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PLANAR COMPACT MULTI-BAND C-SHAPE MONOPOLE ANTENNA WITH INVERTED L-SHAPE PARASITIC STRIP FOR WIMAX APPLICATIONS

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Abstract—A novel compact multi-band design of planar C-shape monopole antenna with inverted L-shape parasitic strip is proposed for IEEE 802.16 m WiMAX system. The obtained impedance bandwidth across the 2.6/3.5/5.5 GHz operating bands can reach about 240/570/4470 MHz, respectively. Only with the antenna size of $15 \times 30 \times 0.8\,\mathrm{mm}^3$, the proposed monopole antenna has the compact operation with more than 25% antenna size reduction. The measured peak gains and radiation efficiencies are about 1.6/1.9/2.9 dBi and 91/96/94% for the 2.6/3.5/5.5 GHz operating band, respectively, with nearly omni-directional pattern in the XY-plane.

1. INTRODUCTION

Due to the rapid developments of wireless communication technology, several wireless systems integrated in a single portable device has become a major new trend. Especially, the Worldwide Interoperability for Microwave Access (WiMAX) system with three allocated frequency bands of 2.6/3.5/5.5 GHz has recently attracted great attention due to the theoretical up to 30-mile radius coverage and the data rate of 70 Mbps to make multi-band operation become demanding in practical applications for broadband access in wireless metropolitan area network (WMAN) environment. Unlike using multiple single-band antennas for multi-band operations, a multi-band antenna can simultaneously cover several operating bands for different wireless services. The great demands in antenna design include low-profile,

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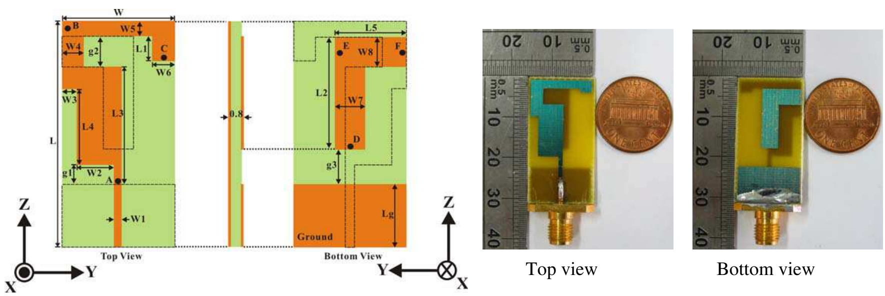
lightweight, easy fabrication, and multi-band operation. Thus, to meet the specifications of the WiMAX applications, the use of compact multi-band antennas is very attractive and important for practical commercial applications. Meanwhile, planar monopole antenna becomes a popular candidate owing to its merit of low profile and the feature of multi-band operation. The related monopole antenna (MA) designs for WiMAX applications have been presented by using dual U-shaped MA [1], inverted L-shaped MA [2], rhomb shaped MA with slits [3] or modified Minkowski fractal geometry [4], inverted-F antenna [5], MA with branch slits [6], MA with rectangular horizontal strips and trapezoidal ground plane [7], mirrored-L MA [8], asymmetric rectangular MA with additional strips [9], rectangular MA with a circular disc [10], MA loaded with four different grooves [11], MA using branch strips [12], pentagonal MA with two thin bent slots [13], MA with an etched ∩-shaped slot and a parasitic ring resonator [14], MA with two semi-circle strips [15], T-shaped MA with a trapezoidal ground plane [16], MA with C-shaped and S-shaped meander strips [17] or with C-shaped and L-shaped monopole strips [18] and rectangular MA with parasitic outside ring [19]. However, there is the disadvantage of being larger antenna size for these above MAs [1–7, 9, 10, 14–17, 19] or complex antenna structure [8, 11–13, 18]. And, there is increasing demand for antennas having more compact size to be suitably embedded in the practical portable devices for multi-input/multi-output (MIMO) IEEE 802.16m WiMAX system. Therefore, in this paper, we propose a novel planar compact C-shape monopole antenna with inverted L-shape parasitic strip for multi-band WiMAX communication. From the related measured results, it provides wider impedance bandwidth of 240 MHz (2.48 $\sim$ 2.72 GHz), 570 MHz (3.27 $\sim$ 3.84 GHz) and 4470 MHz (4.93 $\sim$ 9.4 GHz) for the 2.6/3.5/5.5 GHz bands, respectively to meet the bandwidth specifications of WiMAX system. This proposed planar monopole antenna also provides nearly omni-directional radiation patterns with maximum measured peak antenna gains and radiation efficiencies of 1.6/1.9/2.9 dBi and 91/96/94% across the operating bands, respectively. Compared with the overall antenna volume including the ground plane for the presented antenna designs in the literature [1–19], this proposed monopole antenna has more than 25% antenna size reduction to obtain compact operation, which is suitable for embedding into the USB dongle. Details of the proposed monopole antenna design are described in this study, and the related results for the obtained performance operated across the 2.6/3.5/5.5 GHz bands are presented and discussed.

