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TRI-BAND SLOTTED F-SHAPED ANTENNA WITH DUAL-POLARIZATION CHARACTERISTICS FOR WLAN/WIMAX APPLICATIONS

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Abstract—A tri-band slotted F-shaped antenna with dual-polarization characteristics for wireless applications is presented. The crooked gap and F-shaped monopole are optimized to achieve tri-band operation of 2.4, 3.5 and 5.8 GHz with −10 dB impedance bandwidths of 20%, 14.1%, and 13.6%, respectively. Furthermore, by properly inserting an F-shaped strip on the wide-slot ground, the circular polarization (CP) with a 19% (3.3–4 GHz) 3 dB axial ratio bandwidth is obtained. The proposed antenna has a compact dimension of $42 \times 40 \times 1.6\,\text{mm}^3$. A prototype of the antenna is fabricated and tested, and an agreement with simulated results is obtained.

1. INTRODUCTION

With the rapid development of wireless communications the multi-frequency antenna has become one of the most important devices and attracted much interest. The wireless local area network (WLAN) system which supports the IEEE802.11b/g/a (2.4–2.484 GHz, 5.15–5.35 GHz and 5.725–5.825 GHz) standards and the worldwide interoperability for microwave access (WiMAX) system which supports the IEEE802.16e (2.5–2.69 GHz, 3.3–3.7 GHz and 5.15–5.85 GHz) standards are usually treated as the backbones of short range wireless communication system. They are now used on mobile phones and other handheld devices. Among the various types of antennas, circularly polarized antennas owing to their reducing polarization mismatch and multipath fading win a wide range of applications in the communication systems. As a good candidate, planar printed

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antennas [1–11] have the attractive features of small size, light weight, low profile and ease of fabrication. Some printed monopole antennas with multiple branches, such as F-shaped [1], G-shaped [2], double T-shaped [3], and C-shaped [4] ones, provide dual or triple current paths and resonate at different frequency points. The band-notched UWB printed antennas reported in [5], by appropriately inserting band-pass filter structure, suppressed the dispensable bands and separated multiple narrow frequency bands from broadband. Other hybrid antennas composed of a single monopole and parasitic elements are proposed in [6–8]. The parasitic elements introduce another resonant mode, and tri-band performance is realized. In [9], a probe-fed annular-ring patch by loading an unequal lateral cross-slot ground plane can produce dual-frequency CP characteristics. Another slot antenna [10], by using one cured monopole, one fork-shaped monopole and a crane-shaped strip placed in the ground plane, can achieve circular polarization characteristics. However, the antennas mentioned above can achieve either multi-band or circular polarization, not both of them. A few articles [11] propose tri-band antennas with circular polarization characteristics, but they are antennas large in size or complicated in structure.

Motivated by these issues, in this paper, a triple-band slotted F-shaped antenna with dual- polarization characteristics for wireless WLAN/WiMAX application is presented. With F-shaped structure and a crooked slot the antenna is able to generate three sufficiently wide bands (2.3–2.8 GHz, 3.3–3.8 GHz, and 5.12–5.87 GHz) which match the required bandwidth for both WLAN and WiMAX. But for 3 dB ARBW, it supports only the second band. Furthermore, F-shaped monopole structure and slot loaded make the antenna compact in size.

2. ANTENNA DESIGN

Figure 1 illustrates the geometry of the proposed tri-band slotted F-shape antenna with dual-polarization characteristics for WLAN/WiMAX applications. The antenna is printed on double sides of FR4 substrate with relative dielectric of 4.4 and thickness of 1.6 mm. The overall size of the antenna is as compact as $42 \times 40 \times 1.6\,\mathrm{mm}^3$. The proposed antenna has two different resonant paths (forming an F-shaped structure) and a crooked slot which support three resonances. The F-shaped structure provides two different resonant paths. One path is $L_{p1} = 16.5\,\mathrm{mm}$ ($L_{p1} = L_2 + L_3 + L_4 + W_4 + W_2 - W_3 - L_5 - L_6 - L_9$), and the other is $L_{p2} = 25.5\,\mathrm{mm}$ ($L_2 + L_3 + L_4 + W_2 - L_9$). The resonant path can be calculated by the following equations. The resonant path L_{p1} is $0.308\lambda_g$ at the resonant frequency of 5.6 GHz, and

