

# Multiband Metamaterial-loaded Monopole Antenna for WLAN/WiMAX Applications

He Huang, Ying Liu, *Member, IEEE*, Shaoshuai Zhang, and Shuxi Gong

**Abstract** — A simple multiband metamaterial-loaded monopole antenna suitable for wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) applications is proposed in this letter. The rectangle monopole of the proposed antenna is originally designed to resonate at around 5.2 GHz. When the inverted-L slot is etched, the antenna produces a second resonance at around 4.1 GHz. Then with the addition of the metamaterial reactive loading, the resonant frequency of the antenna will be shifted down and a third resonance covering the 2.4 GHz band occurs. Consequently, the antenna can cover the 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 WiMAX bands with a very compact size of only 12.9×6.5 mm<sup>2</sup>. Monopole-like radiation patterns and acceptable gains and efficiencies have been obtained. Details of the antenna design as well as the experimental results are presented and discussed.

**Index Terms** — Compact antenna, multiband operation, metamaterial (MTM) reactive loading, WLAN/WiMAX applications.

## I. INTRODUCTION

Because of the rapid development of the mobile communication systems such as the wireless local area network (WLAN) and the worldwide interoperability for microwave access (WiMAX), antennas having compact size, multiband operation, low cost and ease of integration are urgently needed. Several techniques such as using meander line, fractal geometries, various shape slots [1-4] or embedding chip inductors in the monopole antennas [5, 6] have been adopted to achieve compact size. Some antennas having multiband performance have also been investigated in [7-10].

In recent years, the unique characteristics of metamaterials (MTM) [11] has been paid more attention to and provide a conceptual route for implementing small resonant antennas [12, 13]. A broadband dual-mode antenna using NRI-TL MTM loading was shown in [14]. When the antenna operates at higher frequency, the shunt inductance on the thin inductive

strip and metallization via are opened, so the antenna radiates like a monopole along x-directed. When it turns to the lower frequency, the antenna radiates in a dipolar fashion along y-directed because the current distribution has been changed with the employment of the MTM-loading. In addition, due to the fact that the current orientation differs from each other at different frequencies, the MTM loaded antenna has orthogonal radiation patterns. In [15], a tri-band monopole antenna realized by the single-cell MTM loading was reported, and its work principle is similar to that of [14] except that a third band covering 3.3-3.8 GHz is attained by using a defected ground plane. Both [14] and [15] have a large size of 22×30 mm<sup>2</sup> and 20×23.5 mm<sup>2</sup> because the entire CPW ground plane acts as the main radiator at the lower frequency band.

In this letter, a microstrip-fed monopole antenna for 2.4 GHz WLAN (2.4–2.484 GHz), 2.5 GHz WiMAX (2.5–2.69 GHz), 3.5/5.5 GHz WiMAX (3.4–3.69, 5.25–5.85 GHz), and 5 GHz WLAN (5.15–5.35/5.725–5.825 GHz) applications is proposed. With the aid of the MTM-inspired reactive loading and L-shaped slot, the antenna can cover the required bands with an extremely small form factor. Different from [14] and [15], the antenna involved in this letter only has a monopole mode, that is to say, the ground plane is no longer to be treated as part of the radiator, so the effective radiation area can be decreased significantly. To the author's best knowledge, the antenna developed in this paper occupies the smallest area and has simpler geometry to realize the required operating bands compared with other designs shown in Table I.

TABLE I  
DIMENSIONS OF MULTIBAND ANTENNAS

Ref.	Dimensions (mm <sup>3</sup> )	2.4/5.2/5.8 -GHz WLAN	2.5/3.5/5.5-GHz WiMAX
[7]	23×36.5×0.8	2.4/5.8	2.5/3.5
[8]	25×38×1.59	2.4/5.2/5.8	2.5/3.5/5.5
[9]	3.5×17×1.6	2.4/5.2/5.8	3.5/5.5
[10]	15×15×1.6	2.4/5.2/5.8	2.5/3.5/5.5
[14]	22×30×1.59	5.2/5.8	3.5
[15]	20×23.5×1.6	2.4/5.2/5.8	3.5/5.5
Proposed antenna	6.5×12.9×1	2.4/5.2/5.8	2.5/3.5/5.5

## II. ANTENNA DESIGN

Fig. 1 shows the design evolution for the proposed antenna. The antenna with the monopole only, the monopole and inverted-L slot only, and the proposed antenna are respectively designated as Ant. 1, Ant. 2, and Ant. 3. All the antennas in Fig.