2. ANTENNA DESIGN

A novel planar C-shape monopole antenna with inverted L-shape parasitic strip has been proposed to meet multi-band operation requirement for WiMAX system. Fig. 1 illustrates the geometry and photos of the proposed compact C-shape monopole antenna. A microstrip line of $50\,\Omega$ is connected to point A as the feeding structure and etched on the inexpensive FR4 substrate with the antenna volume of $15 \times 30 \times 0.8\,\mathrm{mm}^3$, dielectric constant $\varepsilon_r = 4.7$ and loss tangent $\tan\delta = 0.0245$.



(a) Geometry (b) Photos

Figure 1. Geometry and photos of the proposed compact C-shape monopole antenna with inverted L-shape parasitic strip for multi-band operation.

The C-shape monopole strip ($A \to B \to C$) is arranged at the front side of the proposed compact antenna to excite the fundamental and second modes near 2.6/5.5 GHz bands in this study. By adding the inverted L-shape parasitic strip ($A \to D \to E \to F$) at the back side, the fundamental mode near 3.5 GHz band can be easily excited. For achieving the resonant mode at 2.6 GHz band, the total length of the C-shape monopole strip ($A \to B \to C$) is chosen to be about 31.5 mm corresponding approximately to 0.27/0.54 operating wavelengths of 2.6/5.5 GHz bands, respectively, which is a little longer than 0.25/0.5 operating wavelength probably due to the coupling effect caused by the inverted L-shape parasitic strip. Detailed effects of the total length on the antenna performances are analyzed with the aid of Table 2 and Fig. 4 in Section 3. Then, to obtain the resonant mode for 3.5 GHz WiMAX operation, the excited length ($A \to D \to E \to F$) including the inverted L-shape parasitic strip is chosen to be about 21 mm corresponding approximately to 0.25 operating wavelength of 3.5 GHz bands. The antenna performances versus the inverted L-shape parasitic strip's length is shown in Fig. 5 and listed in Table 3 as comparison. Meanwhile, by properly adjusting the width of the feeding microstrip line to be $w_1 = 1.0\,\mathrm{mm}$, good impedance matching across the operating band can easily be obtained.

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 to the proposed monopole antenna design. Fig. 2 shows the related simulated and experimental results of return loss for the proposed monopole antenna design of Fig. 1 with the inverted L-shape parasitic strip or not. The related results are listed in Table 1 as comparison. The simulated and measured results show the satisfactory agreement for the proposed monopole antenna design operating at the 2.6/3.5/5.5 GHz bands.

Table 1. Simulated and measured return loss against frequency for the proposed compact C-shape monopole antenna; $L = 30\,\mathrm{mm}$, $W = 15\,\mathrm{mm}$, $L_1 = 3\,\mathrm{mm}$, $L_2 = 15\,\mathrm{mm}$, $L_3 = 15.5\,\mathrm{mm}$, $L_4 = 10\,\mathrm{mm}$, $L_5 = 9.5\,\mathrm{mm}$, $W_1 = 1\,\mathrm{mm}$, $W_2 = 5\,\mathrm{mm}$, $W_3 = 2\,\mathrm{mm}$, $W_4 = 3\,\mathrm{mm}$, $W_5 = 2\,\mathrm{mm}$, $W_6 = 3\,\mathrm{mm}$, $W_7 = 4\,\mathrm{mm}$, $W_8 = 4\,\mathrm{mm}$, $g_1 = 2.5\,\mathrm{mm}$, $g_2 = 4\,\mathrm{mm}$, $g_3 = 4.5\,\mathrm{mm}$.

