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COMPACT PLANAR TRIPLE-BAND FOLDED DIPOLE ANTENNA FOR WLAN/WiMAX APPLICATIONS

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Abstract—A planar folded dipole antenna with triple-band operation for WLAN and WiMAX applications is proposed. It comprises a pair of symmetrical branch arms, which occupy a compact size of 35 $(L) \times 4$ (W) mm^2 to be easily embedded inside a portable device as an internal antenna. By properly designing the branch radiating strips, three operating bands covering 2.39–2.5 GHz, 3.3–3.94 GHz, and 5.06–6.06 GHz can be acquired with the antenna. Moreover, the antenna's resonance can be appropriately adjusted to optimize the radiation performance for actual application. A fabricated prototype of the proposed antenna is tested and analyzed. Experiments show that good omnidirectional coverage and stable gain variation to enhance communication quality for WLAN/WiMAX operations can be obtained with the antenna.

1. INTRODUCTION

In recent years, planar dipole antennas have been widely used for various communication systems due to fairly good omnidirectional coverage and stable radiation performance. In order to meet more real applications, there are several design challenges for dipole antennas, such as compact size, multiband operation and easy fabrication. Many promising dipole antenna designs to achieve above demands have been recently investigated in [1–17]. A bent dipole antenna [1] came with a short-circuited structure to reduce its size, so it was well suitable for wireless local area network (WLAN) 2.4 GHz operation in a module

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device. For dual-band application, several useful techniques like a U-slot arm [2], a centre-fed structure [3] and a spider-shaped radiator [4] were reported to resonate at WLAN 2.4/5 GHz. The use of an internal matching circuit also makes a planar dipole antenna [5] possible for achievement in both a compact structure and dual-band property.

In addition to dual-band operation, some studies to further enlarge the dipole's bandwidth for ultra-wide band (UWB) system have been attractively discussed in [6–11]. By utilizing a pair of twin-arm strips, a wideband dipole design shown in [6] can obtain an over 100% operating bandwidth for UWB application. Moreover, if a dipole is formed with an elliptical radiator [7] or a trapezoidal structure [8], good impedance match across the licensed UWB band can be attained. It is also attractive that a double-printed dipole antenna [9] can properly widen its operating bandwidth for UWB operation due to a coupling-fed structure. As a low-profile antenna design was required within a small module, a printed dipole design using a composite corrugated-reflector to support the UWB band was proposed in [10]. An UWB dipole antenna with good band-rejected performance suitable for high speed transmission was also presented in [11], which could avoid the frequency influence from the WLAN system.

For a modern communication application, on the other hand, numerous dipole designs capable of achieving not only a compact structure but also triple-band operation have received very high attention [12–17]. An electrically small dipole antenna [12], formed with a pair of folded radiating strips to create three distinct resonant modes, was quite useful for bandwidth enhancement. By means of a parasitic element near the radiating arms, two planar dipole antennas shown in [13, 14] could serve more communication systems owing to triple-band operation. The use of a meander dipole design [15] was effective to reduce the antenna's size as well as create triple-band operation. A compact planar dipole antenna [16] was constructed with an amc-his structure on the radiating arm in order to have good triple-band behavior. By employing a pair of aperture-coupled protruded slots, a uniplanar CPW-fed dipole antenna presented in [17] could also provide three operating bands.

In this paper, we propose a printed folded dipole antenna for WLAN (2.4–2.483 /5.15–5.35/5.725–5.85 GHz) and worldwide interoperability for microwave access (WiMAX: 3.3–3.8/5.25–5.85 GHz) operations. This antenna design has triple-band operation and comes with a pair of symmetrical branch arms, which is printed on a 0.4-mm-thick FR4 substrate. By utilizing a folded structure as the dipole's arm, the proposed antenna can approach not only a small size of 35 $(L) \times 4$ (W) mm^2 but also three distinct operating bands including

2.39–2.5 GHz, 3.3–3.94 GHz, and 5.06–6.06 GHz. The proposed dipole may function as an internal antenna for a portable device due to its compact size. As the antenna is used inside a portable device, the antenna's performance can be optimized by appropriately tuning the radiating strips. Therefore, the effects about objects close to the antenna can be suitably tackled, such as the external casing and display panel. Details of the antenna design are then described in Section 2. A fabricated prototype of the antenna will be experimentally tested and analyzed in Section 3. Parametric study for understanding the antenna performance will be performed and discussed as well. Finally, this paper will be concluded with a brief summary in Section 4.

