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TRIPLE-BAND SLOT ANTENNA WITH U-SHAPED OPEN STUB FED BY ASYMMETRIC COPLANAR STRIP FOR WLAN/WIMAX APPLICATIONS

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Abstract—A novel compact microstrip planar slot antenna with triple-band operations for WALN and WiMAX applications is proposed. The antenna, which occupies an overall dimension of $35 \times 19 \times 1.6\,\text{mm}^3$, has a simple structure which consists of an asymmetric coplanar strip with a reverse G-shaped slot and a U-shaped open stub. The U-shaped open stub excites a resonant mode at 2.4 GHz. On the other hand the asymmetric coplanar strip could excite the resonant modes at 5.2 GHz. Meanwhile, the reverse G-shaped slot is aimed to excite resonant modes at 3.5 and 5.8 GHz. It has good omnidirectional radiation patterns in the azimuth plane and reaches 1.1 dBi at 2.4 GHz, 2.3 dBi at 3.5 GHz, 3.1 dBi at the band of 5 GHz. The designed antenna is simulated by HFSS software and a good agreement with experimental results is demonstrated.

1. INTRODUCTION

Recently, wireless communications have been developed widely and rapidly, which leads to a great demand in designing low-profile, and multiband antennas for mobile terminals, especially the WLAN and WiMAX applications [1–27]. In order to meet the Wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) standards simultaneously, multiband antennas which are integrating these two communication standards into a single device are required with good performance. Many related researches have been done for both WLAN and WiMAX applications. Coplanar waveguide (CPW)-fed monopole antennas with various structures have been become popular candidate in dual- or triple-band operations

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to further reduce the antenna size. In these designs, dual or triple current patchs are provided by the different shaped strips to produce resonant frequencies at multi-bands, but disadvantages of frequency collision [11–14, 19], large size [2, 8–10, 17, 18, 20, 21], complicated fabrication structure [1, 7, 23, 24], not adequate low profile [4, 6, 16] or not very stable radiating pattern [3, 5, 15, 22] exist.

In this paper, we have proposed a novel compact triple-band monopole antenna for WLAN and WiMAX applications. The measured 10 dB bandwidth for return loss is from 2.38 to 2.5 GHz, 3.35 to 3.67 GHz and 4.76 to 6.55 GHz for WLAN and WiMAX applications. The designed antenna consists of an asymmetric coplanar strip with a reverse G-shaped slot and a U-shaped open stub, and a CPW feeding. First, we have designed a CPW-fed antenna operating in a frequency range of upper band of 5 GHz. Second, the reverse G-shaped slot is used to control the 3.5 GHz resonant mode response. Thrid, 2.4 GHz resonant mode is introduced by adding a U-shaped open stub. Parametric studies and radiation characteristics for the triple-band antenna are presented. The simulation was carried out by Ansoft high frequency structure simulator (HFSS). The details of the antenna design and experimental results are presented in the following sections.

2. ANTENNA DESIGN

Figure 1 exhibits the configuration of the proposed triple-band antenna. The overall dimension of the antenna are $35 \times 19\,\text{mm}^2$ ($L1 \times W1$). The proposed antenna is designed, optimized, and printed on the FR4 substrate of dielectric constant $\varepsilon_r = 4.4$ and substrate thickness $H = 1.6\,\text{mm}$. A 50-Ω microstrip line with a width of $W4$ and a gap distance between the signal strip and coplanar tappered ground plane is feeding the asymmetric coplanar strip at the lower edge. The antenna consists of an asymmetric coplanar strip with a reverse G-shaped slot and a U-shaped open stub. The U-shaped open stub has the lengths $L2 + L3 + L4$ which are nearly equal to one-half wavelength of the fundamental mode at 2.4 GHz for WALN application; on the other hand the reverse G-shaped slot AA' has the lengths nearly equal to one-half wavelength of the fundamenta resonance at 3.5 GHz for WiMAX application. The vertical strip has the length $L5$ which is about a quarter of wavelength in free space at 5.2 GHz. Another resonant mode at 6.4 GHz is given by the coupling in the reverse G-shaped slot. The band at 5 GHz can be increased by introducing the tappered structure around the reverse G-shaped slot.

