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PLANAR MULTI-BAND T-SHAPED MONOPOLE ANTENNA WITH A PAIR OF MIRRORED L-SHAPED STRIPS FOR WLAN/WIMAX OPERATION

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Abstract—A novel compact design of planar T-shaped monopole antenna with multi-band operation for WLAN/WiMAX system is proposed. By insetting a pair of mirrored L-shaped monopole strips, multi resonant modes close to 2.45/3.5/5.5 GHz band are excited to meet the specifications of WLAN/WiMAX system. And, the obtained impedance bandwidth across the operating bands can reach about 160/1100/2690 MHz for the 2.45/3.5/5.5 GHz bands, respectively. Only with the antenna size of $30\times42\times0.8\,\mathrm{mm}^3$, the proposed monopole antenna has the compact operation with more than 20% antenna size reduction. The measured peak gains and radiation efficiencies are about 3.2/3.5/5.4 dBi and 72/98/96% for the 2.45/3.5/5.5 GHz band, respectively, with nearly omni-directional pattern in the XY-plane.

1. INTRODUCTION

Due to low cost, lightweight and process simplicity, planar multiband monopole antennas have become popular candidates in recent years to provide quick and easy wireless access for multimode communication systems. The currently presented antenna designs suitable for multi-band operations in the 2.45 GHz (2.4–2.484 GHz), 3.5 GHz (3.4–3.69 GHz) and 5.5 GHz (5.15–5.95 GHz) bands for WLAN/WiMAX applications have been reported in [1–13]. The related monopole antenna (MA) designs includes a patch MA with two bent slots [1], a planar rectangular MA with conductor-backed plane [2], MA with multi-branch strips [3, 4], asymmetric rectangular MA with additional

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strips [5], inverted-F antenna [6], mirrored-L MA [7], MA with rectangular horizontal strips and trapezoidal ground plane [8], a planar rectangular MA connected with a circular disc by via hole [9], MA with an etched ∩-shaped slot and a parasitic ring resonator [10], MA with two semi-circle strips [11], T-shaped MA with a trapezoidal ground plane [12], MA with C-shaped and S-shaped meander strips [13], inverted L-shaped MA [14] and dual U-shaped MA [15]. However, there is the disadvantage of being larger antenna size for these above MAs [1–7] and increasing demand for antennas having more compact size to be suitably embedded in the practical portable devices for WLAN/WiMAX application. And, the related T-shaped monopole antenna designs [16–19] had been presented and only focused at dual-band (2.45/5 GHz) operation for WLAN system by using longer monopole strip to excite the lower (2.45 GHz) operating frequency and shorter strip for the resonance of the higher (5 GHz) band [16–18] or with triple-T monopole antenna for 2.45, 5.2 and 5.8 GHz WLAN operations [19]. However, the compact T-shaped monopole antenna design for WLAN/WiMAX system is scant in the literature except for the proposed antenna design [12] with less antenna peak gain. Therefore, in this article, we propose a novel planar T-shaped monopole antenna with a pair of mirrored L-shaped strips for multi-band WLAN/WiMAX communication. And, from the related measured results, it provides relatively wider impedance bandwidth of 160/1100/2690 MHz for the 2.45/3.5/5.5 GHz bands, respectively. The proposed planar monopole antenna also provides the nearly omni-directional radiation patterns with maximum measured peak antenna gains and radiation efficiencies of 3.2/3.5/5.4 dBi and 72/98/96% across the operating bands, respectively, which are more than that for the presented compact antenna designs [8–10, 12–14]. Also, compared with the presented antenna designs in the literature [1–7, 16–19], this proposed monopole antenna has more than 20% antenna size reduction to achieve compact operation. Details of the proposed monopole antenna design are described, and experimental results for the obtained performance operated across the 2.45/3.5/5.5 GHz bands are presented and discussed.

