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A New Compact Microstrip-Fed Monopole Antenna for Triple Band WLAN/WiMAX Applications

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Abstract—A new compact printed tri-band antenna for WLAN/WiMAX applications is presented. The proposed antenna consists of three inverted L-shaped strips whose geometry looks like a "bent fork". These strips are attached to the feed line through a horizontal strip. By optimizing the geometries of the inverted L-shaped strips, distinct resonant points can be effectively created for different frequency bands. The overall size of the proposed antenna is $18 \times 33\,\mathrm{mm}^2$. Simulated and measured results show that the presented antenna can cover 2.5/3.5/5.5 WLAN and WIMAX bands with fairly stable radiation patterns. The antenna structure is simple, small, easily configurable and tuneable, and therefore suitable for practical applications.

1. INTRODUCTION

With rapid development of wireless communication systems, designing compact, multi-band, and omni-directional radiation patterns for multisystems, especially for wireless local area network (WLAN: 2.4–2.48, 5.15–5.35, 5.72–5.85 GHz) and worldwide interoperability for microwave access (WIMAX: 2.5–2.67, 3.4–3.69, 5.25–5.85 GHz) is of major importance. Some broadband antennas can cover both WLAN/WIMAX frequencies. However the multiband antenna is more attractive since filters do not have to be implemented to block out interfering bands [1].

Several types of antennas have been proposed for multiband applications [2–9]. Some of these antennas have been designed for dual bands [2, 3]. Recently, several triple band antennas have been reported in [4–9]. However their designs may increase the complexity, and/or may have large sizes and/or may have small bandwidths. For example in [4], a tri-band E-shaped printed monopole was introduced. However it only operates in the three WLAN bands and its bandwidth doesn't cover any WiMAX bands. Additionally, its overall size is relatively big ($35 \times 38\,\mathrm{mm}^2$). In [5], a tri-band antenna covering both the WLAN and WiMAX bands was presented. Its resonant frequencies are achieved by inserting a pair of T-shaped strips into a wide rectangular slot. Even though stable radiation patterns were achieved, the antenna is complicated which will make tuning difficult, and the overall size ($36\times30\,\mathrm{mm}^2$) of the antenna is relatively big. In [6], a relatively small tri-band antenna ($23 \times 36.5\,\mathrm{mm}^2$) was presented. It consists of modified rectangular slots, a pair of symmetrical inverted-L slots, and a Y-shaped monopole radiator with meandering split ring slots. This structure is complicated and tuning on the bands cannot be easily done. Much smaller tri-band antennas have been proposed in [7–9]. An overall size of $21 \times 29\,\mathrm{mm}^2$ with stable radiation patterns was proposed in [7]. This antenna uses a CPW-feed with two inverted L slots cut on the extended part of the feed line above the ground plane. Two rectangular corners of the substrate are also cut off to improve antenna performance. Additionally, both simulated and measured results reveal that the antenna does not cover both WLAN and WiMAX triple bands. A new antenna, smaller than the antennas in [6, 7], is reported in [8]. The overall size of the antenna is $18 \times 37\,\mathrm{mm}^2$. The antenna consists of 3 simple circular-arc shaped strips. However, the antenna is

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influenced by the angles between the closely-spaced arcs which make it tedious when tuning is done, especially on the arcs. Recently, a new type of tri-band antenna has been reported [9]. This antenna uses stepped impedance resonators (SIR) with attached parasitic slots to achieve tri-band performance and improve omni-directional radiation respectively. However, the omni-directional radiation patterns are still unstable and the antenna size is very big ($180 \times 180\,\mathrm{mm}^2$) making it impractical for portable devices.

In this paper, a novel compact tri-band antenna is proposed to cover both the WLAN/WiMAX bands. It uses three inverted L-shaped strips to achieve resonances at distinct frequencies. It has a smaller and simpler structure compared with the antennas in [2–9]. It has fairly stable omnidirectional radiation patterns and is very easy to tune making it suitable for portable devices.

