Modified T-Shaped Planar Monopole Antennas for Multiband Operation

Sheng-Bing Chen, Yong-Chang Jiao, Wei Wang, and Fu-Shun Zhang

***Abstract*—In this paper, we propose a novel modified T-shaped planar monopole antenna in that two asymmetric horizontal strips are used as additional resonators to produce the lower and upper resonant modes. As a result, a dual-band antenna for covering 2.4- and 5-GHz wireless local area network (WLAN) bands is implemented. In order to expand the lower band, a multiband antenna for covering the digital communications systems, personal communications systems, Universal Mobile Telecommunications Systems, and 2.4/5-GHz WLAN bands is also developed. Prototypes of the multiband antenna have been successfully implemented. Good omnidirectional radiation in the desired frequency bands has been achieved. The proposed multiband antenna with relatively low profile is very suitable for multiband mobile communication systems.**

***Index Terms*—Monopole antenna, multiband antenna, wireless communication.**

I. Introduction

WIRELESS communications have been developed widely and rapidly in the modern world, which leads to a great demand in designing compact, low-profile, and multiband antennas for mobile terminals. To meet these requirements, compact high-performance multiband planar antennas with good radiation characteristics are needed. Recently many antennas with multiband and wideband characteristics have been successfully designed for wireless applications [1]–[8]. In these designs, they can provide a dual-band operation for the application in the wireless local area network (WLAN) communication systems. However, a multiband system is becoming necessary to provide more services including the digital communication system (DCS), Universal Mobile Telecommunications System (UMTS) and personal communications system (PCS), and yet a multiband antenna covering DCS1800, PCS1900, UMTS2000, and 2.4- and 5-GHz WLAN bands is very scant in the literature.

In this paper, we first propose a novel modified T-shaped planar monopole antenna. Two asymmetric horizontal strips are used to provide two broadband dual-resonance modes. As a result, a dual-band antenna for covering the 2.4- and 5-GHz WLAN systems is achieved, which was initially presented in [9]. By widening the right horizontal strip and using an L-shaped notch in the right horizontal strip, a multiband antenna covering DCS1800, PCS1900, UMTS2000, and 2.4- and 5-GHz WLAN bands is then implemented. The proposed antenna is both compact in size and multiband operation suitable for the DCS (1710–1880 MHz), PCS (1850–1990 MHz), UMTS (1920–2170 MHz), 2.4-GHz WLAN (IEEE 802.11b in the U.S.: 2400–2484 MHz), and 5-GHz WLAN (HIPERLAN/2 in Europe: 5150–5350/ 5470–5725 MHz and IEEE 802.11a in the U.S.: 5150–5350/ 5725–5825 MHz) applications.

This paper is organized as follows. As a starting point, Section II presents the dual-band antenna and its measured, as well as simulated results. After that, the multiband antenna design and parameter study are described in Section III, and a prototype of the antenna is also constructed and tested. Finally, the entire study is summarized in Section IV.

Manuscript received December 24, 2005; revised March 23, 2006. This work was supported by the National Natural Science Foundation of China under Grant 60171045.

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Digital Object Identifier 10.1109/TMTT.2006.877811

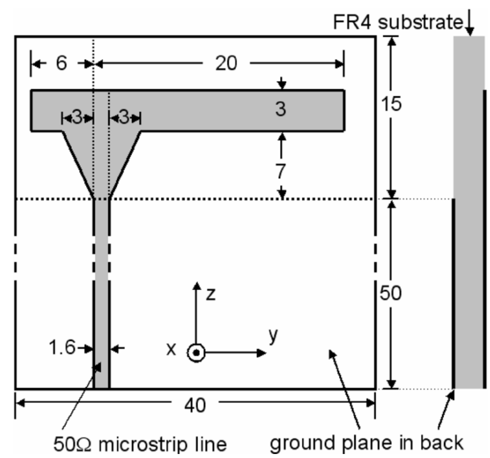

Fig. 1. Geometry of the modified T-shaped monopole antenna. The dimensions (in millimeters) shown in this figure are not to scale.

II. Dual-Band Antenna

A. Antenna Geometry

Fig. 1 shows the geometry and dimensions of the initial proposed modified T-shaped planar monopole antenna for multiband operation. The proposed antenna is excited using a 50-Ω microstrip feed line. The radiating element has compact dimensions of 10×26 mm^2 and is printed on the front of an inexpensive FR4 substrate with a thickness of 1 mm and a relative permittivity of 4.4. The ground plane is selected to be 40×50 mm^2 and is printed on the back of the substrate.