	$f_{1L} \sim f_{1H}$ (GHz)	BW (MHz/%)	$f_{2L} \sim f_{2H}$ (GHz)	BW (MHz/%)	$f_{3L} \sim f_{3H}$ (GHz)	BW (MHz/%)
The proposed MA (Simulated)	2.45 ∼ 2.7	250/9.7	3.403 ∼ 3.929	526/14.3	5.032 ∼ 8.791	3759/54.4
The proposed MA (Measured)	2.48 ∼ 2.72	240/9.2	3.27 ∼ 3.84	570/16.1	4.93 ∼ 9.4	4470/62.4
MA without parasitic Strip (Simulated)	2.475 ∼ 2.925	450/16.6	-	-	4.7 ∼ 8.68	3980/59.5
MA without parasitic Strip (Measured)	2.58 ∼ 2.95	370/13.4	-	-	4.6 ∼ 9.31	4710/67.7

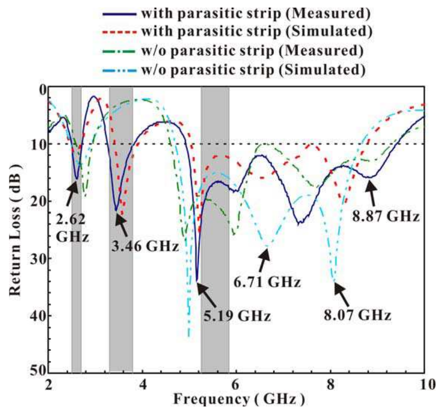
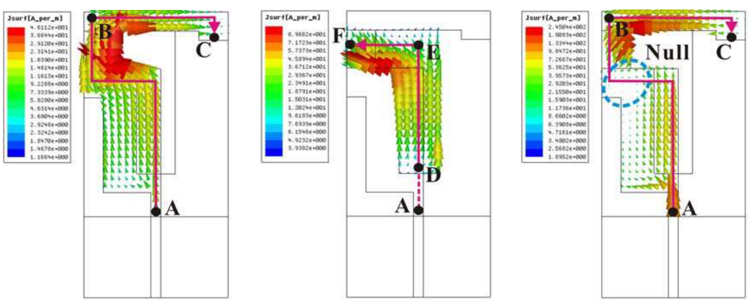


Figure 2. Simulated and measured return loss against frequency for the proposed compact C-shape monopole antenna with inverted L-shape parasitic strip or not; antenna parameters are given in Table 1.



(a) f =2.6 GHz (b) f =3.5 GHz (c) f =5.5 GHz

Figure 3. Simulated surface current distributions for the proposed compact C-shape monopole antenna with inverted L-shape parasitic strip shown in Fig. 1.

From the experimental results, the measured impedance bandwidth ($RL \geqq 10\,\mathrm{dB}$) can reach 9.2/16.1/62.4% (240/570/4470 MHz) for 2.6/3.5/5.5 GHz bands, respectively, which provides much greater bandwidths for all operating bands to meet the IEEE 802.16m specifications. It is easily found that 2.6/5.5 GHz WiMAX operating band can be easily excited by the proposed C-shape monopole strip. And only the resonant mode close to 3.5 GHz band can be excited as the proposed compact monopole antenna with the inverted L-shape parasitic strip. Therefore, the presented design criteria can meet the prediction for the proposed monopole antenna described in Section 2.