The prototype of the proposed antenna has been fabricated, and

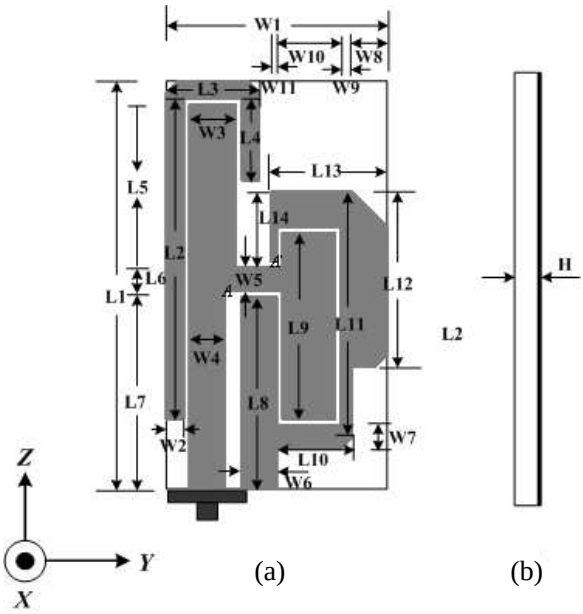

Figure 1. Geometry of the proposed antenna. (a) Top view, (b) side view.

its photo is shown in Figure 2. The antenna dimensions are optimized using the commercially available simulation software of HFSS 11.0. The optimal antenna parameters are set as follows: $L1 = 35\,\text{mm}$, $L2 = 27\,\text{mm}$, $L3 = 8\,\text{mm}$, $L4 = 7\,\text{mm}$, $L5 = 14\,\text{mm}$, $L6 = 2\,\text{mm}$, $L7 = 17\,\text{mm}$, $L8 = 16.5\,\text{mm}$, $L9 = 16\,\text{mm}$, $L10 = 6.5\,\text{mm}$, $L11 = 22\,\text{mm}$, $L12 = 15\,\text{mm}$, $L13 = 10\,\text{mm}$ $L13 = 6.5\,\text{mm}$, $W1 = 19\,\text{mm}$, $W2 = 1.5\,\text{mm}$, $W3 = 4\,\text{mm}$, $W4 = 3\,\text{mm}$, $W5 = 2\,\text{mm}$, $W6 = 3\,\text{mm}$, $W7 = 2\,\text{mm}$, $W8 = 3\,\text{mm}$, $W9 = 1\,\text{mm}$, $W10 = 5.5\,\text{mm}$, $W11 = 0.5\,\text{mm}$.

3. RESULTS AND DISCUSSION

Figure 3 shows the simulated and measured S_{11} against frequency for the proposed antenna. It was measured using a Vector Network Analyzer. It can be seen that the measured results reasonably agree with the simulated results with an acceptable frequency discrepancy. Slight discrepancies between the simulation and measurement results may be attributed to measurement errors, fabrication inaccuracies, and the ununiformity of the substrate permittivity. For $S_{11} < -10\,\text{dB}$, the measured impedance bandwidths are about 120 MHz (2.38–2.5 GHz), 320 MHz (3.35–3.67 GHz) and 1750 MHz (4.76–6.55 GHz), covering

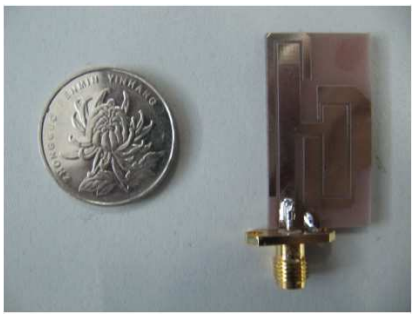

Figure 2. Photograph of the proposed antenna.

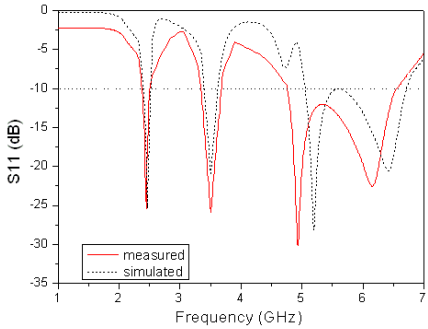

Figure 3. Simulated and measured S_{11} for the proposed antenna.

