Research Article

A CPW-Fed Monopole Antenna with Double Rectangular Rings and Vertical Slots in the Ground Plane for WLAN/WiMAX Applications

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A compact triple-band monopole antenna consisting of double rectangular rings and vertical slots cut into the ground is proposed for WLAN and WiMAX operations. The antenna has a compact size of $27.1 \times 38.8 \times 1.6 \text{ mm}^3$, with simulated and measured impedance bandwidths of 2.37~2.81, 3.21~3.82, and 4.61~6.34 GHz with a reflection coefficient of less than -10 dB . The antenna also exhibits an almost omnidirectional radiation pattern and stable gain levels in the triple bands. The characteristics of the proposed antenna have been investigated using the numerical simulations and experiments.

1. Introduction

Recently, there has been rapid progress in wireless communications technology employing various frequency bands. For short-range and long-range communication applications, many antenna designs have been studied that are suitable for wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) operation. There is also a growing demand in wireless communication technology for integration of the WLAN (2.412~2.482 GHz, 5.15~5.825 GHz) and WiMAX (2.500~2.690 GHz, 3.400~3.690 GHz, 5.250~5.850 GHz) frequency bands into a single device, thus necessitating the development of multiband antennas with simple structure and low profile. Numerous multiband antenna designs with simple structure have already been reported, including a printed planar wide-slot antenna [1], a CPW-fed planar monopole antenna [2], a printed inverted-L- (IL-) shaped monopole antenna [3], a slot-monopole antenna with embedded rectangular parasitic elements [4], and a monopole antenna with a split ring [5]. However, for the realization of multiband operation, additional structures must be employed on the bottom layer such

as a T-shape, S-shape, vertical strip resonator, or parasitic elements.

In this paper, we propose a CPW double rectangular ring-shaped monopole antenna design that incorporates the frequency bands for WLAN and WiMAX applications (i.e., operates at frequencies in the ranges 2.4~2.690, 3.4~3.69, and 5.15~5.850 GHz). Triple band characteristics are achieved by an inner/outer ring structures and thin slots in the ground plane. The outer ring structure controls the resonance at the lower and upper frequency bands, whereas the inner ring structure controls the resonance at the middle frequency band. Two thin slots etched into the ground are used to reject an unwanted resonance at around 4 GHz. Details of the proposed antenna design and experimental results are presented and discussed.

2. Antenna Design

The geometry of the CPW-fed double rectangular ring-shaped antenna is shown in Figure 1, together with a photograph of the fabricated optimized structure. The antenna has overall dimensions of $27.1 \times 38.8 \times 1.6 \text{ mm}^3$ and was

FIGURE 1: Geometry and photograph of the proposed antenna: (a) geometry, (b) photograph.

FIGURE 2: Simulated return losses for the proposed antenna with and without the inner ring and vertical slots.

fabricated on an FR4 substrate with relative permittivity $\epsilon_r = 4.4$. A $50\ \Omega$ CPW transmission line with a signal strip width of 3.5 mm and a gap distance of 0.3 mm is used to feed the antenna. Two ground planes of the CPW line with dimensions of $11.5 \times 17\ \text{mm}^2$ are situated symmetrically on either side of the CPW line. The size of the outer rectangular ring is $17 \times 21.8\ \text{mm}^2$, and the size of the inner ring is $7 \times 8.8\ \text{mm}^2$. The antenna consists of a single-layer metallic structure for the simple fabrication, which is etched onto one side of the substrate. The optimal design parameters in Figure 1(a) are $W = 27.1\ \text{mm}$, $L = 38.8\ \text{mm}$, $G_W = 11.5\ \text{mm}$, $G_L = 17.0\ \text{mm}$, $W_f = 3.5\ \text{mm}$, $g = 0.3\ \text{mm}$, $h = 1.6\ \text{mm}$,

$L_1 = 2.8\ \text{mm}$, $L_2 = 8.5\ \text{mm}$, $L_3 = 19.0\ \text{mm}$, $L_4 = 5.0\ \text{mm}$, $L_5 = 7.0\ \text{mm}$, $L_6 = 7.0\ \text{mm}$, $S_L = 10.0\ \text{mm}$, and $S_W = 0.3\ \text{mm}$.