In this design, the proposed antenna consists of a vertical strip and two asymmetric horizontal strips on the top that can produce two different surface current paths and result in a dual-resonance mode. The right horizontal strip provides the lower mode covering the 2.4-GHz WLAN band, while the left one controls

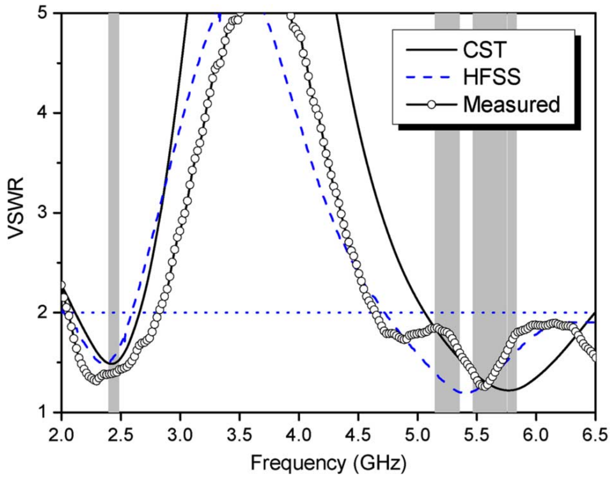

Fig. 2. Simulated and measured VSWRs for the proposed antenna. Standards bandwidth requirement in gray. (Color version available online at: http://ieeexplore.ieee.org.)

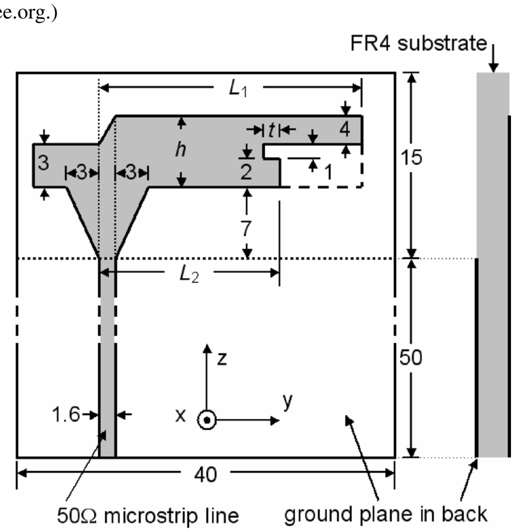

Fig. 3. Geometry of the multiband monopole antenna. The dimensions (in millimeters) shown in this figure are not to scale.

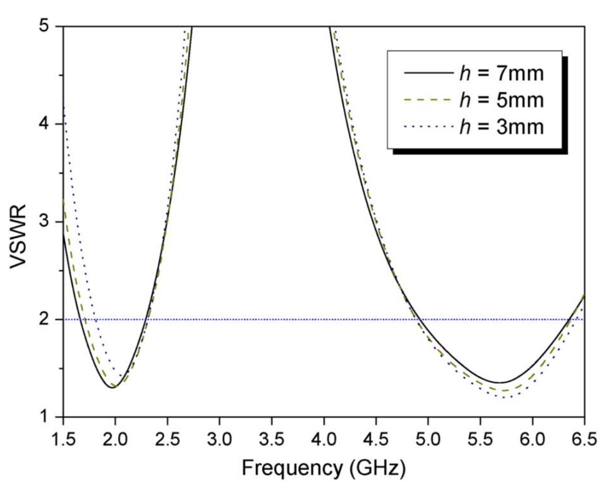

Fig. 4. Simulated VSWRs with variation of H for the antenna in Fig. 3 with $t = 0$ mm and $L_1 = L_2 = 25$ mm.

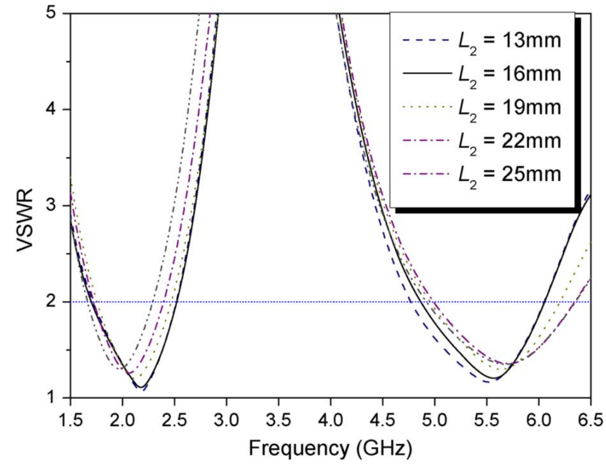

Fig. 5. Simulated VSWRs with variation of L_2 for the antenna in Fig. 3 with $t = 0$ mm and $L_1 = 25$ mm. (Color version available online at: http://ieeexplore.ieee.org.)