This work is supported by Program for New Century Excellent Talents in University (NCET-11-0690) and the Fundamental Research funds for the Central Universities (K5051202049) and by the National Natural Science Foundation of China (No. 61372001).

The authors are with the National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi, 710071, China. (e-mail: liuying@mail.xidian.edu.cn).

1 are designed on an FR4 substrate with a relative permittivity of 4.4, loss tangent of 0.02, and thickness of 1 mm.

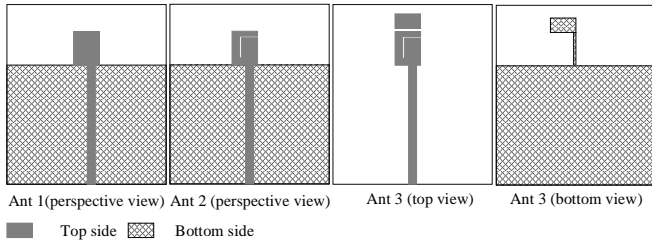


Fig. 1. Design evolution for the proposed MTM-loaded antenna.

Fig. 2 gives the simulated return loss of various antennas involved in Fig. 1. All the structures are simulated and optimized using high frequency structure simulator (HFSS v13.0). Ant. 1 in Fig. 1 is originally designed to produce a resonance at around 5.2 GHz as shown in Fig. 2. Then an inverted-L slot is etched on this monopole (Ant. 2) to divide it into two resonant branches thus generating two different resonant frequencies at around 4.1 and 5.6 GHz. Finally, in order to get a third frequency band at 2.4 GHz, a top rectangle patch (denoted as patch I), a bottom rectangle patch (denoted as patch II) and a thin strip are added to Ant. 2 forming Ant. 3. Series capacitance formed between patch I and patch II, and shunt inductance formed by the thin short-circuited strip constitute the single cell MTM-inspired reactive loading. At the same time, the original frequencies centered at 4.1 and 5.6 GHz are shifted down covering the 3.5/5.5 GHz WiMAX and 5.2/5.8 GHz WLAN bands. In addition, the resonance produced by the inverted-L slot at around 3.5 GHz merges together with the 2.4 GHz band resulting in a wideband from 2.3 to 4.1 GHz.

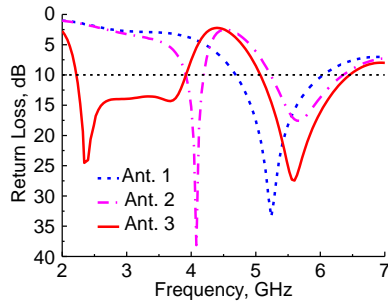


Fig. 2. Simulated return losses of Ant. 1, 2 and 3 involved in Fig. 1.

Fig. 3 illustrates the geometry of the proposed antenna (Ant. 3). The radiation element is very compact with an area of only  $12.9 \times 6.5 \text{ mm}^2$  ( $0.105\lambda_0 \times 0.05\lambda_0$ ,  $\lambda_0$  is the free space wavelength at 2.44 GHz) and the overall size of the antenna including the ground plane is  $40 \times 45 \text{ mm}^2$ . A  $50 \Omega$  transmission line, a monopole with an inverted-L slot and a rectangle patch (patch I) lie on the top side of the substrate, while a second rectangle patch (patch II) and a short-circuited inductive strip are located on the bottom side of the substrate. It is worth to mention that patch I is located right above the monopole through a small gap

(g3) in between, and that the size of the patch II is set to be the same as the patch I for the purpose of miniaturization. Some key parameters are adjusted to obtain a better performance, and the optimized dimensions of the antenna are as follows (in millimeters):  $W = 40$ ,  $L = 45$ ,  $L_f = L_g = 30$ ,  $W_f = 1.9$ ,  $W_g = 18$ ,  $W_1 = 4$ ,  $W_2 = 2$ ,  $W_3 = 6.5$ ,  $W_4 = 0.3$ ,  $L_1 = 7$ ,  $L_2 = 1.3$ ,  $L_3 = 4$ ,  $L_4 = 8.9$ ,  $g_1 = 0.5$ ,  $g_2 = 0.2$ ,  $g_3 = 0.4$ ,  $d = 1.5$ .