2. ANTENNA DESIGN

Figure 1 illustrates the geometry and photo of the proposed T-shaped monopole antenna with a pair of mirrored L-shaped strips. A 50 Ω microstrip line is etched as the feeding structure on the inexpensive FR-4 substrate with the antenna volume of $30 \times 42 \times 0.8\,\text{mm}^3$, dielectric constant $\varepsilon_r = 4.7$ and loss tangent $\tan\delta = 0.0245$. The T-shaped

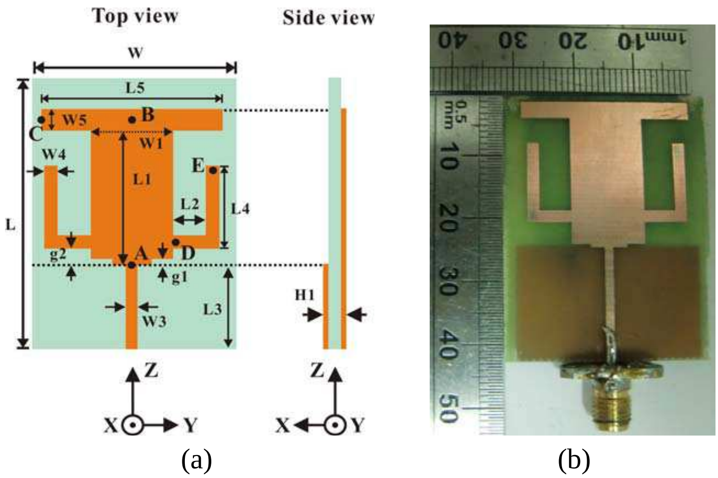


Figure 1. Geometry and photo of the proposed T-shaped monopole antenna with a pair of mirrored L-shaped strips for multi-band operation. (a) Geometry. (b) Photo.

monopole patch is fed at point A and used to excite the fundamental and second modes near 2.45/5.5 GHz bands, respectively, in this study. And, the L-shaped monopole strip ($L2 + L4$, from point D to point E) is inset at point D along the side edge of the T-shaped monopole patch to excite the fundamental mode close to 3.5 GHz band. Compared with the related T-shaped monopole antenna designs in the literature [16–19] only with dual-band (2.45/5 GHz) operation by using dual- or triple-T strips, this proposed triple-band monopole antenna provides various design criteria to support the worldwide interoperability for microwave access (WiMAX) applications and achieve the multi-band operation to cover the 2.45/3.5/5.5 GHz WLAN/WiMAX bands. First, for achieving the resonant mode at 2.45 GHz band, the surface current length of the T-shaped patch (A $\rightarrow$ B $\rightarrow$ C) is chosen to be about 34 mm corresponding approximately to 0.28 and 0.59 wavelengths of 2.45/5.5 GHz bands. Detailed effects of the total length on the antenna performances are analyzed with the aid of Table 2 and Figure 4 in Section 3. Also, the excited length (A $\rightarrow$ D $\rightarrow$ E) including the L-shaped strip ($L2 + L4$) is chosen to be about 28 mm corresponding approximately to 0.32 wavelength of 3.5 GHz operation. The discussion of the antenna performances versus the L-shaped strip's vertical length ($L4$) will be listed at Table 3 and shown in Figure 5. By properly adjusting the width of the feeding microstrip line, good impedance matching across the operating band can easily be obtained.

Table 1. Simulated and measured return loss against frequency for the proposed T-shaped monopole antenna with a pair of mirrored L-shaped strips; $L = 42\,\text{mm}$, $W = 30\,\text{mm}$, $L1 = 20\,\text{mm}$, $L2 = 5.0\,\text{mm}$, $L3 = 28\,\text{mm}$, $L4 = 13\,\text{mm}$, $L5 = 28\,\text{mm}$, $W1 = 12\,\text{mm}$, $W3 = 1.5\,\text{mm}$, $W4 = 2\,\text{mm}$, $W5 = 2\,\text{mm}$, $g1 = 0.5\,\text{mm}$, $g2 = 4\,\text{mm}$.