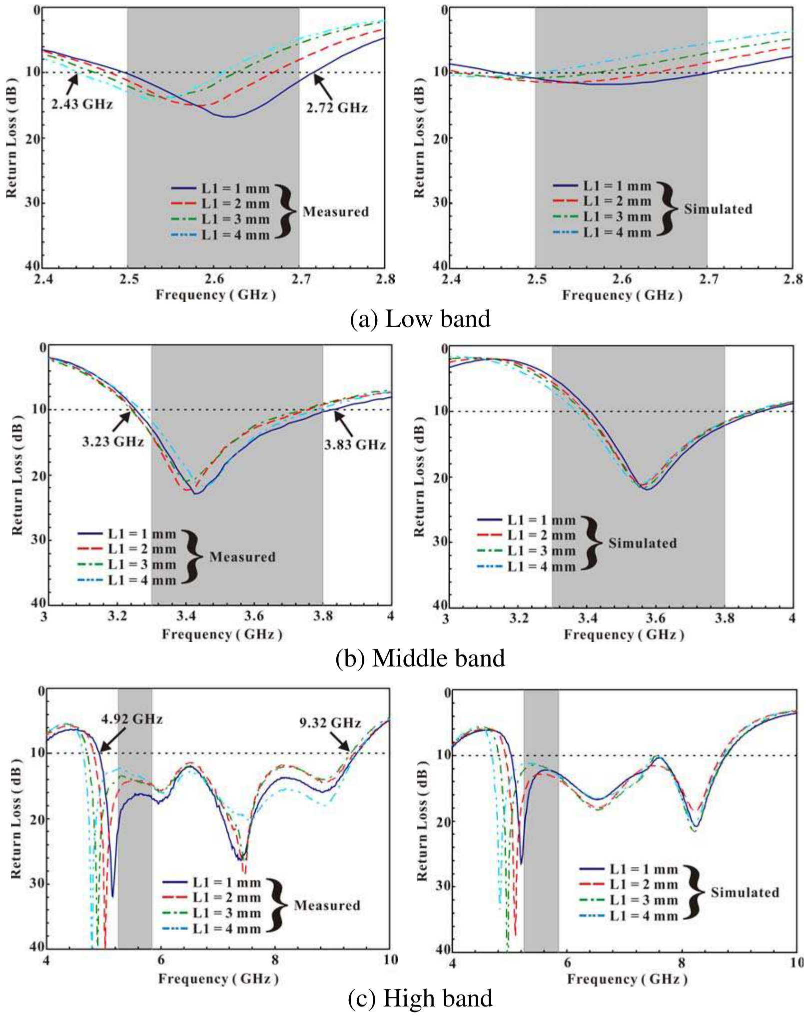


Figure 4. Measured and simulated return loss against frequency for the proposed compact monopole antenna with various lengths (L_1) of the C-shape monopole strip.

To fully comprehend the excitation of each WiMAX band, the simulated surface current distributions at typical frequencies are shown in Fig. 3, along with an additional pinky arrow sign showing the excited current path of each resonant mode. From the surface current distributions, it can be seen that the C-shape monopole strip (A $\rightarrow$ B $\rightarrow$ C) is excited at its fundamental mode at 2.6 GHz and its second-

Table 2. Measured return loss against frequency for the proposed compact monopole antenna with various lengths (L_1) of the C-shape monopole strip; other antenna parameters are given in Table 1.

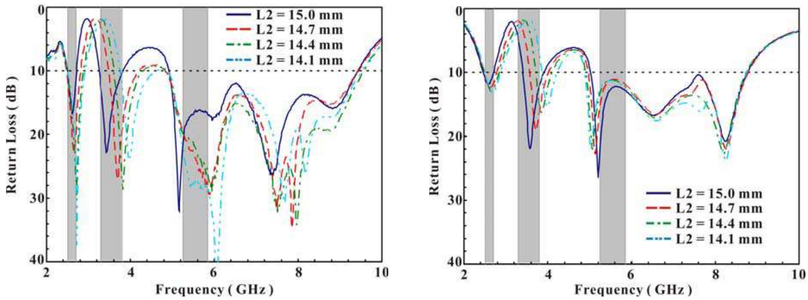
L_1 (mm)	$f_{1L} \sim f_{1H}$ (GHz)	BW (MHz/%)	$f_{2L} \sim f_{2H}$ (GHz)	BW (MHz/%)	$f_{3L} \sim f_{3H}$ (GHz)	BW (MHz/%)
1	2.48 ~ 2.72	240/9.2	3.27 ~ 3.84	570/16.1	4.93 ~ 9.4	4470/62.4
2	2.47 ~ 2.67	200/7.8	3.25 ~ 3.775	525/14.9	4.82 ~ 9.42	4600/64.6
3	2.46 ~ 2.613	153/6.0	3.25 ~ 3.763	513/14.6	4.712 ~ 9.35	4638/65.9
4	2.43 ~ 2.592	162/6.5	3.27 ~ 3.845	575/16.2	4.637 ~ 9.462	4825/68.4

Table 3. Measured return loss against frequency for the proposed compact C-shape monopole antenna with various lengths (L_2) of the inverted L-shape parasitic strip; other antenna parameters are given in Table 1.