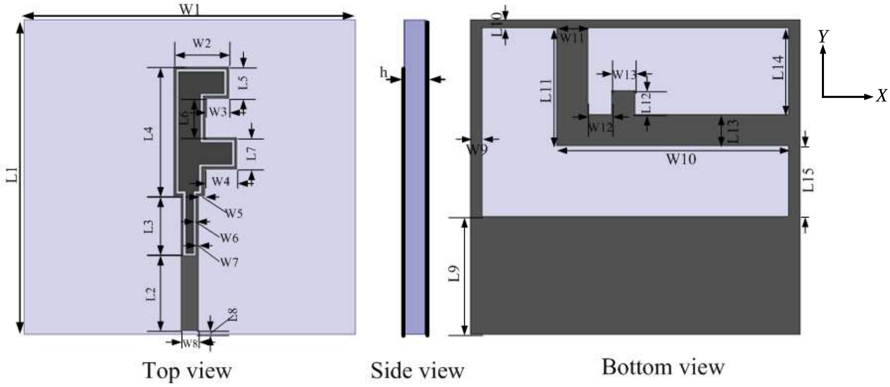


Figure 1. Geometry of the proposed tri-band CP antenna ($L_1 = 40$, $L_2 = 9.5$, $L_3 = 7.5$, $L_4 = 16.5$, $L_5 = 4$, $L_6 = 5$, $L_7 = 4$, $L_8 = 0.5$, $L_9 = 15$, $L_{10} = 1$, $L_{11} = 15$, $L_{12} = 3$, $L_{13} = 4$, $L_{14} = 11$, $L_{15} = 9$, $W_1 = 42$, $W_2 = 7$, $W_3 = 3$, $W_4 = 4$, $W_5 = 0.8$, $W_6 = 0.3$, $W_7 = 0.3$, $W_8 = 2.4$, $W_9 = 1.5$, $W_{10} = 29.5$, $W_{11} = 4$, $W_{12} = 3$, $W_{13} = 3$) (Unit: mm).

the L_{p2} is $0.221\lambda_g$ at the resonant frequency of 2.6 GHz.

$$L = \frac{\lambda_g}{4} \tag{1}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{2}$$

where L is the resonate path (L_{p1}, L_{p2}), λ_g the dielectric wavelength, λ_0 the air wavelength, and ε_{eff} the effective dielectric constant. The crooked gap around the F-shaped monopole couples the electromagnetic energy and reaches the third frequency of 3.5 GHz. By properly varying the lengths L_{p1}, L_{p2} and crooked gap width (W_6), the antenna can achieve three resonant modes over the frequency ranges of 2.3–2.8 GHz, 3.3–3.8 GHz and 5.12–5.87 GHz. The CP operation of the presented antenna is mainly attributed to the F-shape strips located on the wide-slot ground plane. The F-shaped monopole mainly produces vertical polarization, and the F-shape strip couples the energy that mainly excites a horizontal polarization, so that the CP is achieved.

An electromagnetic software package, HFSS 13.0 based on the Finite element method is used for required numerical analysis to examine the performance of the antenna.

3. RESULTS AND DISCUSSIONS

Based on the values of the proposed model, an antenna prototype is fabricated and measured (Figure 2). Through Figure 3 three improved designs of the proposed CP antenna is presented. The antenna design is started by applying a simple F-shaped monopole antenna which resonates at 2.4 and 5.8 GHz (Antenna 1). An improvement is achieved by inserting a crooked gap around the F-monopole to obtain a third resonant frequency at 3.5 GHz (Antenna 2). By properly adding a F-shaped stub on the wide-slot ground, the antenna can excite orthogonal radiations and realize circular polarization (Antenna 3). −10 dB impedance matching curves of the antenna (Antenna 1–3) are presented in Figure 4. 3 dB ARBW curves of the antenna (Antenna 1–3) are presented in Figure 5. The simulated results show that by introducing a crooked gap around the F-monopole and an F-shaped stub on the wide-slot ground and by adjusting the parameters, a tri-band and CP characteristic can be accomplished for the proposed antenna. The simulated and measured reflection coefficients (S_{11}) of the proposed antenna are illustrated in Figure 6. Reasonable agreements between the simulation and measurement results are attained. Some discrepancies between them may be attributed to the