	$f_{1L} \sim f_{1H}$ (GHz)	BW (MHz/%)	$f_{2L} \sim f_{2H}$ (GHz)
The proposed MA (Simulated)	$2.29 \sim 2.63$	340/13.7	$3.26 \sim 6.74$
The proposed MA (Measured)	$2.38 \sim 2.54$	160/6.5	$3.14 \sim 4.24$
MA without L-shaped strips (Measured)	$2.41 \sim 2.81$	400/15.3	- - - -

	BW (MHz/%)	$f_{3L} \sim f_{3H}$ (GHz)	BW (MHz/%)
The proposed MA (Simulated)	3860/69.6	- - - -	- - - -
The proposed MA (Measured)	1100/29.8	$5.12 \sim 7.81$	2690/40.2
MA without L-shaped strips (Measured)	- - - -	$4.43 \sim 5.57$	1140/23.0

Table 2. Measured return loss against frequency for the proposed compact monopole antenna with various lengths ($L1$) of the T-shape monopole patch; other antenna parameters are given in Table 1.

$L1$ (mm)	$f_{1L} \sim f_{1H}$ (GHz)	BW (MHz/%)	$f_{2L} \sim f_{2H}$ (GHz)	BW (MHz/%)	$f_{3L} \sim f_{3H}$ (GHz)	BW (MHz/%)
16	$2.41 \sim 2.62$	210/8.3	$3.21 \sim 4.43$	1220/31.9	$5.84 \sim 7.43$	1590/23.9
18	$2.41 \sim 2.58$	170/6.8	$3.24 \sim 4.31$	1070/28.3	$5.68 \sim 7.22$	1540/23.8
20	$2.38 \sim 2.54$	160/6.5	$3.14 \sim 4.24$	1100/29.8	$5.12 \sim 7.81$	2690/40.2
22	$2.33 \sim 2.48$	150/6.2	$3.31 \sim 4.29$	980/25.7	$5.57 \sim 6.27$	700/11.8

3. RESULTS AND DISCUSSIONS

To demonstrate the above deduction and guarantee the correctness of simulated results, the electromagnetic simulator HFSS based on the finite element method [20] has been applied for the proposed monopole antenna design. Figure 2 shows the related simulated and experimental

Table 3. Measured return loss against frequency for the proposed compact monopole antenna with various vertical lengths ($L4$) of the L-shaped strip; other antenna parameters are given in Table 1.

$L4$ (mm)	$f_{1L} \sim f_{1H}$ (GHz)	BW (MHz/%)	$f_{2L} \sim f_{2H}$ (GHz)	BW (MHz/%)	$f_{3L} \sim f_{3H}$ (GHz)	BW (MHz/%)
9	$2.49 \sim 2.81$	320/12	$4.01 \sim 9.72$	5710/83.1	- - - -	- - - -
11	$2.46 \sim 2.78$	320/12.2	$3.76 \sim 8.52$	4760/77.5	- - - -	- - - -
13	$2.38 \sim 2.54$	160/6.5	$3.14 \sim 4.24$	1100/29.8	$5.12 \sim 7.81$	2690/40.2
15	$2.43 \sim 2.64$	210/8.2	$3.11 \sim 6.62$	3510/72.1	- - - -	- - - -

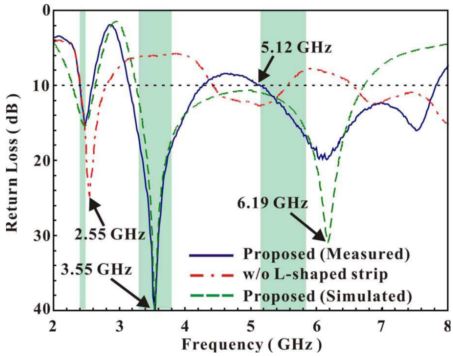


Figure 2. Simulated and measured return loss against frequency for the proposed T-shaped monopole antenna with the L-shaped strips or not; antenna parameters are given in Table 1.

results of return loss for the proposed T-shaped monopole antenna design of Figure 1 with the L-shaped strips or not. The related results are listed in Table 1 as comparison. Results show the satisfactory agreement for the proposed T-shaped monopole antenna design operating at the 2.45/3.5/5.5 GHz bands. From the experimental results, the measured impedance bandwidth (RL $\geqq$ 10 dB) can reach 6.5/29.8/40.2% (160/1100/2690 MHz) for 2.45/3.5/5.5 GHz bands, respectively, which provides much greater bandwidths for all operating bands to meet WLAN/WiMAX specifications. It is easily found that the fundamental mode close to 3.5 GHz band is excited by the L-shaped monopole strip. And, the fundamental and second modes near 2.45/5.5 GHz bands are controlled by the T-shaped monopole patch. Therefore, the presented design criteria can meet the prediction for the proposed monopole antenna described in Section 2.