2. ANTENNA DESIGN AND ORIENTATION

The geometry of the proposed antenna is shown in Figure 1. It is printed on an FR4 substrate with a dielectric permittivity of 4.4 and a thickness of 1 mm. The microstrip feed line is connected to the inverted L strips through a horizontal strip, and printed on the top of the substrate. The ground plane is printed on the other side of the substrate. The antenna is fed with a 50-Ω coaxial cable. The overall size of the antenna is $18 \times 33 \times 1\,\mathrm{mm}^3$, which to the best of our knowledge is the smallest tri-band antenna, with respect to physical size. The L shape geometry was used to reduce the volume of the antenna. The width of each strip is the same, as well the gap between them. The proposed antenna contains three L-shaped strips to achieve three distinct resonances. The total length of each L-shaped strip is about a quarter of the guided wavelength at the desired resonant frequency. Therefore the length of the L-strip is calculated as;

$$L_{total} \approx \lambda_g/4, \tag{1}$$

$$\lambda_g = \frac{C}{f\sqrt{\varepsilon_{ff}}}, \quad \varepsilon_{ff} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

where c is the speed of light, f is the desired resonant frequency, ε_{ff} is the effective relative permittivity. The value of L_{total} can serve as a starting point to calculate the length of the strip from which it can be optimized to obtain a final value. From the equations above, we can deduce that the middle, the left, and the right L-shaped strips resonate at 2.5/3.5/5.5 respectively. The calculated value and the final optimized values are given in Table 1. From Figure 1, the left strip is calculated as $(7 - 0.5) + (8.5 + 0.5 + 0.5) = 16\,\mathrm{mm}$, middle strip is calculated as $(19 + 0.5) + (9.5 - 0.5) = 28.5\,\mathrm{mm}$, and the right strip is calculated as $(4 - 0.5) + (3.5 + 0.5 + 0.5) = 8\,\mathrm{mm}$.

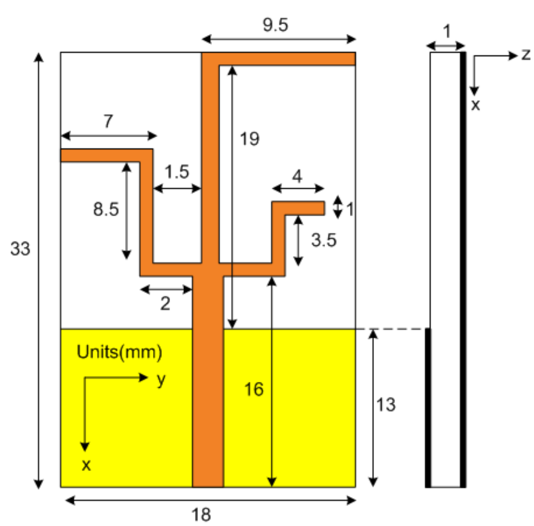

Figure 1. Geometry of the proposed antenna.

Table 1. Initial (Calculated) and optimized (final) values of the L-shaped strips.

L-shaped strips	Calculated (initial)	Optimized (final)
Middle, 2.5 GHz	25.5 mm	28.5 mm
Left, 3.5 GHz	13 mm	16 mm
Right, 5.5 GHz	8.3 mm	8 mm