2. ANTENNA DESIGN

Figure 1(a) depicts the whole geometry with detailed design parameters of the proposed triple-band folded dipole antenna for WLAN/WiMAX operations. This antenna is composed of a pair of symmetrical branch arms, whose dimension is only about 35 $(L) \times 4$ $(W)\,\text{mm}^2$ to be easily embedded inside a portable device as an

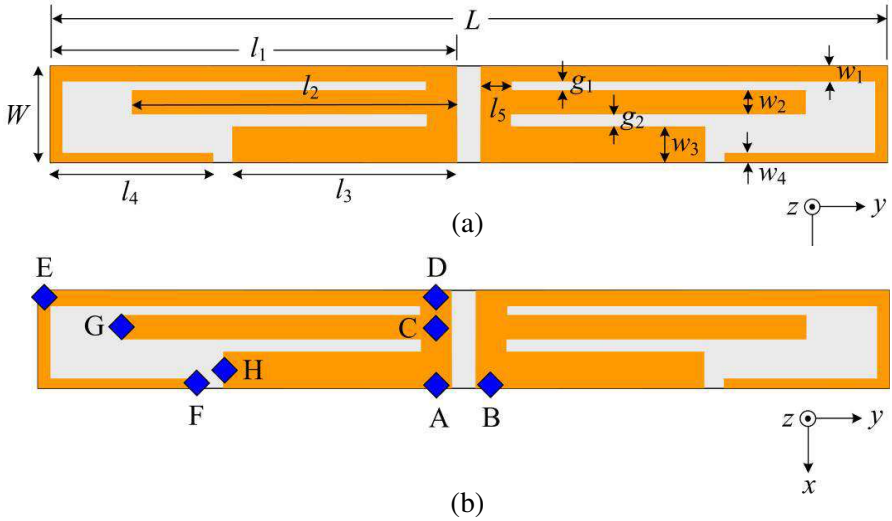


Figure 1. Design structure of the proposed triple-band folded dipole antenna. (a) Antenna geometry. ($L = 35\,\text{mm}$, $W = 4\,\text{mm}$, $l_1 = 17\,\text{mm}$, $l_2 = 13.7\,\text{mm}$, $l_3 = 9.2\,\text{mm}$, $l_4 = 6.8\,\text{mm}$, $l_5 = 1.3\,\text{mm}$, $w_1 = 0.5\,\text{mm}$, $w_2 = 1\,\text{mm}$, $w_3 = 1.5\,\text{mm}$, $w_4 = 0.3\,\text{mm}$, $g_1 = 0.4\,\text{mm}$, and $g_2 = 0.6\,\text{mm}$). (b) Eight nodes of the antenna.

internal antenna. It is fabricated on a 0.4-mm-thick FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and loss tangent $\tan\delta = 0.02$. In this study, both the left and right branch arms of the dipole antenna must be developed near a quarter-wavelength, so four expected resonant modes including 2.45 GHz, 3.55 GHz, 5.3 GHz and 6 GHz can be excited to realize triple-band operation for the proposed antenna. In order to clearly interpret the antenna's operation, eight nodes from A to H of the dipole are indicated in Fig. 1(b), and an electromagnetic solver HFSS [18] is used to analyze the surface current distribution of the antenna. As can be seen, two points A and B of the bottom of the antenna are utilized for energy feeding, which are connected to a coaxial cable through a balun. Undesirable current influences around the coaxial cable can be thus avoided for measurement. The path A-C-D-E and its extended path A-C-D-E-F are designed to be about 21 mm and 31 mm, which are equal to a quarter-wavelength of 3.55 GHz and 2.45 GHz, respectively. We also find that strong current distributions at the frequencies of 2.45 GHz and 3.55 GHz flow along the paths A-C-D-E-F and A-C-D-E, respectively, as shown in Figs. 2(a) and (b). Hence these two resonant modes of the antenna can further generate the lower and middle operating bands, covering the WLAN of 2.4–2.483 GHz and the WiMAX of 3.3–3.8 GHz, respectively. Note that the path A-C-D-E-F is implemented using a folded structure in order to reduce the dipole's size.