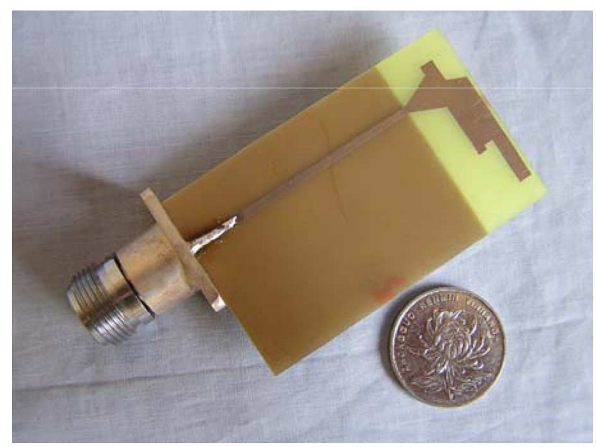

Fig. 6. Prototype of the proposed multiband antenna. (Color version available online at: http://ieeexplore.ieee.org.)

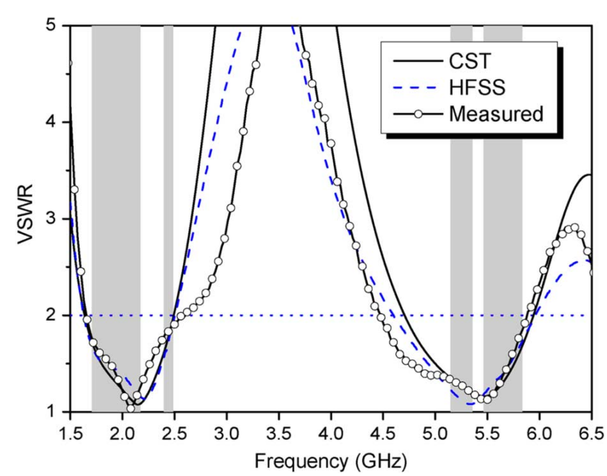

Fig. 7. Simulated and measured VSWRs for the multiband antenna in Fig. 6. Standards bandwidth requirement in gray. (Color version available online at: http://ieeexplore.ieee.org.)

the upper mode including 5-GHz WLAN bands. A conducting triangular section is also added into the vertical strip of the T-shaped monopole, as shown in Fig. 1, which improves the impedance matching for both bands. With this structure, it is very easy to achieve the desired bandwidth for the lower and upper modes.