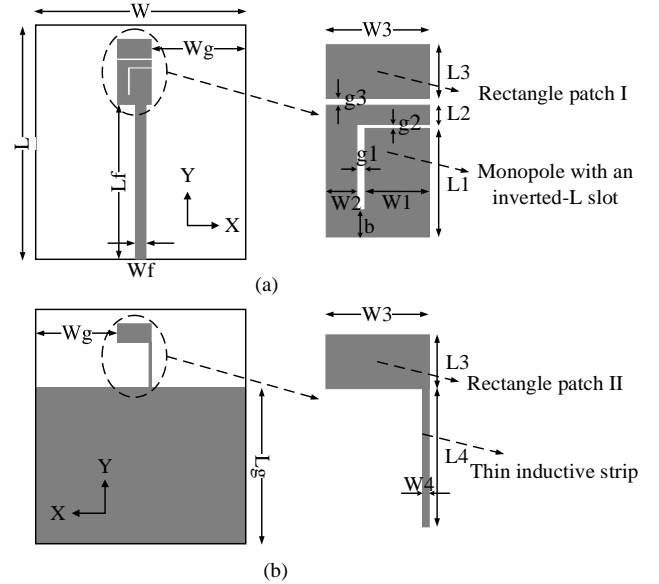


Fig. 3. Geometry of MTM-loaded monopole antenna. (a) Top view and (b) Bottom view.

### III. RESULTS AND DISCUSSION

#### 3.1. Return losses and working principle

To investigate the performance of the proposed antenna, a prototype has been fabricated and tested, and its photograph is depicted in Fig. 4.



Fig. 4. Photograph of the fabricated MTM-loaded antenna.

The simulated and measured return loss are plotted in Fig. 5. It can be observed that the measured 10-dB impedance bandwidth can reach 1.7 GHz from 2.3 to 4 GHz and 1.6 GHz from 5 to 6.6 GHz, respectively, which cover all the 2.4/5.2/5.8-GHz WLAN and 2.5/3.5/5.5-GHz WiMAX bands. Small discrepancy between the simulation and measurement may be attributed to the fabrication imperfections, substrate losses, and

measurement circumstance.

In order to get a deep insight into the working principle of the antenna, Fig. 6 presents the vector current distributions of the antenna at 2.44, 3.5, and 5.5 GHz. As we can see from Fig. 6, the currents at 5.5 GHz mainly concentrates on the shorter branch of the monopole, and at 3.5 GHz it turns to the longer branch of the monopole. When it comes to the 2.44 GHz band, the waves arrive the MTM loading through electromagnetic couple thus forming an energy loop and enabling the effective radiation at 2.44 GHz. Note that the effect of the MTM loading in this letter differs from that of in [14] and [15]. Detailed speaking, the MTM loading used in those aforementioned papers is employed to form a short circuit and act as a balun so as to generate an in-phase current on the top edge of the CPW ground plane to radiate in a dipolar fashion. Together with the regular monopole mode, there are two operation modes in those antenna. But in this paper, the deliberately designed antenna only radiates along y-directed namely operating at a single monopole mode. What's more, the ground involved in this letter do not have to be used as the main radiator any more, thus the effective radiation area is decreased further.

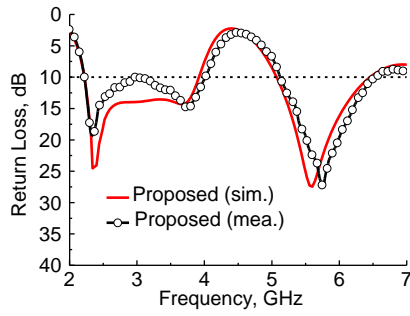


Fig. 5. Simulated and measured return losses of the proposed antenna.