Moreover, the upper band of the proposed antenna must have a wide bandwidth to cover not only the WLAN of 5.15–5.35 GHz and 5.725–5.85 GHz but also the WiMAX of 5.25–5.85 GHz. To this end, the paths A-C-G and A-H are designed at the frequencies of 5.3 GHz and 6 GHz, whose lengths are calculated around 15 mm and 9.2 mm, respectively. Fig. 2(c) simulates the surface currents at 5.3 GHz for the antenna, where intense distributions can be excited around the path A-C-G. It can be also observed that the length of the path A-H is shorter than a quarter- wavelength of 6 GHz. This is because a capacitive coupling occurs between the paths A-C-G and A-H, as shown in Fig. 2(d). By combining above two resonant modes, the upper band can be properly widened to contain the WLAN/WiMAX operations for the antenna. To reach good impedance matching over the desirable bands of interest, the gap g_1 between the paths C-G and D-E as well as the gap g_2 between the paths A-H and C-G are appropriately designed to be about 0.4 mm and 0.6 mm for the antenna, respectively.

According to above design guidelines, the lowest operating frequency f_L of the proposed antenna may be empirically approximated

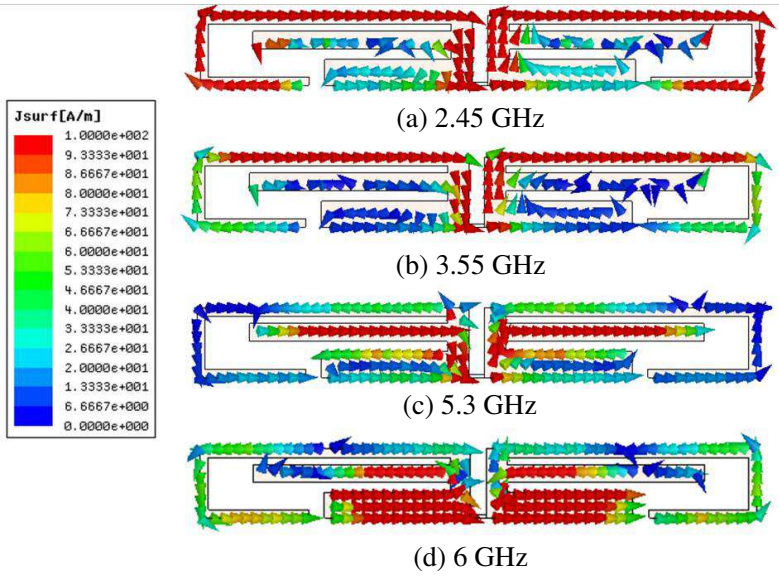


Figure 2. Simulated surface current distributions at four resonant frequencies for the proposed antenna. (a) 2.45 GHz, (b) 3.55 GHz, (c) 5.3 GHz, (d) 6 GHz.

as follows.

$$f_L \approx \frac{c}{4 \cdot L_l} \tag{1}$$

$$L_l = 2W + l_1 + l_4 \tag{2}$$

where c is the speed of light in free space, and L_l is the estimated longest resonance path of the antenna. These two equations interpret that the proposed structure resonated in half wavelength is a kind of dipole antenna. Regarding the design process of the antenna, the folded path A-C-D-E-F is firstly developed for achieving the lower and middle bands. This also decides the antenna's size. The paths A-C-G and A-H for the upper band operation are then formed by carefully considering an electromagnetic coupling effect from the path A-C-D-E-F. The geometric model and electrical characteristics of the antenna are performed and analyzed by using a full-wave simulator, SEMCAD [19]. All design parameters optimized for the dipole antenna have been eventually determined with $L = 35\,\text{mm}$, $W = 4\,\text{mm}$, $l_1 = 17\,\text{mm}$, $l_2 = 13.7\,\text{mm}$, $l_3 = 9.2\,\text{mm}$, $l_4 = 6.8\,\text{mm}$, $l_5 = 1.3\,\text{mm}$, $w_1 = 0.5\,\text{mm}$, $w_2 = 1\,\text{mm}$, $w_3 = 1.5\,\text{mm}$, $w_4 = 0.3\,\text{mm}$, $g_1 = 0.4\,\text{mm}$, and $g_2 = 0.6\,\text{mm}$. Furthermore, detailed comparisons including antenna

Table 1. Comparisons for the proposed antenna with other triple-band designs.