Figure 2 shows the effects on the return losses produced by the inner ring and the vertical slots in the ground plane via numerical simulations. Antenna 1 (in Figure 2), which consists solely of the outer rectangular ring, can easily achieve resonances at two frequency bands for dual-band WLAN operation [6]. In Antenna 2, which the inner rectangular ring is added, we found that it can excite a middle frequency of 3 GHz. However, the addition of the inner rectangular ring also produces wideband resonances

FIGURE 3: Influence of the outer ring on the return loss of the proposed antenna: (a) various L_2 when $L_3 = 19$ mm, (b) various L_3 when $L_2 = 8.5$ mm.

in frequency bands around 4 GHz where they are not wanted. In Antenna 3, which vertical slots are inserted into the ground plane of Antenna 1, band-notched frequencies appear around 4 GHz, and the resonance in the notched band from 4.0 to 5.0 GHz is removed. The lengths of these slots are equal to the half-guided wavelength at the rejected frequency [7, 8]. Finally, the proposed double-rectangular-ring antenna with double rectangular rings and vertical slots in the ground plane (Antenna 4) can generate three distinct resonances in three wanted separate frequency bands.

In the aforementioned, the lower and upper frequency bands are primarily determined by the outer ring and the middle frequency band is dominated by the inner ring. Figure 3 shows the influence of the geometries of the outer ring on the return loss at the lower and upper frequency bands in the proposed antenna. Figure 3(a) shows the effect of L_2 when the length, L_3 , of the outer ring was fixed at 19 mm and Figure 3(b) shows the effect of L_3 when $L_2 = 8.5$ mm. Since, the parameter L_2 made a primary impact on not the lower and but the upper frequency band and the parameter L_3 made the frequency shift in the upper and lower bands at the same time, we adjusted the length of L_2 to finely tune the upper frequency band.

For the adjustment of the middle frequency bands, we adjusted the geometries of the inner ring as shown in Figure 4. Figure 4 shows the effects of varying lengths of the rectangular inner ring, and L_4 , L_5 , and L_6 cannot make any variation at the lower and upper frequency bands when the parameters of the outer ring are fixed. As the parameters L_4 , L_5 , and L_6 increased, the middle resonant frequencies were decreased.

3. Experiment Result

Figure 5 shows the simulated and measured return losses of the proposed antenna with the optimized parameters, and good agreement between simulation and measurement is observed. For a 10 dB return loss, the measured impedance bandwidths of the three individual operating bands are about 500 MHz (2.37~2.81 GHz), 800 MHz (3.21~3.82 GHz), and 1 GHz (4.61~6.34 GHz), simultaneously covering the 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX operational bands.

Figure 6 shows the simulated current distributions under the optimized structure at the different frequencies. The current distributions varied significantly depending on the resonant frequency. It is evident from these current distributions that, at lower frequency band, the radiation mainly resulted from the outer ring, as shown in Figure 6(a). The inner ring mainly contributes the radiation at middle frequency band, as shown in Figure 6(b). Likewise, the horizontal strip line of the outer ring mainly contributes the radiation at upper frequencies band, as shown in Figure 6(c).

The measured XY-plane and ZX-plane radiation patterns are shown in Figure 7. The XY-plane patterns appear to be nearly omnidirectional, whereas the ZX-plane patterns are in the broadside direction at all operating frequencies. Figure 8 shows the measured peak gain of the proposed antenna in the 2.4 GHz, 3.5 GHz, and 5.5 GHz bands. The measured peak realized gain levels of the antenna are about 5.5, 4.0 and 3.5 dBi for 2.4, 3.5 and 5.5 GHz, respectively.

4. Conclusion

We proposed a CPW-fed monopole antenna with double rectangular rings and vertical slots for WLAN/WiMAX

FIGURE 4: Influence of the inner ring on the return loss of proposed antenna: (a) various L_4 when $L_5 = 7$ mm and $L_6 = 7$ mm, (b) various L_5 when $L_4 = 5$ mm and $L_6 = 7$ mm, (c) and various L_6 when $L_4 = 5$ mm and $L_5 = 7$ mm.

applications. The antenna design is compact, with dimensions of only $27.1 \times 38.8 \times 1.6 \text{ mm}^3$. A band notch for unwanted frequency bands is achieved by adding vertical slots to the ground plane. The antenna has a simple geometry and is relatively easy to fabricate because of its single-layer metallic structure. Because the bandwidths of the lower, middle, and upper bands of the proposed monopole antenna are sufficient to cover the 2.4, 3.5, and 5.5 GHz bands, the design is suitable for WLAN/WiMAX triple-band applications. Additionally, the proposed antenna provides good radiation patterns and stable gain in each of the operating bands.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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FIGURE 5: Measured and simulated reflection coefficients of the proposed antenna.

FIGURE 6: Simulated current density distribution of the proposed antenna at (a) 2.4 GHz, (b) 3.5 GHz, and (c) 5.5 GHz.

FIGURE 7: Simulated and measured radiation patterns of the proposed antenna at (a) 2.4 GHz, (b) 3.5 GHz, and (c) 5.5 GHz.

FIGURE 8: Measured peak gain of the proposed antenna at operational frequency bands.

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