To fully comprehend the excitation of each WLAN/WiMAX bands, the surface current distributions at 2.45, 3.5 and 5.5 GHz are shown in Figure 3, along with an additional pinky arrow sign showing the path length of each resonant mode. For both 2.45 and 5.5 GHz modes, they are clearly the conventional MA modes showing a near 0.25 and 0.5 wavelength distribution along the surface current path (A → B → C), respectively. As for 3.5 GHz resonant mode, a 0.25 wavelength distribution along an effective path (A → D → E) is observed in Figure 3(b).

The measured return losses for the proposed T-shaped monopole antenna with various lengths ($L1$) of the T-shaped patch are illustrated in Figure 4. By properly decreasing the T-shaped patch's length ($L1$) from 22 mm to 16 mm, the operating frequencies near 2.45/5.5 GHz

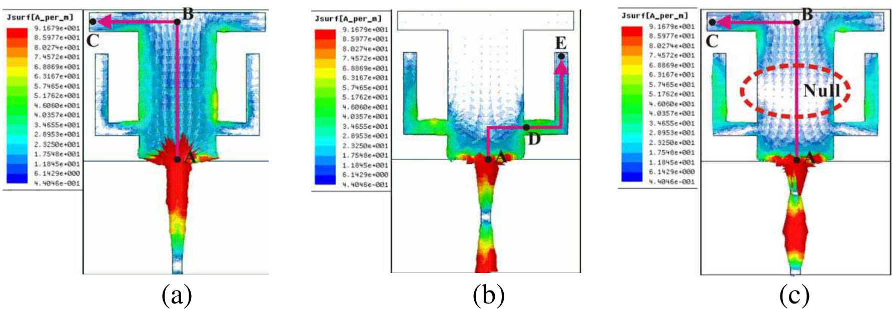


Figure 3. Simulated surface current distributions for the proposed T-shaped monopole antenna with a pair of mirrored L-shaped strips shown in Figure 1. (a) $f = 2.45$ GHz. (b) $f = 3.5$ GHz. (c) $f = 5.5$ GHz.

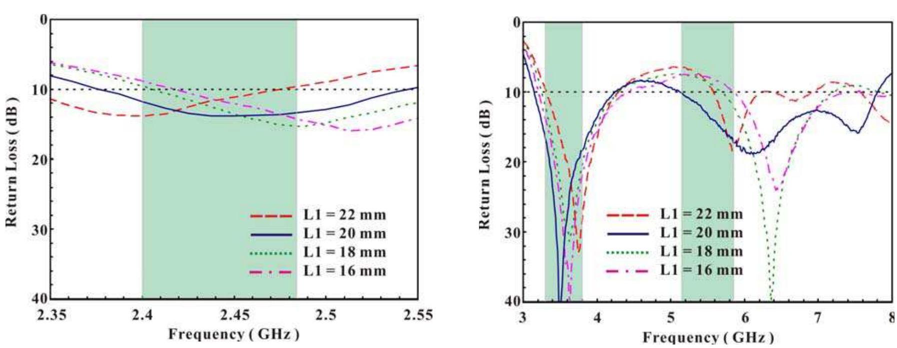


Figure 4. Measured return loss for the proposed monopole antenna with various lengths ($L1$) of the T-shape monopole patch; other antenna parameters are given in Table 1.

bands become significantly increasing with 3.5 GHz band less varied. On the other hand, It can be found that when the vertical length ($L4$) of the L-shaped strip increases from 9 mm to 15 mm, the surface