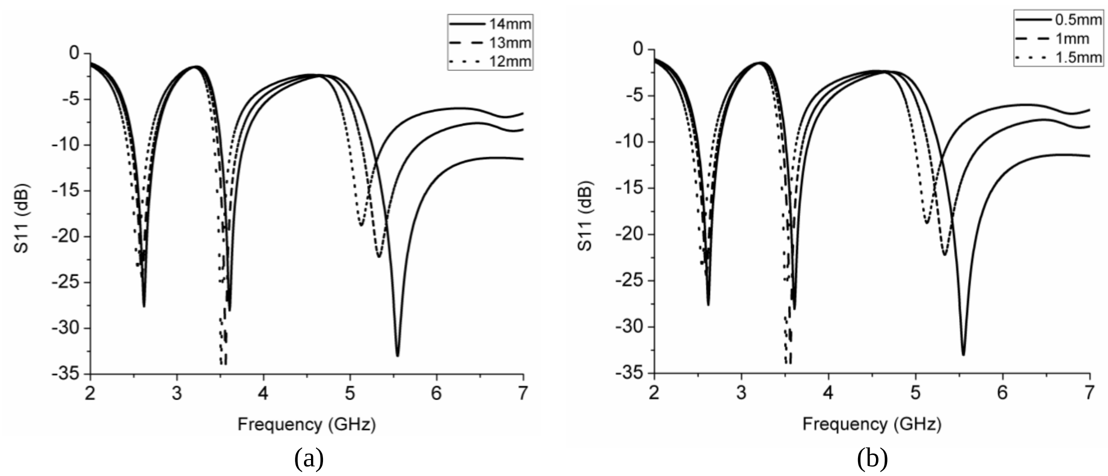

Figure 2. Simulated return loss for different; (a) ground plane heights, (b) gap between the L-shaped strips.

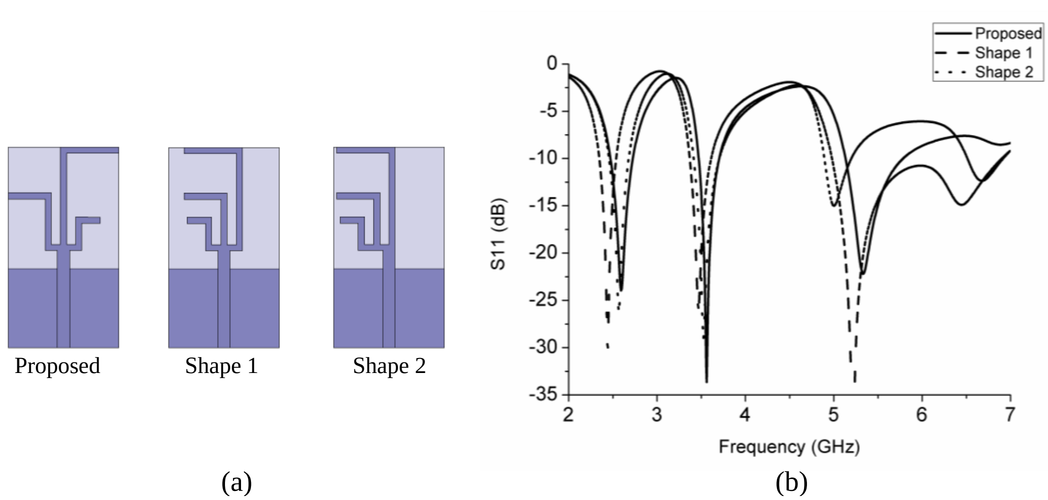

Figure 3. (a) Different antenna orientations and (b) their corresponding return losses.

2.1. Parametric Study

In this section, two main parts of the proposed antenna are studied to see how the antenna's resonances are affected by them. The parameters are; the length of the ground plane, and the gap between the L-shape stubs. Figure 2(a) shows the return loss when the ground plane length is changed. It can be noticed that the first and the second resonant points are barely affected with changes in the ground plane lengths. However, the third resonant point shows improved impedance matching and bandwidth when the ground plane length increases from 12 mm to 14 mm. This phenomenon will also be noticed when the SMA connector is attached to the antenna during measurement, in Section 3.

Figure 2(b) shows a similar phenomenon when the gap between the L-shaped strips changes. It can be noticed that, the first resonance is not affected, but the second resonance shows a slight shift to the upper frequency when the gap reduces. The third frequency exhibits the highest discrepancy by shifting to a higher frequency when the gap width is reduced.