L_2 (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/%)
14.1	2.48 ~ 2.925	445/16.5	3.75 ~ 4.675	925/22.0	4.88 ~ 9.517	4637/64.4
14.4	2.48 ~ 2.88	400/14.9	3.6 ~ 4.35	750/18.9	4.825 ~ 9.538	4713/65.6
14.7	2.47 ~ 2.795	325/12.3	3.475 ~ 4.237	762/19.8	4.825 ~ 9.463	4638/64.9
15.0	2.48 ~ 2.72	240/9.2	3.27 ~ 3.84	570/16.1	4.93 ~ 9.4	4470/62.4

order mode at 5.5 GHz with a 0.27 and 0.54 wavelength surface current distributions shown in Figs. 3(a) and 3(c), respectively. Also, a null point is observed along the excited current path (A → B → C) of the resonant mode at 5.5 GHz to introduce the overtone characteristics in Fig. 3(c). However, as for 3.5 GHz resonant mode, relatively stronger excited surface current distribution along the inverted L-shape parasitic strip (A → D → E → F) is illustrated in Fig. 3(b).

The measured and simulated return losses for the proposed compact monopole antenna with various lengths (L_1) of the C-shape



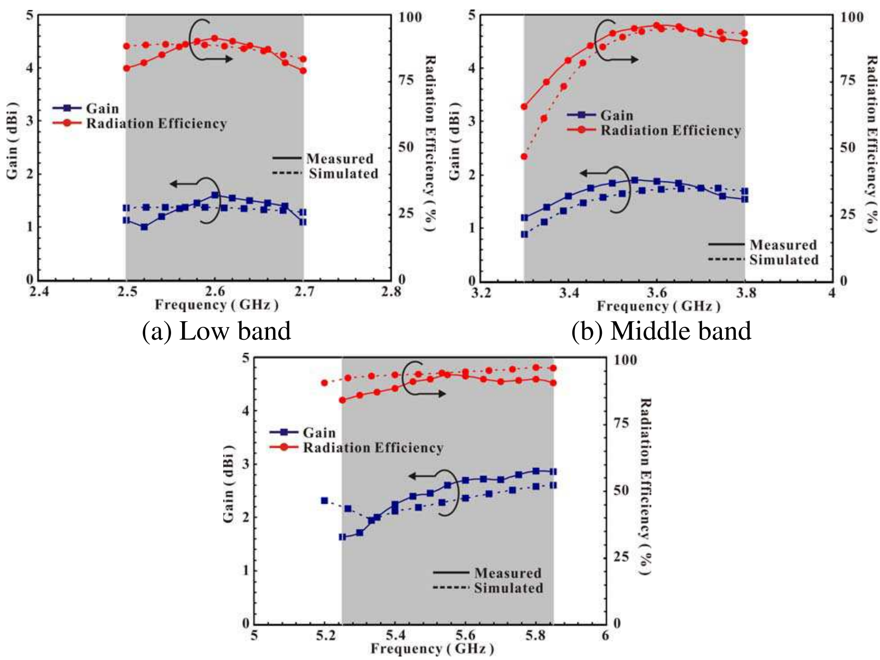
Measured Simulated

Figure 5. Measured and simulated return loss for the proposed C-shape monopole antenna with various lengths (L_2) of inverted L-shape parasitic strip; other antenna parameters are given in Table 1.

Table 4. Comparisons of the overall antenna volume and size reduction for this proposed C-shape monopole antenna and other presented antenna designs in the literature [1–18].