Reference	Antenna size	Frequency band	Omnidirectional property
[12] Zhang and Yang	$0.19\lambda \times 0.06\lambda$	WLAN 2.4/5 GHz, WiMAX 3.5/5.5 GHz	Yes
[13] Floc'h and Rmili	$0.26\lambda \times 0.05\lambda$	IMT-2000, WLAN 5 GHz, X-band	Yes
[14] Chang et al.	$0.35\lambda \times 0.04\lambda$	PCS, IMT-2000, WLAN 2.4 GHz	Yes
[15] Abu et al.	$0.33\lambda \times 0.06\lambda$	RFID 0.92/2.45/5.8 GHz	Yes
[16] Abu et al.	$0.33\lambda \times 0.06\lambda$	RFID 0.92/2.45/5.8 GHz	Yes
[17] Chen et al.	$0.47\lambda \times 0.04\lambda$	WLAN 2.4/5 GHz, WiMAX 3.5/5.5 GHz	Yes
Proposed design	$0.28\lambda \times 0.03\lambda$	WLAN 2.4/5 GHz, WiMAX 3.5/5.5 GHz	Yes

dimension, frequency band and radiation property for the proposed antenna with those triple-band designs presented in [12–17] are given in Table 1, where the size for each design is expressed with free space wavelength at the lowest operating frequency. It is obvious that a smaller design size can be achieved with the antenna. As a result, the proposed compact dipole design having triple-band operation and good omnidirectional coverage is well suitable to be embedded inside a portable device as an internal antenna for WLAN and WiMAX applications.

3. SIMULATED AND EXPERIMENTAL RESULTS

A fabricated prototype of the proposed triple-band folded dipole antenna was constructed and tested, as shown in Fig. 3. The performance of the prototype was measured by utilizing a vector network analyzer (Agilent ENA E5071B) with a suitable balun. The simulated and measured results of the return loss for the antenna were compared in Fig. 4. Good agreement between the simulations and measurements in the lower band can be obtained, but small differences for both the middle and upper bands are mainly attributed to the fabrication inaccuracy of the prototype. According to the measured results with 10 dB return loss, three distinct impedance bandwidths for the proposed dipole antenna can be defined with 2.39–2.5 GHz,

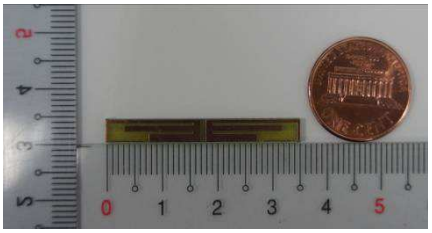


Figure 3. Fabricated prototype of the proposed antenna.

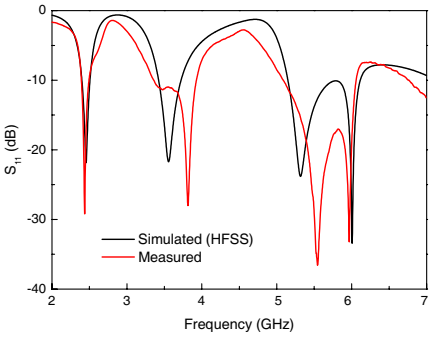


Figure 4. Simulated and measured return losses of the proposed antenna.

3.3–3.94 GHz and 5.06–6.06 GHz, corresponding to 4.5%, 17.7% and 18%, respectively. Consequently, the antenna can satisfy not only the WLAN bands (2.4–2.483/5.15–5.35/5.725–5.85 GHz) but also the WiMAX bands (3.3–3.8/5.25–5.85 GHz).