2.2. Orientation of L-shaped Strips

One benefit of the proposed antenna is its flexibility in tuning and re-arranging the structure without greatly affecting its performance and antenna size. The return loss is shown for three different orientations of our antenna in Figure 3.

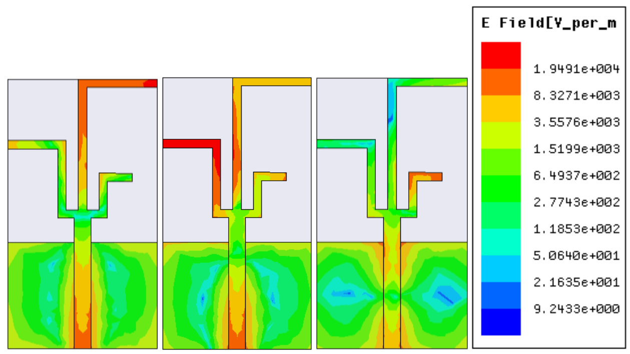

Figure 4. *E*-field distribution at 2.5 GHz, 3.5 GHz, and 5.5 GHz.

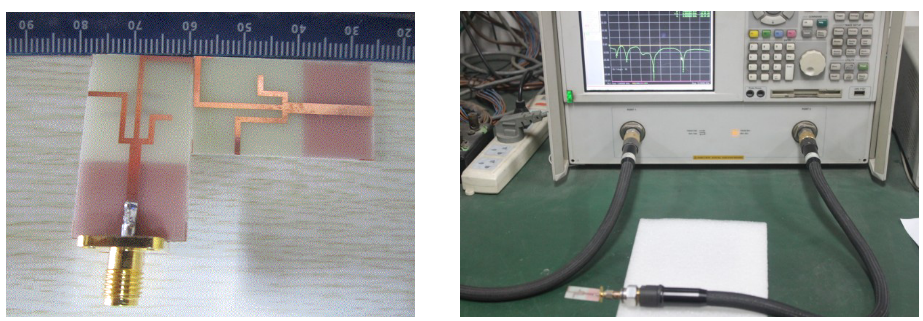

Figure 5. Photograph of the fabricated antenna with measurement setup.

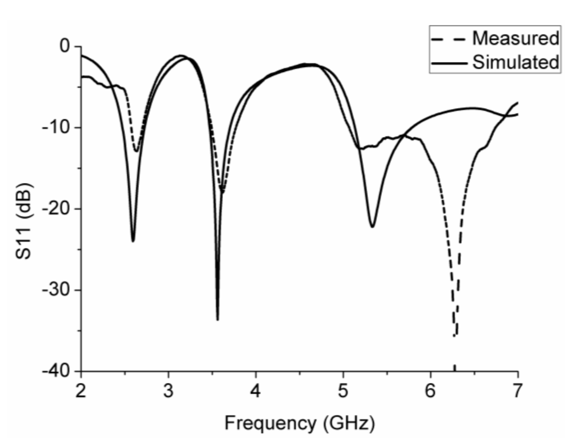

Figure 6. Measured return loss of the proposed antenna.

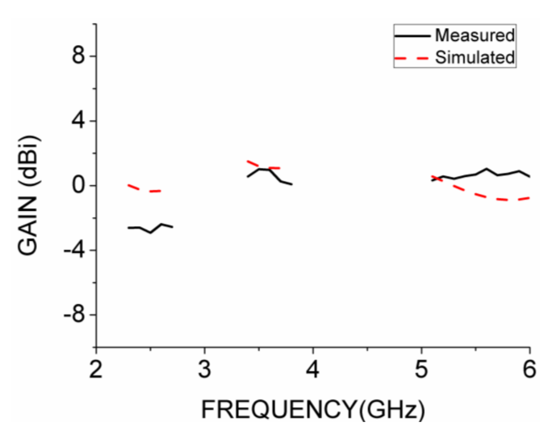

Figure 7. Measured peak gain of the proposed antenna.

