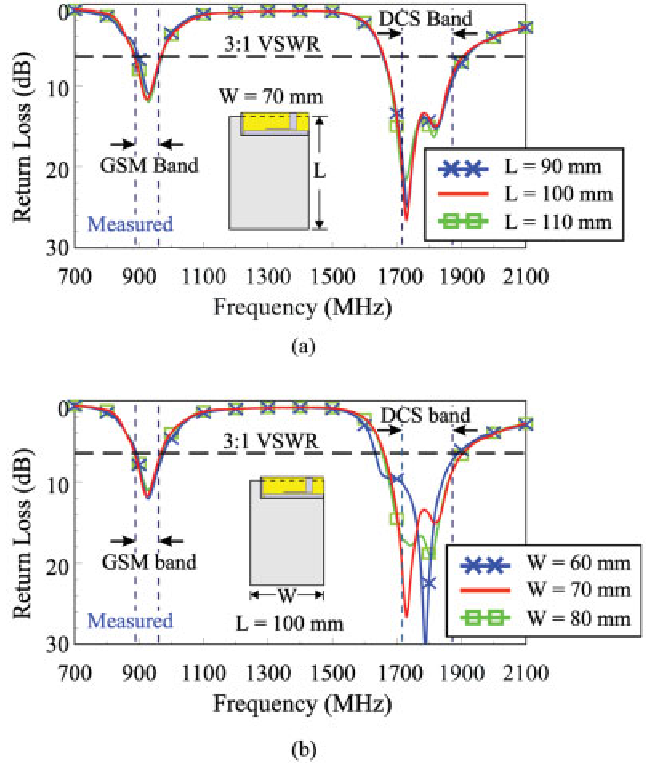


Figure 6 Measured return loss for the antenna studied in Figure 2 (a) as a function of L, the length of the system ground plane, and (b) as a function of W, the width of the system ground plane. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

strongly dependent on the length of the system ground plane [11, 12]. Results of the measured return loss for the ground-plane width W varied from 60 to 80 mm are shown in Figure 6(b). For the lower band, very small variations in the measured return loss are seen. For the upper band, although some variations are observed, the obtained bandwidth is about the same. The obtained results indicate that the proposed antenna is generally not sensitive to the possible variations in the size of the system ground plane, which is an advantage over the conventional mobile phone antennas.

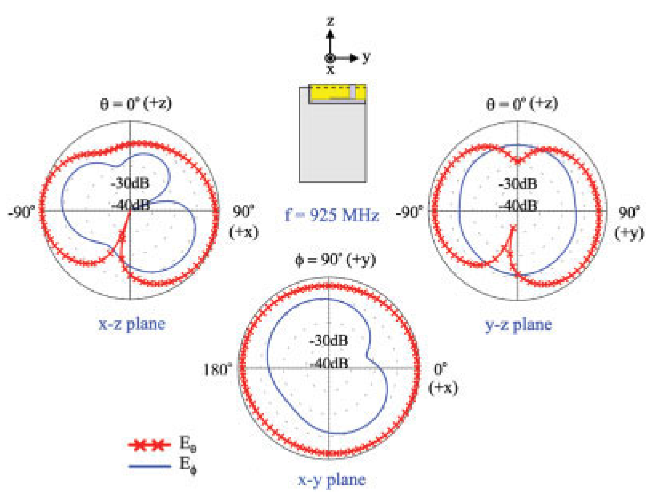


Figure 7 Measured radiation patterns at 925 MHz for the antenna studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

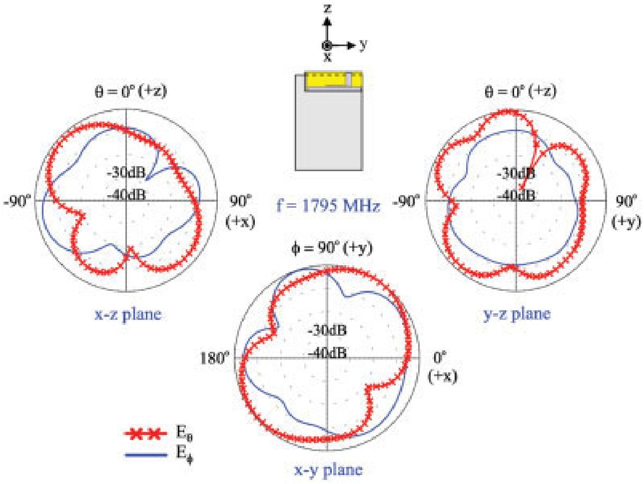


Figure 8 Measured radiation patterns at 1795 MHz for the antenna studied in Figure 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Radiation characteristics of the antenna are also studied. Measured radiation patterns in three principal planes at 925 and 1795 MHz (center frequencies of the GSM and DCS bands) are plotted in Figures 7 and 8, respectively. Results for other frequencies over the GSM and DCS bands are also studied, which are found to be similar to the patterns plotted here and are thus not shown for brevity. At 925 MHz, monopole-like radiation pattern is generally obtained, and near-omnidirectional radiation pattern in the *x–y* plane (azimuthal plane) is seen. At 1795 MHz, more variations in the radiation patterns compared to those at 925 MHz are seen. These radiation patterns show no special distinctions compared with those of the conventional mobile phone antennas [1]. Figure 9 shows the measured antenna gain and simulated (HFSS) radiation efficiency for the antenna studied in Figure 2. Over the GSM band shown in Figure 9(a), the antenna gain is varied from about 1.0 to 2.1 dBi, and the radiation efficiency is all larger than 70%. Over the DCS band shown in Figure 9(b), the antenna gain is about 3.0–3.4 dBi and the radiation efficiency is all larger than 80%.