Reference No.	Proposed	1	2	3	4
Dimension (mm^3)	15 × 30 × 0.8	25 × 30 × 0.8	25 × 30 × 1.6	20 × 43 × 1	59 × 90 × 1.6
Reduction (%)	-	40	70	58	95
Reference No.	5	6	7	8	9
Dimension (mm^3)	45 × 10 × 0.13	45 × 35 × 1.6	38 × 30 × 0.8	67 × 54 × 0.8	42 × 44 × 1.55
Reduction (%)	40	62	61	87	87
Reference No.	10	11	12	13	14
Dimension (mm^3)	20 × 44 × 0.8	20 × 30 × 1.6	17.5 × 40 × 0.8	40 × 40 × 0.8	25 × 42 × 1
Reduction (%)	49	62	36	72	66
Reference No.	15	16	17	18	19
Dimension (mm^3)	30 × 30 ×0.8	32 × 15 × 1	20 × 29 × 1.6	22 × 28 × 0.8	48× 55 ×1.6
Reduction (%)	50	25	61	27	91

monopole strip are illustrated in Fig. 4. The related measured results are listed in Table 2 as comparison. The simulated and measured results show the satisfactory agreement for the proposed monopole antenna design operating at each band. It can also be found that when the length of L_1 increases from 1 mm to 4 mm, the total length of the surface current path (A $\rightarrow$ B $\rightarrow$ C) also increases from 31.5 mm to 34.5 mm to make the 2.6/5.5 GHz operating frequencies significantly decreased. However, the operating frequencies near 3.5 GHz band are less varied as shown in Fig. 4(b). Effects of varying the length L_2 of the inverted L-shape parasitic strip are also studied. The measured and simulated return loss for the length L_2 varied from 14.1 to 15 mm is shown in Fig. 5 with the measured results listed in Table 3 as comparison. It is found that the measured and simulated results have the same variation trend for the proposed compact monopole antenna design operating at each band. And, small effects on the antenna's low (WiMAX 2.6 GHz) and high (WiMAX 5.5 GHz) operating bands are seen. However, the operating bandwidth of the middle (WiMAX



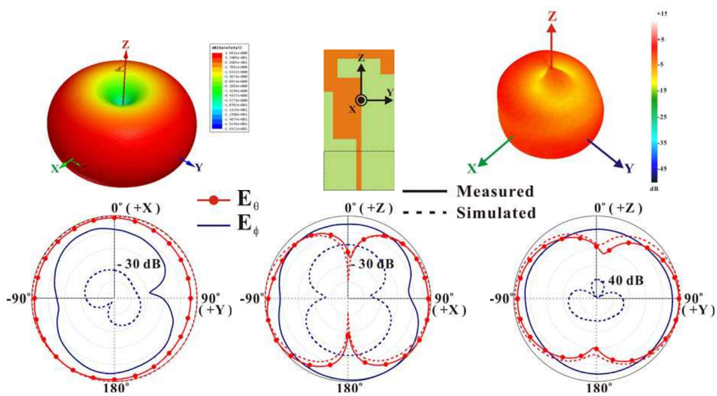
(a) Low band (b) Middle band

(c) High band

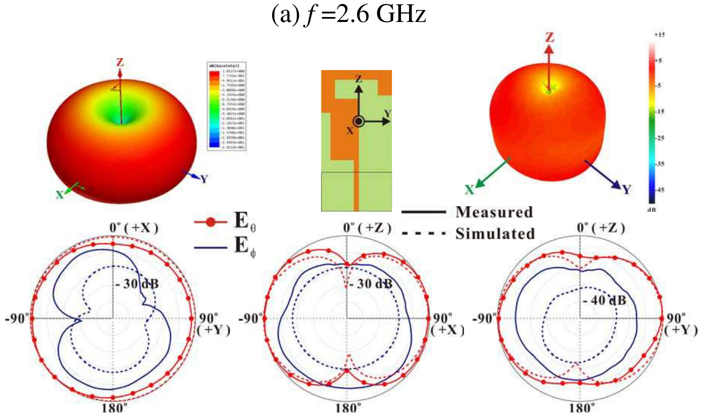
Figure 6. Measured and simulated peak gains and radiation efficiencies across the operating frequencies for the proposed compact C-shape monopole antenna with inverted L-shape parasitic strip.