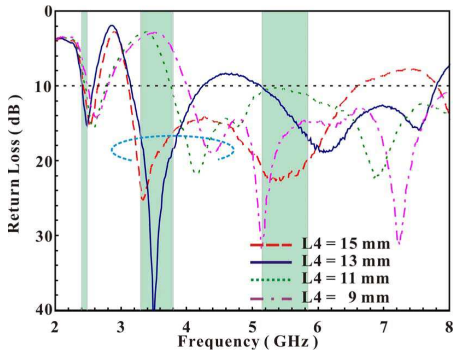


Figure 5. Measured return loss for the proposed T-shaped monopole antenna with various vertical lengths ($L4$) of the L-shaped strip; other antenna parameters are given in Table 1.

Table 4. Comparisons of the overall antenna volume and size reduction for this proposed T-shaped monopole antenna and other presented antennas in the literature [1–7, 16–19].

Reference No.	Proposed	1	2	3
Dimension (mm^3)	$30 \times 42 \times 0.8$	$40 \times 40 \times 0.8$	$48 \times 47 \times 0.8$	$62 \times 26.1 \times 0.8$
Reduction (%)	- - - - - - -	21%	45%	22%
Reference No.	4	5	6	7
Dimension (mm^3)	$43.5 \times 20 \times 1.6$	$44 \times 42 \times 1.6$	$100 \times 45 \times 0.8$	$26 \times 47 \times 1.6$
Reduction (%)	27%	65%	72%	49%
Reference No.	16	17	18	19
Dimension (mm^3)	$50 \times 75 \times 0.8$	$40 \times 65 \times 1$	$68 \times 40 \times 0.8$	$70 \times 75 \times 0.8$
Reduction (%)	66%	62%	54%	76%

current path (A → D → E) also extends to make the 3.5 GHz operating frequency significantly decreased with the operating frequencies near 2.45 GHz band less varied. The related measured return losses are illustrated in Figure 5. And, it is seen that the operating frequency at the 5.5 GHz band has also been influenced by the mutual coupling between the T-shaped patch and L-shaped strip. This defect can be overcome by extending the horizontal arm ($L2$) of the L-shaped strip with the vertical length ($L4$) decreased to reduce the mutual coupling effect.

To study the antenna size reduction for the proposed T-shaped monopole antenna, the comparisons of the overall antenna volume including the ground plane for this proposed and other presented antenna designs in the literature [1–7, 16–19] are listed in Table 4. It is seen that this proposed monopole antenna has more than 20% antenna size reduction to obtain compact operation, which is more suitable for embedding into the USB dongle.