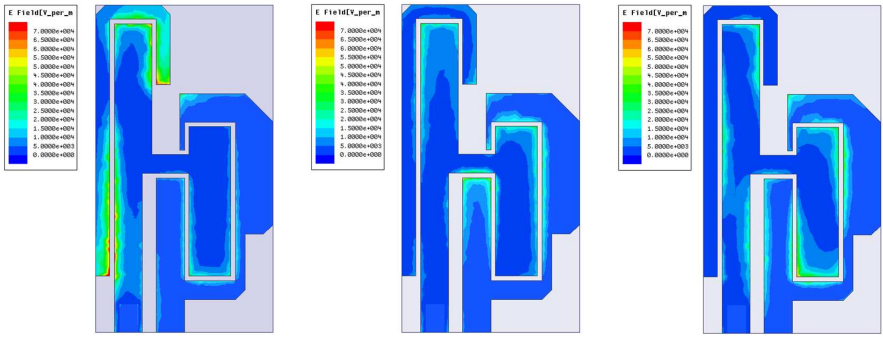

Figure 4. Simulated surface current distribution of the proposed antenna. (a) $f = 2.45$ GHz, (b) $f = 3.5$ GHz, (c) $f = 5.5$ GHz.

WLAN and WiMAX bands.

Figure 4 plots the simulated current distributions at different resonant frequencies (2.4, 3.5, 5.5-GHz) of the proposed antenna for better understanding the excitation behavior. It can be clearly seen that at different bands, the current has different distribution along the antenna. The current focuses on the U-shaped open stub at 2.4 GHz, which implies that it will affect the impedance matching condition at 2.4 GHz mode. Large surface current distributions are observed along the reverse G-shaped slot, which implies that it is major radiating element at the 3.5 GHz band. The current focuses on the reverse G-shaped slot and the vertical strip, which implies the 5 GHz band response is given by them.

Figure 5 shows simulated S_{11} for extra cases of antennas. Obviously, a primary resonant mode is excited at upper frequency of

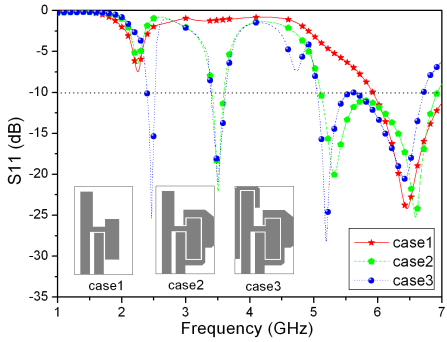

Figure 5. Simulated S_{11} for the proposed antenna in the different cases.

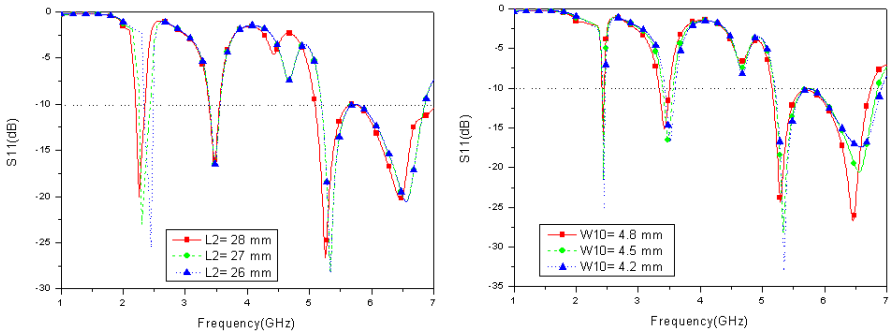

Figure 6. Simulated S_{11} variations for the proposed antenna of different lengths. (a) $L2$, (b) $W10$.

5 GHz band (case 1). By adding the reverse G-shaped slot, the antenna can excite another resonant mode at 3.5 GHz and also improve the impedance match characteristic at 5 GHz band (case 2). When adding the U-shaped open stub, 2.4 GHz resonant mode is introduced and enhanced; although it affects the other two resonant modes. Case 3 is the final design of the proposed antenna.

Two parameters having effects on the resonant mode are analyzed for further investigation on resonant frequency bands. Figure 6 shows simulated S_{11} for the proposed antenna with different parameter. As shown in Figure 6(a), 2.4 GHz resonant mode is shifted toward the lower frequency band when $L2$ increases and the other resonant modes are not affected. From Figure 6(b), 3.5 GHz resonant mode is shifted toward the lower frequency band when $W10$ increases.