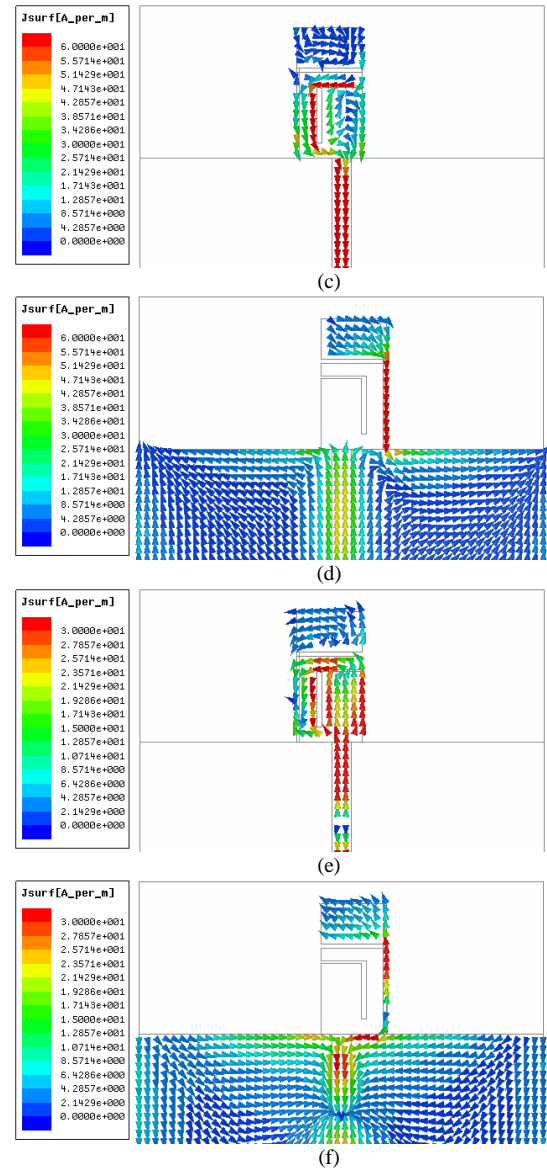
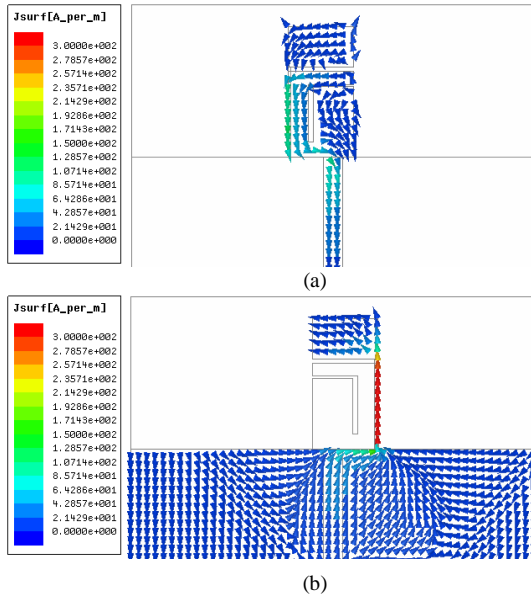
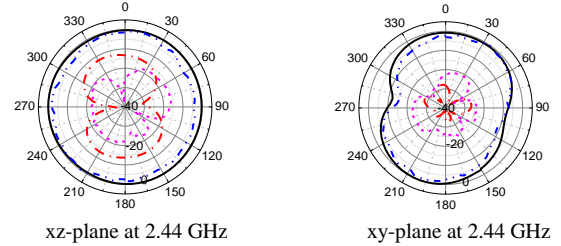


Fig. 6. Current distributions of the proposed antenna (a) front view at 2.44 GHz, (b) rear view at 2.44 GHz, (c) front view at 3.5 GHz, (d) rear view at 3.5 GHz, (e) front view at 5.5 GHz, (f) rear view at 5.5 GHz.

### 3.2. Radiation Performance

Fig. 7 shows the simulated and measured normalized far-field radiation patterns in xz-plane (H-plane) and xy-plane (E-plane) at 2.44, 3.5, and 5.5 GHz. It can be seen that the proposed antenna exhibits good omnidirectional H-plane patterns and bi-directional E-plane patterns across the desired operating bands.



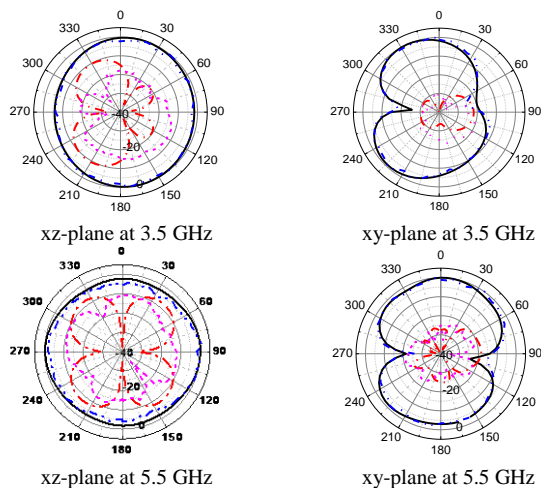


Fig. 7. Simulated and measured normalized radiation patterns for the proposed antenna.

— Simulated co-polarization — Simulated cross-polarization  
 - - - Measured co-polarization - - - Measured cross-polarization

### 3.3. Gains and efficiencies

As shown in Fig. 8, the measured gains are about 3.2, 2.38, and 2.34 dBi, while the measured efficiencies are about 76.5%, 69.5%, and 61.7% at 2.44, 3.5, and 5.5 GHz, respectively. Due to the influence of the measurement environment, and energy losses of the actual antenna material and feeding network, the measured gains and efficiencies are a little less than the simulated ones (simulated results are not shown here for brevity).