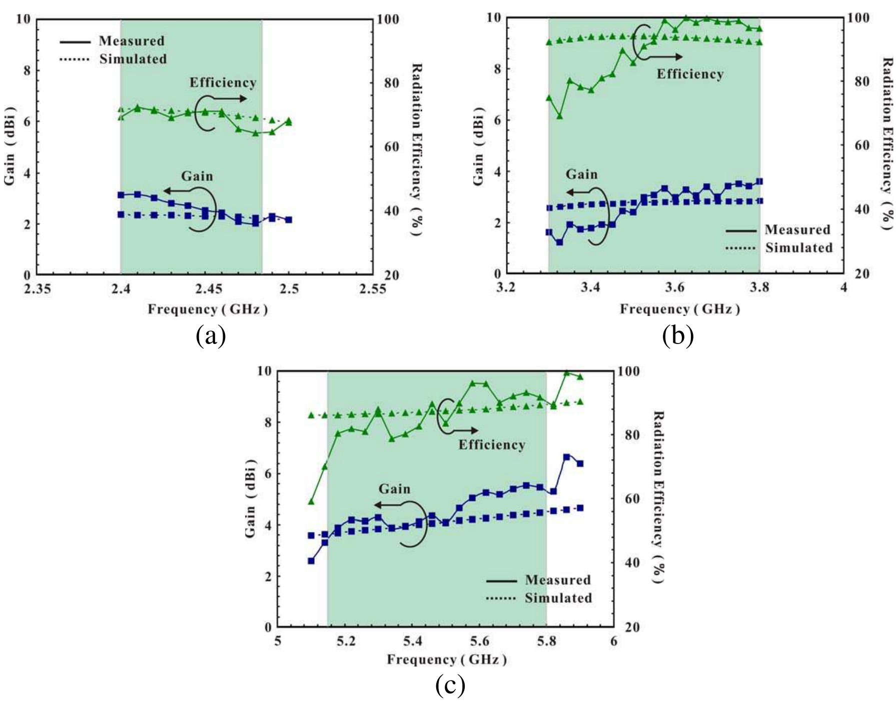
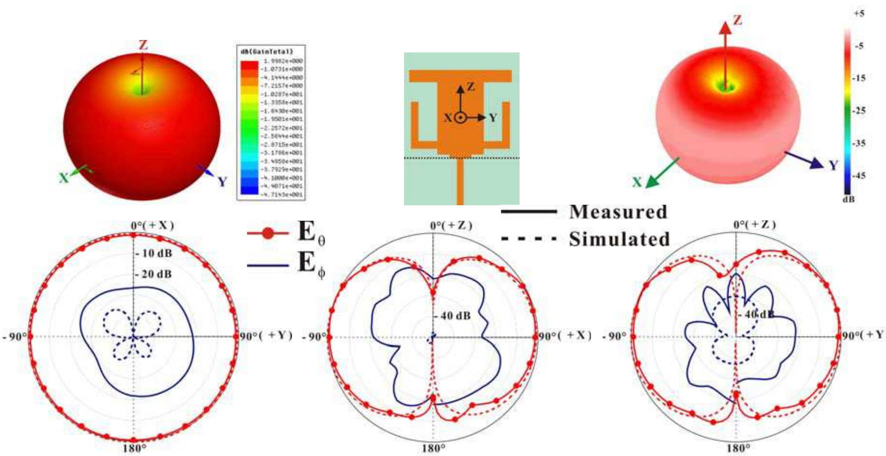
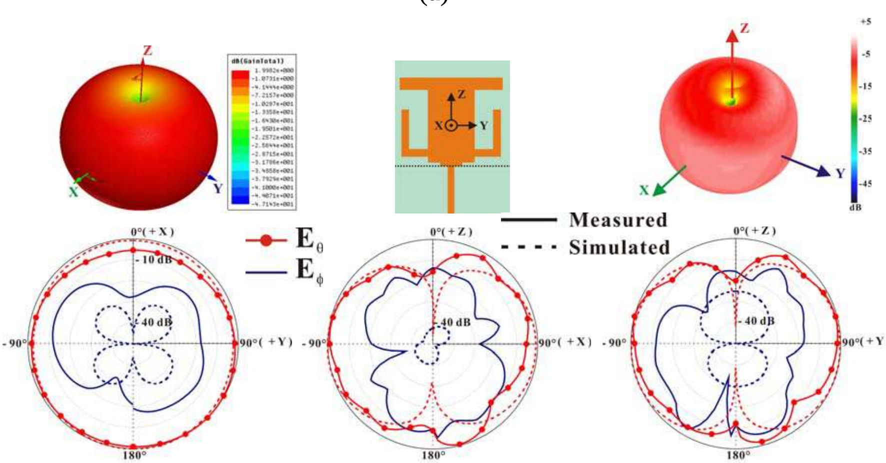


Figure 6. Measured and simulated peak gains and radiation efficiencies across the operating frequencies for the proposed T-shaped monopole antenna with a pair of mirrored L-shaped strips. (a) Low band. (b) Middle band. (c) High band.