The far-field radiation characteristics of the proposed antenna were studied through measurement. Figure 7 describes the measured

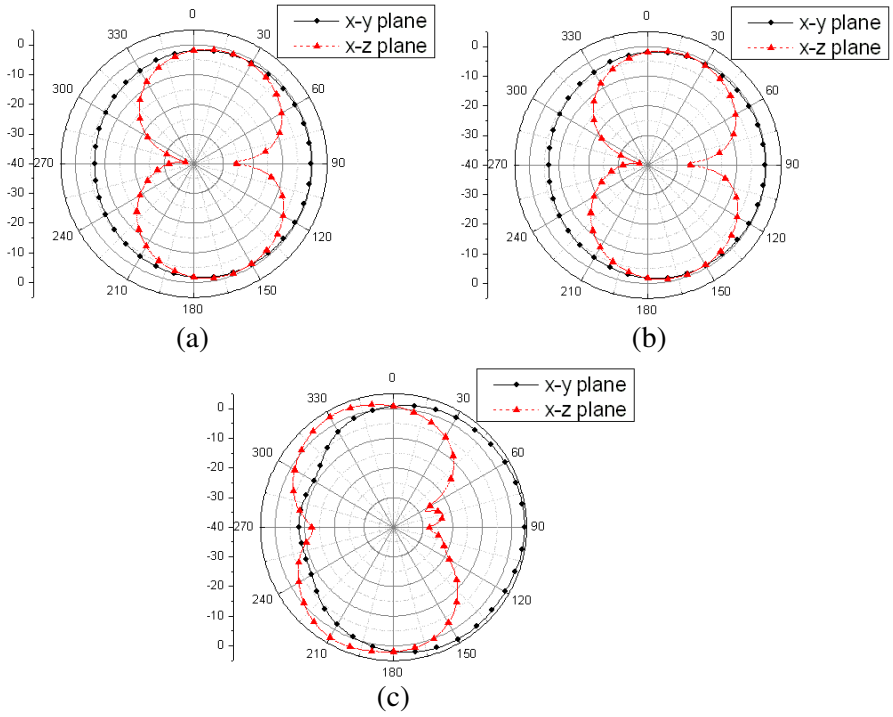

Figure 7. Measured radiation patterns for the proposed antenna. (a) $f = 2.45\,\text{GHz}$, (b) $f = 3.5\,\text{GHz}$, (c) $f = 5.5\,\text{GHz}$.

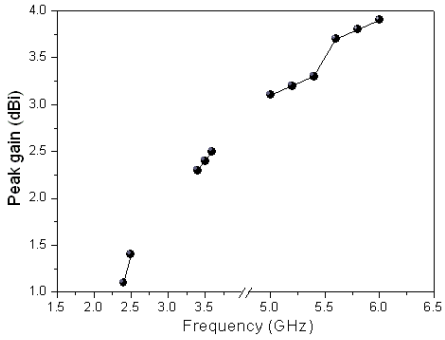

Figure 8. Peak antenna gains for the proposed antenna.

radiation patterns at 2.45, 3.5 and 5.5 GHz bands, respectively. The measured results show generally good omni directional radiation in the azimuth plane (the x-y plane) especially in the lower bands that is the 2.4/3.5 GHz bands and bidirectional radiation in the elevation plane (the x-z plane), which show a monopole-like radiation characteristics.

Stable radiation patterns have been obtained for the proposed antenna.

The peak antenna gains for frequencies through the matching bands for the proposed antenna are measured and shown in Figure 8. The obtained peak gain ranges are about 1.1–1.4 dBi for 2.4 GHz band, 2.3–2.5 dBi for the 3.5 GHz band and 3.1–3.9 dBi for 5 GHz band. For the 2.4 GHz band, the variations are less than 0.3 dBi, while for the 3.5 GHz and 5.5 GHz bands, the variations are less 0.2 dBi and 0.8 dBi, respectively.

4. CONCLUSIONS

A compact triple-band antenna fed by asymmetric coplanar strip for WLAN and WiMAX applications has been presented. In the design, by adding a U-shaped open stub and a reverse G-shaped slot, three resonant modes with good impedance performance are achieved. The measured results show that the antenna can cover 2.4 GHz (2.38–2.5 GHz), 3.5 GHz (3.35–3.67 GHz), and 5.5 GHz (4.76–6.55 GHz), respectively. Also the nearly omnidirectional radiation patterns in the azimuth plane are measured. The proposed antenna would be attractive for wireless communication systems.

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