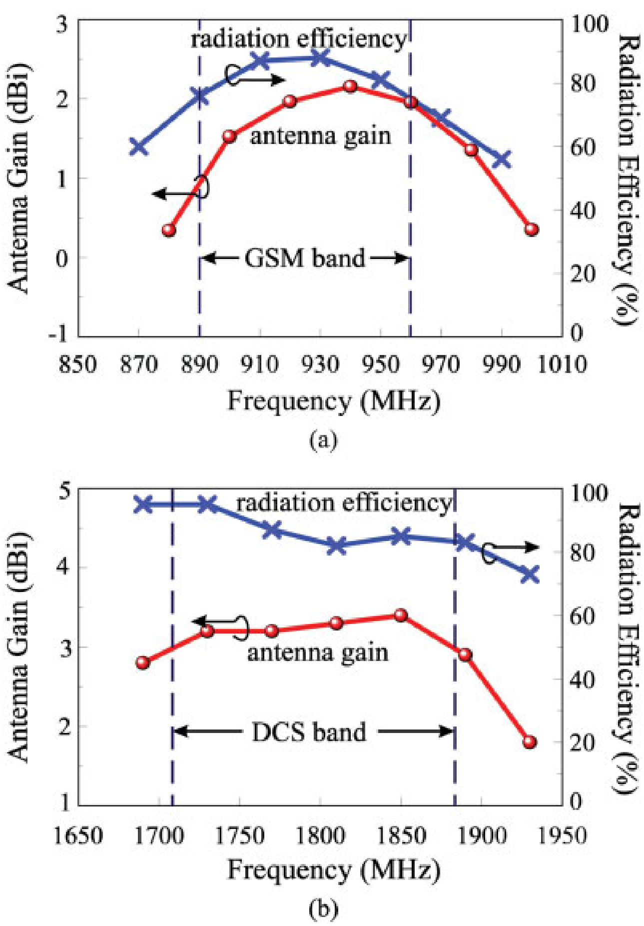


Figure 9 Measured antenna gain and simulated radiation efficiency for the antenna studied in Figure 2. (a) The GSM band. (b) The DCS band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

3. CONCLUSION

An internal dual-band patch antenna mounted above the system ground plane of the PDA phone for GSM/DCS operation has been proposed. The antenna does not directly occupy the valuable space on the system ground plane, and a usable space below the antenna for accommodating the conducting elements or electronic components is provided. In addition, owing to the use of the proposed ground portion that encircles the antenna's top radiating portion, the performances of the antenna are found to be very slightly affected by the conducting element placed below the antenna. This behaviour can lead to a compact integration of the antenna employed in the mobile device. A design rule based on adjusting the antenna's top radiating portion to effectively control the lower and upper bands of the antenna for GSM/DCS operation has also been given and verified in this study.

REFERENCES

1. K.L. Wong, Planar Antennas for wireless communications, Wiley, New York, 2003.
2. K.L. Wong, S.W. Su, C.L. Tang, and S.H. Yeh, Internal shorted patch antenna for a UMTS folder-type mobile phone, IEEE Trans Antennas Propagat 53 (2005), 3391–3394.
3. K.L. Wong and C.H. Chang, Surface-mountable EMC monopole chip antenna for WLAN operation, IEEE Trans Antennas Propagat 54 (2006), 1100–1104.
4. C.M. Su, K.L. Wong, C.L. Tang, and S.H. Yeh, EMC internal patch antenna for UMTS operation in a mobile device, IEEE Trans Antennas Propagat 53 (2005), 3836–3839.
5. K.L. Wong and C.I. Lin, Internal GSM/DCS antenna backed by a step-shaped ground plane for a PDA phone, IEEE Trans Antennas Propagat 54 (2006), 2408–2410.
6. K.L. Wong and C.H. Chang, WLAN chip antenna mountable above the system ground plane of a mobile device, IEEE Trans Antennas Propagat 53 (2005), 3496–3499.
7. K.L. Wong, Y.C. Lin, and T.C. Tseng, Thin internal GSM/DCS patch antenna for a portable mobile terminal, IEEE Trans Antennas Propagat 54 (2006), 238–242.
8. J. Ollikainen and A. Lehtola, Internal multi-band antenna with improved radiation efficiency, U.S. Patent No. 6,552,686 B2, April 22, 2003.
9. http://www.ansoft.com/products/hf/hfss/, Ansoft Corporation HFSS.
10. S.W. Su, K.L. Wong, C.L. Tang, and S.H. Yeh, Wideband monopole antenna integrated within the front-end module package, IEEE Trans Antennas Propagat 54 (2006), 1888–1891.
11. P. Vainikainen, J. Ollikainen, O. Kivekas, and I. Kelander, Resonator-based analysis of the combination of mobile handset antenna and chassis, IEEE Trans Antennas Propagat 50 (2002), 1433–1444.
12. T.Y. Wu and K.L. Wong, On the impedance bandwidth of a planar inverted-F antenna for mobile handsets, Microwave Opt Technol Lett 32 (2002), 249–251.