It can be noticed that the proposed antenna maintains broadband resonant points for the assumed different orientations. It should be noted that, antennas with shapes 1 and 2 were achieved by mainly changing the orientation of the optimized proposed antenna. Therefore they were not optimized for their shapes. That notwithstanding, good results are still realized showing that this antenna is easy to tune and is more flexible than most tri-band antennas reported. Additionally, the sizes of antenna shape 1 and antenna shape 2 can be further optimized to make the antenna more compact and even further reduce the overall antenna size.

2.3. Current Distribution

Figure 4 shows the electric field distribution of the proposed antenna at different frequencies. It can be noticed that distinct resonances are achieved on the different strips of the antenna.

At these frequencies, the resonating strip acts as a quarter wave monopole antenna following (1)–(2). The experimental results of the proposed antenna will be shown in the following section.

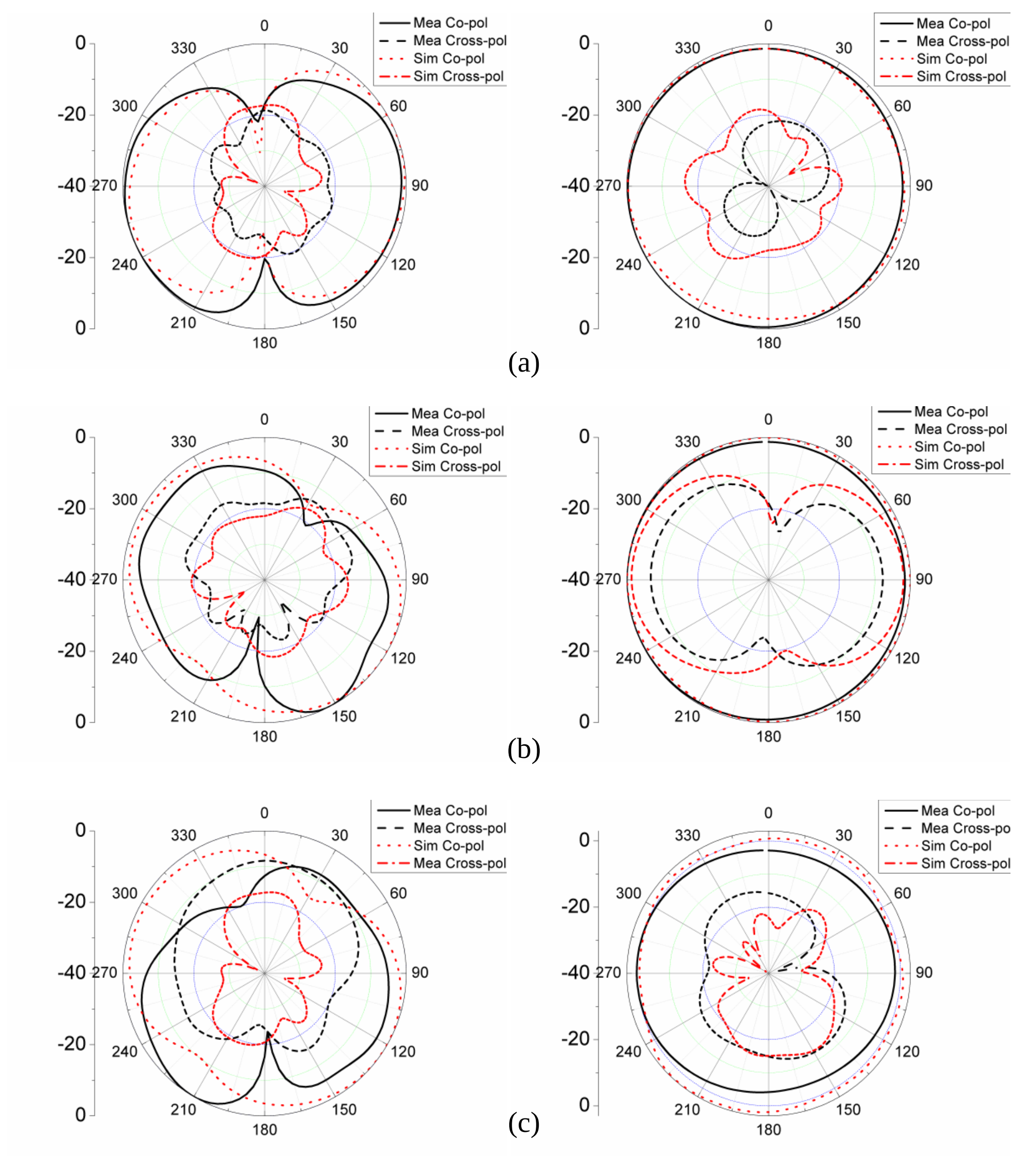

Figure 8. Measured (left) E-plane and (right) H-plane radiation patterns of the antenna at 2.5, 3.5, and 5.5 GHz.

3. EXPERIMENTAL RESULTS

The printed antenna is fabricated and then measured with an Agilent N5230A PNA-L and a SATIMO antenna measurement system. The fabricated antenna is shown in Figure 5. The simulated and measured return losses are plotted in Figure 6. The results show that the antenna can cover bandwidths from 2.5–2.7 GHz (200 MHz), 3.4–3.72 GHz (320 MHz), and 5–6.8 GHz (1800 MHz) for VSWR ≤ 2. The measured results, compared to the simulated results, show slightly less bandwidths in the 2.5 GHz bandwidth, but well matched in the 3.5 GHz bandwidth, and a better matched bandwidth in the 5.5 GHz. This discrepancy is due to the attached SMA connector and fabrication imperfections. When the SMA connector is attached to the antenna, it also somewhat acts like a ground