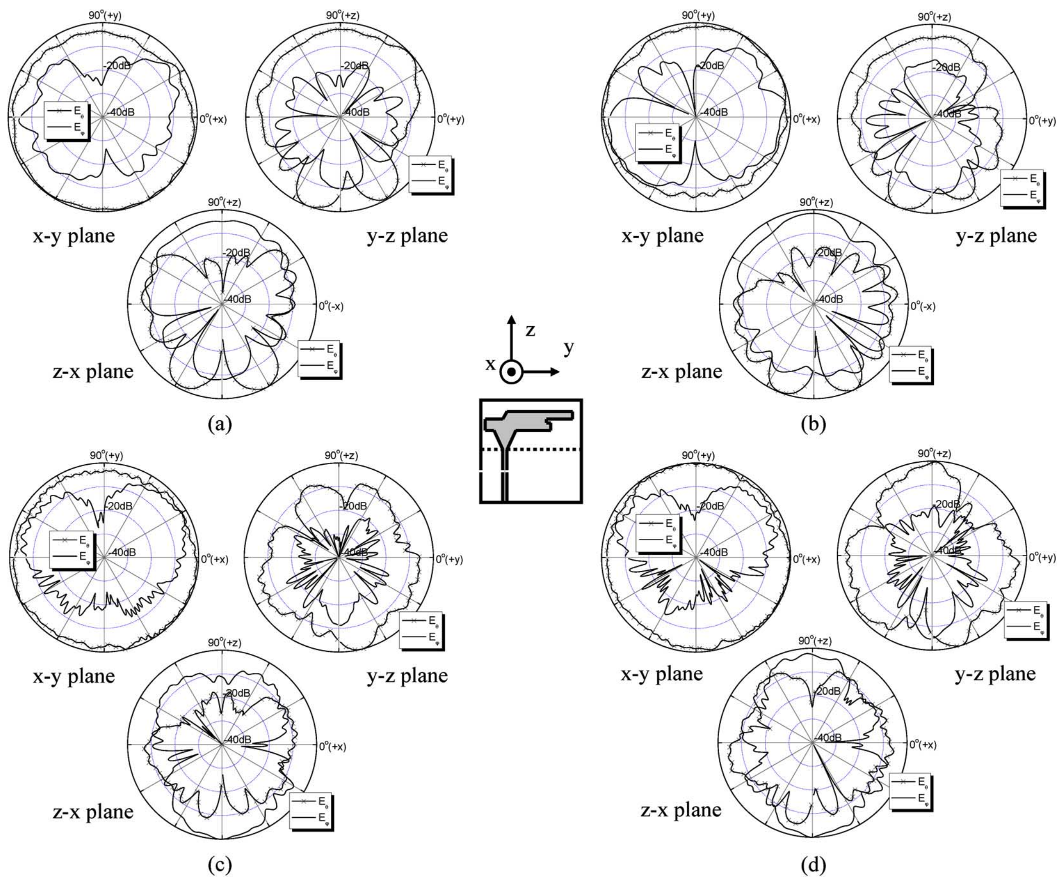

Fig. 8. Measured radiation patterns for the proposed multiband antenna. (a) 1.9 GHz. (b) 2.4 GHz. (c) 5.2 GHz. (d) 5.8 GHz. (Color version available online at: http://ieeexplore.ieee.org.)

B. Measured and Simulated Results

The proposed antenna was simulated using two commercial electromagnetic solvers, Ansoft's High Frequency Structure Simulator (HFSS) and CST's Microwave Studio, and a prototype of the antenna was constructed and tested. Fig. 2 shows the measured and two simulated voltage standing-wave ratios (VSWRs) of the proposed antenna in Fig. 1. The measured data in general agree with the simulated results obtained from Ansoft's HFSS and CST's Microwave Studio. Two separate broadband resonant modes are clearly excited at 2.4 and 5.5 GHz simultaneously with a good matching condition. With the definition of 2 : 1 VSWR, the impedance bandwidth of the lower mode covers the 2.4-GHz WLAN band (2400–2484 MHz). For the upper mode, a wide impedance bandwidth is obtained, which is sufficient to encompass the 5-GHz WLAN bands (5150–5350/5470–5825 MHz).

III. Multiband Antenna

A. Antenna Design

In order to make the antenna cover simultaneously the DCS, PCS, and UMTS bands, we widen the right horizontal strip and use an L-shaped notch in the right horizontal strip. The parametric studies of the antenna are conducted to obtain the influence of the dimensions on the antenna performance and to find a set of optimal design parameters for the desired operating frequency bands. The simulations are performed using CST's Microwave Studio package, which utilizes the finite integration technique for electromagnetic computation.

Here, effects of two key antenna parameters, i.e., the width of the right horizontal strip and the length of the lower right strip, are considered on the antenna bandwidth. The geometry of the improved antenna is shown in Fig. 3. For the simulations here, t and L_1 are fixed at 0 and 25 mm, respectively.

Fig. 4 illustrates the simulated VSWRs versus width of the right horizontal strip ($h = 3, 5, 7$ mm) when $L_2 = 25$ mm. It can be seen from Fig. 4 that with increasing width h, the bandwidths for the lower band increase and the resonant frequencies of the lower band shift down, while the bandwidths of the upper band change slightly.

As a matter of fact, the use of a rectangular corner notch leads to a closer dual-resonant response and, therefore, extends the impedance bandwidth of the lower resonant mode. The simulated VSWR curves with optimal width h of 7 mm and different length L_2 of the lower branch in the right horizontal strip are plotted in Fig. 5. It can be observed that the impedance matching is improved with decreasing L_2.

B. Measured and Simulated Results

After the parametric study, an optimal design of the antenna is suggested, as shown in Fig. 3. Moreover, the use of an additional rectangular notch of the right horizontal strip is helpful for extending the lower mode. The L-shaped notch has two different removed sections with 9×3 mm^2 and 1×1 mm^2 areas at the lower right corner.