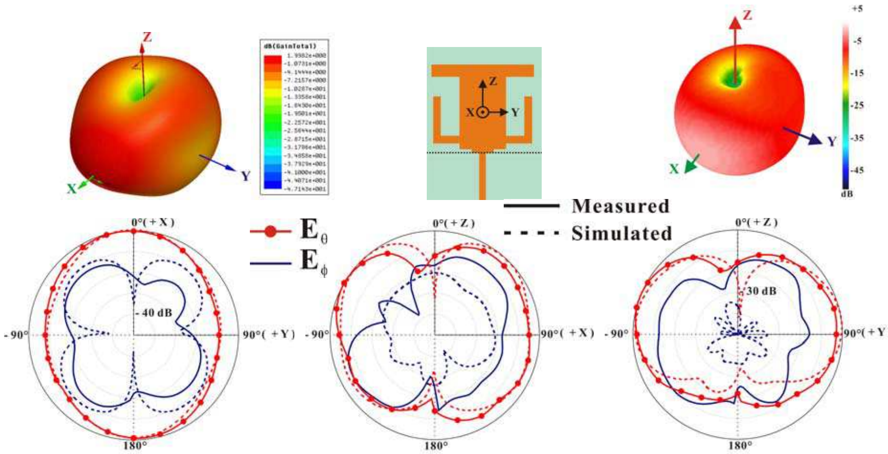
The radiation measurement of the proposed T-shaped monopole antenna is carried out in anechoic chamber by introducing NSI 800F far-field system. The measured peak gains and radiation efficiencies across the operating bands are shown in Figure 6 with the simulated results as comparison. Good agreement is seen between the measured and simulated results. As shown in Figure 6(a), the antenna gain is varied from about 2.1 to 3.2 dBi and the radiation efficiency is about 64%–72% for 2.45 GHz WLAN operation. Over the 3.5 GHz band, the antenna gain is about 1.6–3.5 dBi with the radiation efficiency about 74%–98% as shown in Figure 6(b). And, from the results shown in Figure 6(c), the antenna gain is about 3.3–5.4 dBi and the radiation



(a)



(b)



(c)

Figure 7. Measured and simulated 3D/2D radiation patterns for the proposed T-shaped monopole antenna with a pair of mirrored L-shaped strips. (a) $f = 2.45$ GHz. (b) $f = 3.5$ GHz. (c) $f = 5.5$ GHz.

efficiency is about 80%–96% over the 5.5 GHz band. The measured two-dimensional (2-D) and three-dimensional (3-D) radiation patterns at 2.45, 3.5 and 5.5 GHz are plotted in Figure 7 with the simulated results as comparison. It is easily found that the radiation patterns are with good omni-directional radiation pattern in the XY plane and broadside radiation in the XZ and YZ plane which resemble typical dipole patterns in symmetry with respect to the antenna axis ($\theta = 0$) since the proposed antenna is symmetrical. In Figure 7(c), probably due to L-shaped strip close to the T-shaped monopole patch to have the coupling effect, the radiation pattern at the operating frequency of 5.5 GHz, which is the second mode of the proposed T-shaped monopole patch, becomes similar to that at the fundamental frequency of 2.45 GHz.

4. CONCLUSIONS

A novel compact design of planar T-shaped monopole antenna with multi-band operation for WLAN/WiMAX system has been proposed. The obtained impedance bandwidth across the operating bands can reach about 160/1100/2690 MHz for the 2.45/3.5/5.5 GHz bands, respectively. Only with the antenna size of $30 \times 42 \times 0.8\,\text{mm}^3$, the proposed monopole antenna has the compact operation with more than 20% antenna size reduction. The proposed planar monopole antenna also provides the nearly omni-directional radiation patterns with maximum peak antenna gains and radiation efficiencies of 3.2/3.5/5.4 dBi and 72/98/96% across the operating bands, respectively.