In order to further understand the antenna's operation, several important design parameters including l_2, l_3 and l_4 for the dipole antenna were carefully analyzed with various lengths, where the solver SEMCAD was used for those simulations. Referring to Fig. 5(a), when the length of the strip l_2 was changed, the antenna performance in the lower band was almost identical, but both two resonant modes at 3.55 GHz and 5.3 GHz could be adjusted flexibly. This is because the strip l_2 is mainly working for the 5.3 GHz mode and it is close and parallel to the path A-C-D-E to produce a capacitive coupling for tuning the middle band feature. Fig. 5(b) presents the antenna property varied with the strip l_3. We can observe that the strip l_3 may modify the upper band performance, especially for the 5.3 GHz mode. Such results prove that the strip l_3 functions as not only a resonant path for the 6 GHz mode but also a tuning stub for obtaining good impedance for the 5.3 GHz mode. Besides, the strip l_4 how to affect the antenna performance is analyzed in Fig. 5(c). As the strip l_4 varies with different lengths, all three operating bands of the antenna will change significantly. It is obvious that the strip l_4 is the end of the path A-C-D-E-F, so both two resonant modes at the frequencies of 2.45 GHz and 3.55 GHz are affected reasonably. On the other hand, the upper band property can be evidently adjusted owing to an electromagnetic coupling variation between the strips l_3 and l_4.

Figure 6 illustrates the measured radiation patterns in the xz,

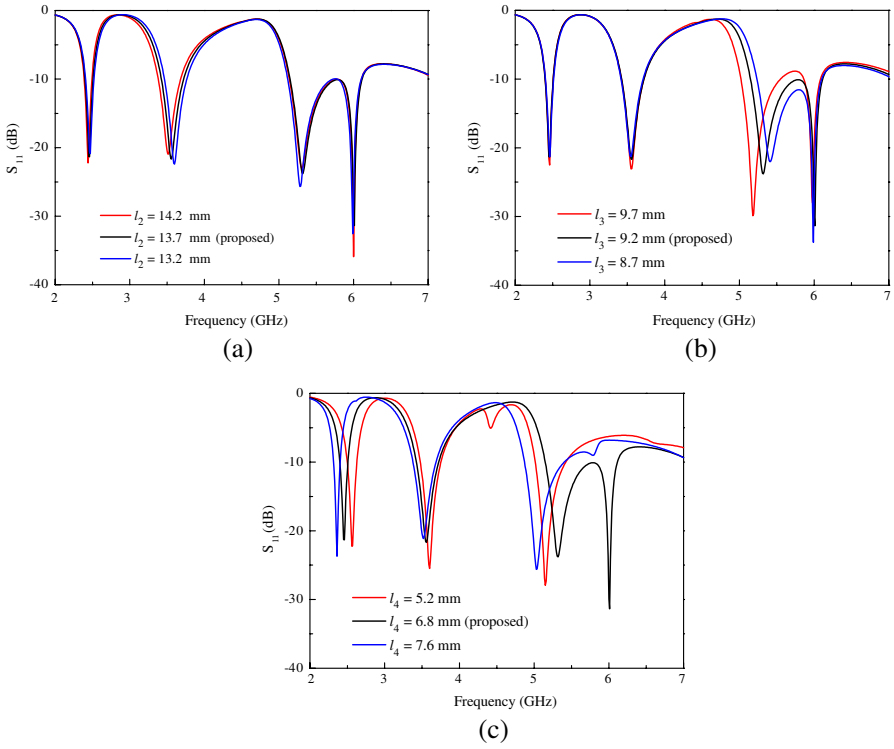
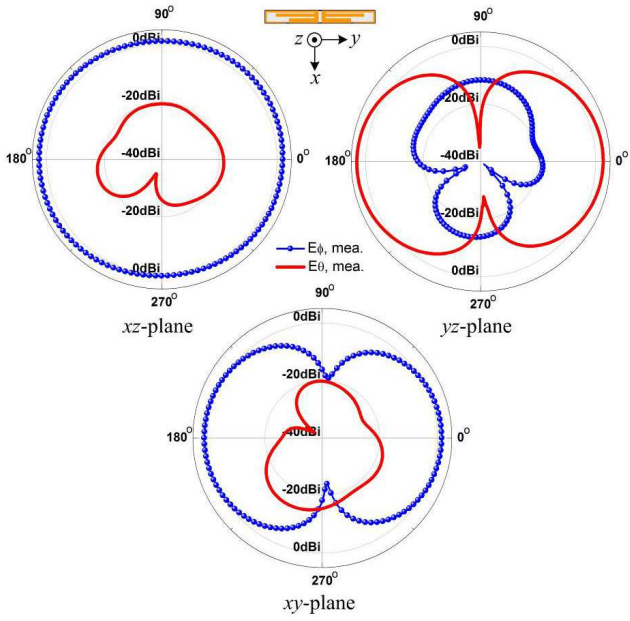