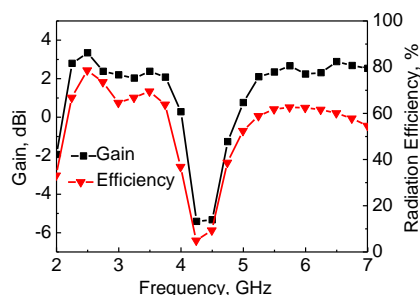


Fig. 8. Measured gains and efficiencies for the proposed antenna.

## IV. CONCLUSION

A multiband monopole antenna for WLAN/WiMAX applications has been proposed and investigated in this paper. With the help of the single cell MTM loading, this antenna could exhibit a single monopole mode along y-directed at all the required frequency bands. Measured results show that the antenna has a 10 dB impedance bandwidth of 1.7 GHz (2.3–4 GHz), and 1.6 GHz (5–6.6 GHz) which cover all the WLAN and WiMAX bands. In addition, omnidirectional radiation pattern, and reasonable gains and efficiencies are also obtained. Having advantages of compact size, low profile, via-less struc-

ture, and easy integration with other microwave circuits, the antenna can be a good candidate for emerging practical wireless communication systems.

## REFERENCES

- [1] Hsuan Yu Chien, Chow Yen Desmond Sim, and Ching-Her Lee, "Dual-Band Meander Monopole Antenna for WLAN Operation in Laptop Computer," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 694–697, 2013.
- [2] D. D. Krishna, M. Gopikrishna, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Compact wideband Koch fractal printed slot antenna," *IEEE Antennas Propag.*, vol. 3, no. 5, pp. 782–789, Aug. 2009.
- [3] C. Y. Chiu, C. H. Chan, and K. M. Luk, "Small dual-band antenna with folded-patch technique," *IEEE Antennas Wireless Propag. Lett.*, vol. 3, pp. 108–110, 2004.
- [4] Tae-Hyun Kim and Dong-Chul Park, "Compact Dual-Band Antenna With Double L-Slits for WLAN Operations," *IEEE Antennas Wireless Propag. Lett.*, vol. 4, pp. 249–252, 2005.
- [5] Kin-Lu Wong, and Shu-Chuan Chen, "Printed single-strip monopole using a chip inductor for penta-band WWAN operation in the mobile phone," *IEEE Trans. Antennas Propag.*, vol. 58, no. 3, pp. 1011–1014, Mar. 2010.
- [6] Ting-Wei Kang and Kin-Lu Wong, "Chip-inductor-embedded small-size printed strip monopole for WWAN operation in the mobile phone," *Microwave Opt Technol Lett.*, vol. 51, pp. 966–971, 2009.
- [7] P. A. Liu, Y. L. Zou, B. R. Xie, X. L. Liu, and B. H. Sun, "Compact CPW-fed tri-band printed antenna with meandering split-ring slot," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1242–1244, 2012.
- [8] J. Pei, A. Wang, S. Gao, and W. Leng, "Miniaturized triple-band antenna with a defected ground plane for WLAN/WiMAX applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 298–302, 2011.
- [9] Hong Chen, X. Yang, Y. Z. Yin, S. T. Fan, and J. J. Wu, "Triband Planar Monopole Antenna With Compact Radiator for WLAN/WiMAX Applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 1440–1443, 2013.
- [10] Mahdi Moosazadeh and Sergey Kharkovsky, "Compact and Small Planar Monopole Antenna With Symmetrical L- and U-Shaped Slots for WLAN/WiMAX Applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 388–391, 2014.
- [11] G. V. Eleftheriades, A. K. Iyer, and P. C. Kremer, "Planar negative refractive index media using periodically L-C loaded transmission lines," *IEEE Trans. Microw. Theory Tech.*, vol. 50, pp. 2702–2712, 2002.
- [12] M. A. Antoniades and G. V. Eleftheriades, "A folded-monopole model for electrically small NRI-TL metamaterial antennas," *IEEE Antennas Wireless Propag. Lett.*, vol. 7, pp. 425–428, 2008.
- [13] J. Zhu and G. V. Eleftheriades, "A compact transmission-line metamaterial antenna with extended bandwidth," *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 295–298, 2009.
- [14] Marco A. Antoniades and George V. Eleftheriades, "A Broadband Dual-Mode Monopole Antenna Using NRI-TL Metamaterial Loading," *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 258–261, 2009.
- [15] Jiang Zhu, Marco A. Antoniades, and George V. Eleftheriades, "A Compact Tri-Band Monopole Antenna With Single-Cell Metamaterial Loading," *IEEE Trans. Antennas Propag.*, vol. 58, no. 4, pp. 1031–1038, Apr. 2010.