A prototype of the proposed multiband antenna was fabricated according to the aforementioned design result, as shown in Fig. 6. A 50-Ω microstrip line is used to feed this proposed antenna and is etched on the FR-4 substrate. The dimensions of the multiband antenna with $L_1 = 25$ mm, $L_2 = 16$ mm, and $t = 1$ mm are depicted in Fig. 3. The measured and simulated VSWRs of the proposed multiband antenna are shown in Fig. 7. The measured data agree in general with the simulated results. Two separate broadband resonant modes are clearly excited at 2.15 and 5.47 GHz simultaneously with a good matching condition. With the definition of a 2 : 1 VSWR, the impedance bandwidth of the lower mode is 930 MHz (1.66–2.59 GHz) covering the DCS, PCS, UMTS, and 2.4-GHz WLAN bands. For the upper mode, an impedance bandwidth of 1410 MHz (4.48–5.89 GHz) is obtained, which is sufficient to encompass the 5-GHz WLAN bands.

The measured radiation patterns at 1.9, 2.4, 5.2, and 5.8 GHz for the proposed antenna are plotted in Fig. 8. It can be seen that the radiation patterns in x–y-plane are nearly omnidirectional for four frequencies, and those in the z–x- plane, as expected, are very monopole-like. Thanks to the low signal level and complex environments for the measurement of an omnidirectional antenna, some measured patterns look rough in spots.

IV. Conclusion

A compact modified T-shaped planar monopole antenna has been proposed. The proposed antenna can provide sufficient impedance bandwidths and suitable radiation patterns for wireless applications. A dual-band antenna for the 2.4- and 5-GHz WLAN systems is addressed. As a further design, a multiband antenna prototype is constructed for applications in the DCS, PCS, UMTS, and 2.4- and 5-GHz WLAN systems. The measured impedance bandwidths are 0.93 GHz at the lower frequency band of 2.4 GHz, and 1.41 GHz at the upper frequency band of 5 GHz. The measured radiation patterns in the x–y-plane are of a nearly omnidirectional characteristic at operating frequencies. Therefore, the antennas are good candidates for multiband communication applications.

References

[1] P. Ciais, R. Staraj, G. Kossiavas, and C. Luxey, "Compact internal multiband antenna for mobile phone and WLAN standards," *Electron. Lett.*, vol. 40, pp. 920–921, Jul. 2004.

[2] H. C. Go and Y. W. Jang, "Multi-band modified fork-shaped microstrip monopole antenna with ground plane including dual-triangle portion," *Electron. Lett.*, vol. 40, pp. 575–577, May 2004.

[3] S. Y. Lin, "Multiband folded planar monopole antenna for mobile handset," *IEEE Trans. Antennas Propag.*, vol. 52, no. 7, pp. 1790–1794, Jul. 2004.

[4] H. D. Chen, J. S. Chen, and Y. T. Cheng, "Modified inverted-L monopole antenna for 2.4/5 GHz dual-band operations," *Electron. Lett.*, vol. 39, pp. 1567–1568, Oct. 2003.

[5] C.-M. Su, H.-T. Chen, and K.-L. Wong, "Printed dual-band dipole antenna with U-slotted arms for 2.4/5.2 GHz WLAN operation," *Electron. Lett.*, vol. 38, pp. 1308–1309, Oct. 2002.

[6] Y.-L. Kuo and K.-L. Wong, "Printed double-T monopole antenna for 2.4/5.2 GHz dual-band WLAN operations," *IEEE Trans. Antennas Propag.*, vol. 51, no. 9, pp. 2187–2192, Sep. 2003.

[7] J.-Y. Jan and L.-C. Tseng, "Small planar monopole antenna with a shorted parasitic inverted-L wire for wireless communications in the 2.4-, 5.2-, and 5.8-GHz bands," *IEEE Trans. Antennas Propag.*, vol. 52, no. 7, pp. 1903–1905, Jul. 2004.

[8] T. H. Kim and D. C. Park, "CPW-fed compact monopole antenna for dual-band WLAN applications," *Electron. Lett.*, vol. 41, pp. 291–293, Mar. 2005.

[9] S.-B. Chen, Y.-C. Jiao, F.-S. Zhang, and Q.-Z. Liu, "Modified T-shaped planar monopole antenna for 2.4/5 GHz WLAN applications," in *Proc. Asia–Pacific Microw. Conf.*, Suzhou, China, Dec. 4–7, 2005, vol. 4, pp. 2714–2716.

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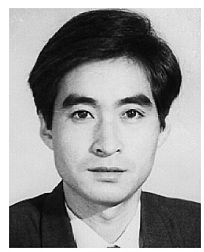

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