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REFERENCES

1. Liu, H. W. and C. H. Ku, "Novel planar triple band monopole antenna for WiMAX/WLAN applications," *Microwave Opt. Technol. Lett.*, Vol. 52, 2405–2408, 2010.
2. Pan, C. Y., T. S. Horng, W. S. Chen, and C. H. Huang, "Dual wideband printed monopole antenna for WLAN/WiMAX applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 6, 149–151, 2007.
3. Huang, J. F., M. T. Wu, and J. Y. Wen, "A compact triple-band antenna design for UMTS, WLAN and WIMAX applications," *Microwave Opt. Technol. Lett.*, Vol. 51, 2207–2212, 2009.
4. Zuo, S. and Y. Yin, "A Coupling-fed multiband antenna for WLAN/WiMAX applications," *Microwave Opt. Technol. Lett.*, Vol. 52, 1283–1286, June 2010.
5. Lee, S. Y. and C. C. Yu, "A novel wideband asymmetric hybrid antenna for WLAN/WiMAX application," *Microwave Opt. Technol. Lett.*, Vol. 51, 1055–1057, 2009.
6. Pazin, L., N. Telzhensky, and Y. Leviatan, "Multi band flat-plate inverted-F antenna for Wi-Fi/WiMAX operation," *IEEE Antennas Wireless Propag. Lett.*, Vol. 7, 197–200, 2008.
7. Chaimool, S. and K. L. Chung, "CPW-fed mirrored-L monopole antenna with distinct triple bands for WiFi and WiMAX applications," *IET Electron. Lett.*, Vol. 45, 928–929, 2009.
8. Thomas, K. G. and M. Sreenivasan, "Compact triple band antenna for WLAN/WiMAX applications," *IET Electron. Lett.*, Vol. 45, 811–813, 2009.
9. Thomas, K. G. and M. Sreenivasan, "A novel triple band printed antenna for WLAN/WiMAX applications," *Microwave Opt. Technol. Lett.*, Vol. 51, 2481–2485, 2009.
10. Fan, S.-T., Y.-Z. Yin, H. Li, S.-J. Wei, X.-H. Li, and L. Kang,

"A novel tri-band printed monopole antenna with an etched ∩-shaped slot and a parasitic ring resonator for WLAN and WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 16, 61–68, 2010.

11. Wen, L.-H., Y.-Z. Yin, Z.-Y. Liu, D. Xi, M. Zhang, and Y. Wang, "Performance enhancement of tri-band monopole antenna for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 15, 61–68, 2010.
12. Cui, Y.-Y., Y.-Q. Sun, H.-C. Yang, and C.-L. Ruan, "A new triple-band CPW-FED monopole antenna for WLAN and WiMAX applications," *Progress In Electromagnetics Research M*, Vol. 2, 141–151, 2008.
13. Li, F., L.-S. Ren, G. Zhao, and Y.-C. Jiao, "Compact triple-band monopole antenna with C-shaped and S-shaped meander strips for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 15, 107–116, 2010.
14. Lu, J. H. and B. J. Huang, "Planar multi-band monopole antenna with L-shaped parasitic strip for WiMAX application," *IET Electron. Lett.*, Vol. 46, 671–672, 2010.
15. Lu, J. H. and W. C. Chou, "Planar dual U-shaped monopole antenna with multi-band operation for IEEE 802.16e," *IEEE Antennas Wireless Propag. Lett.*, Vol. 9, 1006–1009, 2010.
16. Kuo, Y. L. and K. L. Wong, "Printed double-T monopole antenna for 2.4/5.2 GHz dual-band WLAN operations," *IEEE Trans. Antennas Propagation*, Vol. 51, No. 9, Sep. 2003.
17. Chen, S. B., Y. C. Jiao, W. Wang, and F. S. Zhang, "Modified T-shaped planar monopole antennas for multiband operation," *IEEE Trans. Microwave Theory and Techniques*, Vol. 54, No. 8, Aug. 2006.
18. Wu, J. W., Y. D. Wang, H. M. Hsiao, and J. H. Lu, "T-shaped monopole antenna with shorted L-shaped strip-sleeves for WLAN 2.4/5.8 GHz operation," *Microwave Opt. Technol. Lett.*, Vol. 46, No. 1, 65–69, Jul. 5, 2005.
19. Li, Z., Z. Yang, Q. Guo, J. Wang, and W. Jiang, "Printed triple-T monopole antenna for 2.4, 5.2, and 5.8 GHz WLAN operations," *International Conference on Microwave Technology and Computational Electromagnetics*, 2009.
20. Ansoft Corporation HFSS, http://www.ansoft.com/products/hf/hfss.