Figure 5. Simulated performance variation with three design parameters for the proposed antenna, (a) parameter l_2, (b) parameter l_3, (c) parameter l_4.

yz and *xy* planes for the four frequencies at 2.45 GHz, 3.55 GHz, 5.3 GHz and 6 GHz, respectively. Referring to these measured results, nearly good omnidirectional patterns in the *xz* plane and bidirectional patterns in both the *yz* and *xy* planes have been obtained across the 2.45 GHz, 3.55 GHz and 6 GHz. It can be also found that for the 5.3 GHz mode, the radiation patterns in the *xy* plane are close to omnidirectional, but bidirectional patterns are revealed in both the *xz* and *yz* planes. This is because the path A-C-G served for the 5.3 GHz mode is designed at the center of the dipole, and then its radiation behavior is reasonably affected from other paths.

Besides, the measured peak gain and radiation efficiency for the three operating bands of the proposed antenna are exhibited in Fig. 7. According to the lower band results shown in Fig. 7(a), the antenna gain varies slowly from 2.35 to 2.61 dBi and the efficiency has a


90°
0dBi
-20dBi
-40dBi
-20dBi
0dBi
180°
0°
270°
z
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Eϕ, mea.
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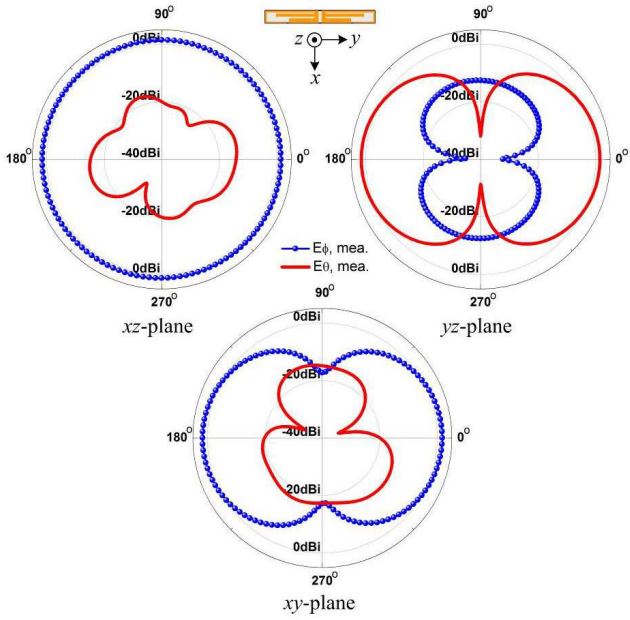
xz-plane
yz-plane
xy-plane

(a)


90°
0dBi
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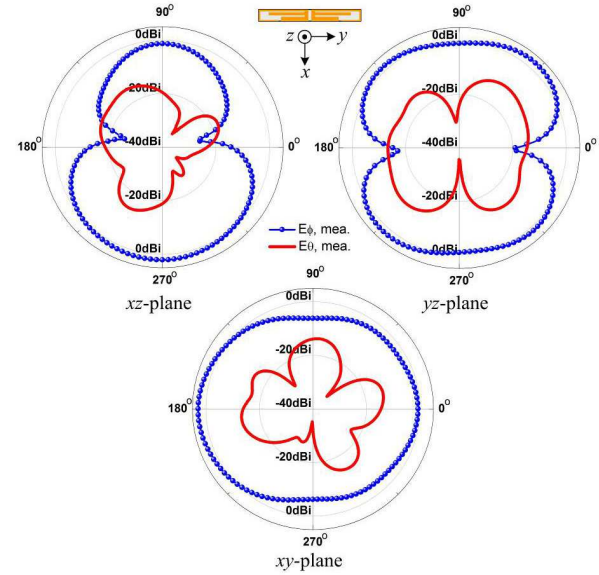
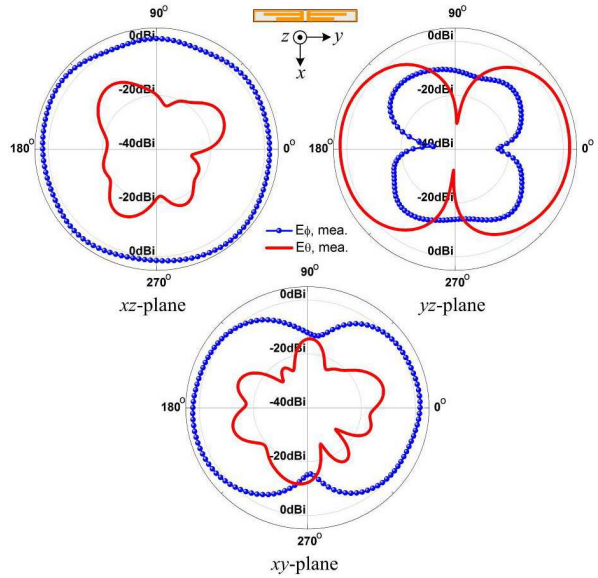