plane due to the current flow to and from the ground to the SMA. This slightly increases the ground plane size and causes the bandwidth in 5.5 GHz to increase. This phenomenon was previously explained in Figure 2(a) where an increase in the ground plane size caused an increase in bandwidth around 5.5 GHz. That notwithstanding, the measurement results satisfy both WLAN (5.15–5.35, 5.72–5.85 GHz) and WiMAX (2.5–2.67, 3.4–3.69, 5.25–5.85 GHz) applications.

The measured peak gains are shown in Figure 7. Measured peak gains of -2 dBi, 1.5 dBi, and 1 dBi are achieved at 2.6 GHz, 3.4 GHz, and 5.5 GHz, respectively. The above characteristics show that the antenna can provide stable gains in all the three bands.

The radiation patterns are shown in Figure 8. The antenna lies on the xoy-plane as shown in the coordinate system inside Figure 1. E-plane (xy-plane, $\theta = -90$) and H-plane (yz-plane, $\phi = 90$) are measured at 2.5, 3.5, and 5.5 GHz. As expected, the E-plane radiation patterns depict a monopole-like radiation pattern, showing a quasi-omnidirectional radiation pattern with low cross-polarization. The H-plane radiation patterns depict an omnidirectional radiation with low cross-polarization. The slight shift in the E-plane radiation at 3.5 and 5.5 GHz is due to the sideways position of their respective L strips on the antenna.

4. CONCLUSION

In this paper, a microstrip fed monopole antenna for tri-band is presented for WLAN/WiMAX applications. The triple band is achieved by using three inverted L-shaped strips. Results also show that the antenna can be easily re-arranged in several forms without affecting its performance. This shows that the proposed antenna is simpler, more compact, easier to tune and more flexible than other proposed triple band antennas. Experimental results reveal stable radiation properties, and broad bandwidths, thus making it suitable for practical WLAN/WiMAX applications.

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