3.5 GHz) band can be seriously controlled by the length L_2. By decreasing the length L_2, the 3.5 GHz band can be shifted to higher frequencies. Therefore, by selecting a proper length L_2 (15 mm in this study), the 3.5 GHz operating band can be adjusted to cover the desired frequency range of 3.4–3.7 GHz.

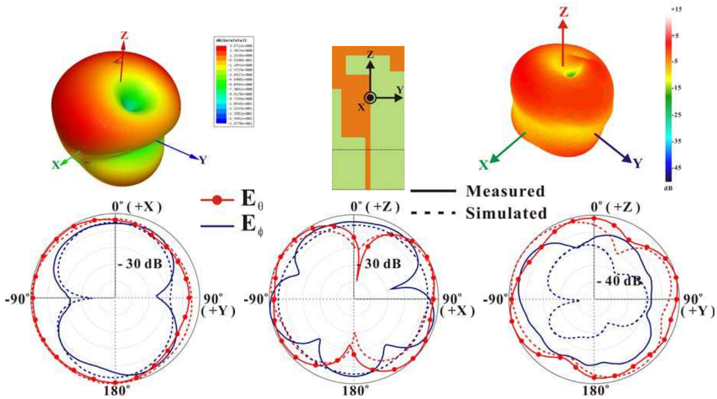
To study the antenna size reduction for the proposed C-shape monopole antenna, the comparisons of the overall antenna volumn including the ground plane for this proposed and other presented antenna designs in the literature [1–18] are listed in Table 4. It is seen that this proposed monopole antenna has more than 25% antenna size reduction to obtain compact operation, which is more suitable for embedding into the USB dongle. The radiation measurement of the proposed compact monopole antenna is carried out in anechoic chamber by introducing NSI 800F 3D far-field system. The related radiation characteristics are studied in Figs. 6 and 7. The measured peak gains and radiation efficiencies across the operating bands are shown in Fig. 6 with the simulated results as comparison. Good



(a) f =2.6 GHz



(b) f =3.5 GHz



(c) f =5.5 GHz

Figure 7. Measured and simulated 3D/2D radiation patterns for the proposed compact C-shape monopole antenna with inverted L-shape parasitic strip.

agreement is seen between the measured and simulated results. As shown in Fig. 6(a), the antenna gain is varied from about 1.0 to 1.6 dBi and the radiation efficiency is about 79%–91% for 2.6 GHz WiMAX operation. Over the 3.5 GHz band, the antenna gain is about 1.2–1.9 dBi with the radiation efficiency about 66%–96% as shown in Fig. 6(b). And, from the results shown in Fig. 6(c), the antenna gain is about 1.6–2.9 dBi and the radiation efficiency is about 84%–93% over the 5.5 GHz band. The measured two-dimensional (2-D) and three-dimensional (3-D) radiation patterns at 2.6, 3.5 and 5.5 GHz are plotted in Fig. 7 with the simulated results as comparison. The 3-D radiation patterns show the total radiation power, while the 2-D patterns plot the E_θ and E_ϕ components, separately. As seen in the azimuthal plane (X-Y plane), there are generally good omni-directional radiation pattern, which is advantageous and required for WiMAX applications. Since the proposed antenna's structure is unsymmetrical with respect to the antenna axis ($\theta = 0$), the 2D radiation patterns in the YZ plane are tilted probably due to the surface current distribution concentrated in the — Y direction.

4. CONCLUSIONS

A novel planar compact C-shape monopole antenna with multi-band operation for WiMAX system (IEEE 802.16m) has been proposed and investigated. The obtained impedance bandwidth across the operating bands can reach about 240/570/4470 MHz for the 2.6/3.5/5.5 GHz bands, respectively. Only with the antenna size of $15 \times 30 \times 0.8\,\text{mm}^3$, the proposed monopole antenna has the compact operation with more than 25% antenna size reduction, which is more suitable for embedding into the USB dongle. The proposed planar monopole antenna also provides nearly omni-directional radiation patterns with maximum peak antenna gains and radiation efficiencies of 1.6/1.9/2.9 dBi and 91/96/94% across the operating bands, respectively.

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