(c)



(d)

Figure 6. Measured radiation patterns at four frequencies of the proposed antenna, (a) 2.45 GHz, (b) 3.55 GHz, (c) 5.3 GHz, (d) 6 GHz.

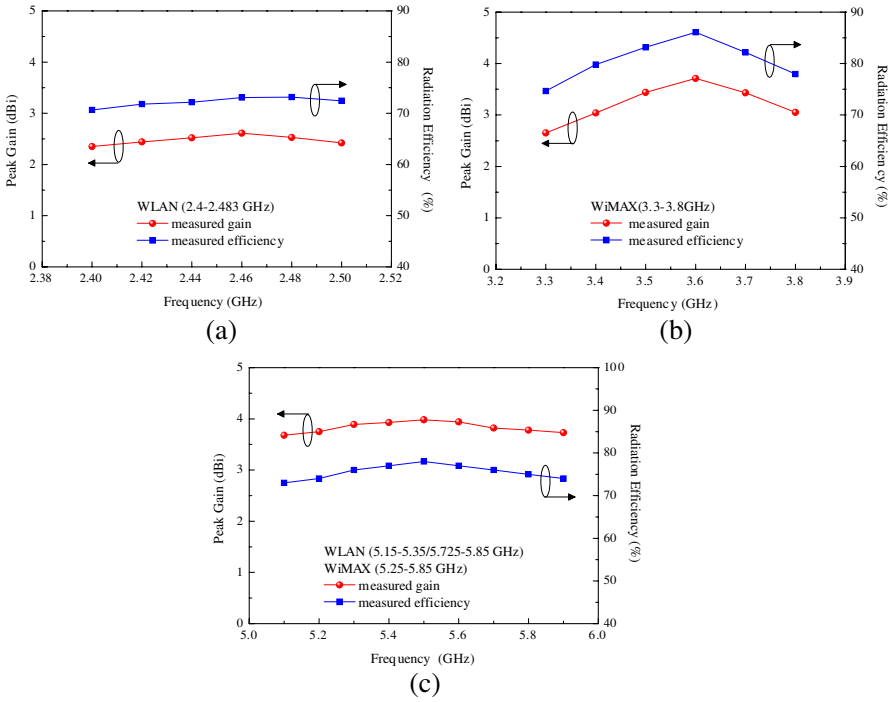


Figure 7. Measured peak gain and radiation efficiency of the proposed antenna, (a) lower band, (b) middle band, (c) upper band.

small variation range of 70–73%. Fig. 7(b) presents the measured results of the middle band, where the antenna gain is from 2.65 to 3.71 dBi and the radiation efficiency is around 75–86%. As shown in Fig. 7(c), the antenna also works with good performance in the upper band, where the gain changes within a range of 3.68–3.98 dBi and the efficiency varies from 73 to 78%. From these measured results, good omnidirectional coverage with stable radiation performance can be acquired for the proposed antenna, so better communication quality for both the WLAN and WiMAX systems can be further implemented.

4. CONCLUSION

A planar folded dipole antenna for WLAN and WiMAX applications has been presented, studied and analyzed in this paper. By appropriately forming a pair of branch arms, the antenna can achieve not only a compact structure but also three distinct operating bands. Several critical design parameters to tune the antenna's characteristic

for real application are also carefully discussed. The gain, efficiency and radiation patterns of the antenna are measured and described. Fairly good omnidirectional coverage and stable radiation performance across the bands of interest are obtained with the antenna. According to these reasons, the proposed triple-band dipole antenna can be flexibly embedded within a portable device as an internal antenna for WLAN/WiMAX operations.

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