Multiband Metamaterial-Loaded Monopole Antenna for WLAN/WiMAX Applications
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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-GHz WiMAX bands with a very compact size of only 6.5 × 12.9 mm². 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, metamaterial (MTM) reactive loading, multiband operation, 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 (MTMs) [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-direction. When it turns to the lower frequency, the antenna radiates in a dipolar fashion along y-direction 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 and 20 × 23.5 mm² because the entire coplanar waveguide (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 letter occupies the smallest area and has simpler geometry to realize the required operating bands compared to other designs shown in Table I.

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. 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. 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 ver. 13.0). 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 wide band from 2.3 to 4.1 GHz.

Fig. 3 illustrates the geometry of the proposed antenna (Ant. 3). The radiation element is very compact with an area of only $12.9 \times 6.5$ mm$^2$ ($0.105\lambda_0 \times 0.65\lambda_0$, $\lambda_0$ is the free space wavelength at 2.44 GHz), and the overall size of the antenna including the ground plane is $40 \times 45$ mm$^2$. A 50-Ω 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 mentioning that patch I is located right above the monopole through a small gap ($g3$) in between, and that the size of patch II is set to be the same as 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): $W = 40$, $L = 45$, $L_f - L_g = 30$, $W_f = 1.9$, $W_g = 18$, $W1 = 4$, $W2 = 2$, $W3 = 6.5$, $W4 = 0.3$, $L1 = 7$, $L2 = 1.3$, $L3 = 4$, $L4 = 8.9$, $g1 = 0.5$, $g2 = 0.2$, $g3 = 0.4$, $d = 1.5$.

III. RESULTS AND DISCUSSION

A. 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.

The simulated and measured return losses 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 concentrate on the shorter branch of the monopole, and at 3.5 GHz, they turn 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 in [14] and [15]. In more detail, 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. However, in this letter, the deliberately designed antenna only radiates along y-direction, namely operating at a single monopole mode. What is more, the ground involved in this letter does not have to be used as the main radiator anymore, thus the effective radiation area is decreased further.

B. 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 bidirectional E-plane patterns across the desired operating bands.

C. 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).

IV. CONCLUSION

A multiband monopole antenna for WLAN/WiMAX applications has been proposed and investigated in this letter. With the help of the single-cell MTM loading, this antenna could exhibit a single monopole mode along y-direction at all the required frequency bands. Measured results show that the antenna has 10-dB impedance bandwidths 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,
Fig. 7. Simulated and measured normalized radiation patterns for the proposed antenna.

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

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

REFERENCES