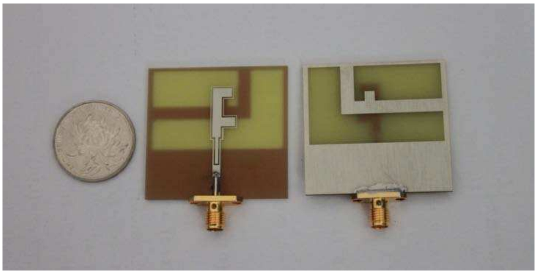


Figure 2. Photograph of the fabricated prototype.

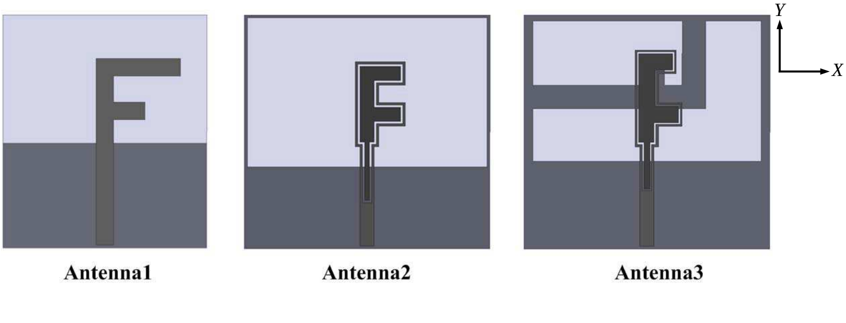


Figure 3. Three improved cases of the antenna.

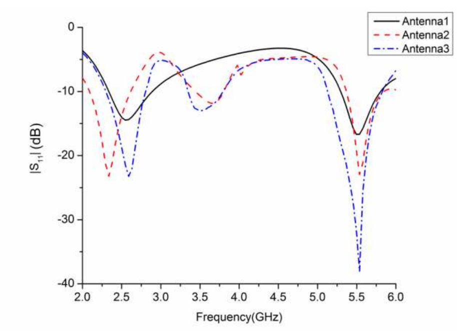


Figure 4. $|S_{11}|$ of the Antenna 1–3.

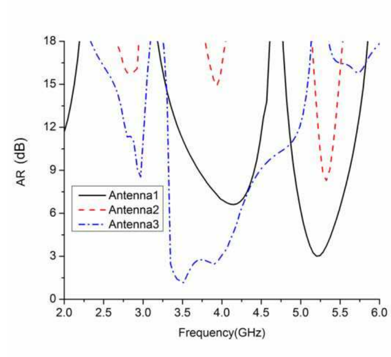


Figure 5. AR of the Antenna 1–3.

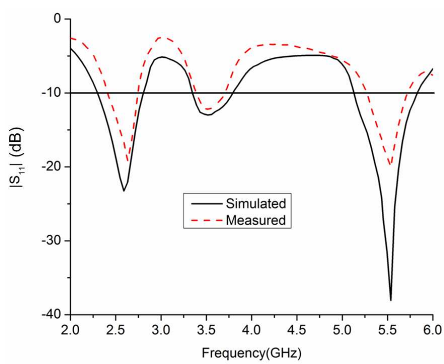


Figure 6. Simulated and measured $|S_{11}|$ variations of the proposed antenna.

machining accuracy of the crooked gap which is a sensitive parameter, measurement errors, relative dielectric change and the impact of the SMA connector.

For better understanding the CP characters of the proposed antenna, the simulated surface current distributions viewed from the F-shaped stub are illustrated in Figure 7. The direction of the surface current on the monopole and slotted ground is at 3.5 GHz as the phase changes from 0° through 270° degrees. The surface currents of the main frequency points within the operating bandwidth from two orthogonal line currents due to the guidance of the F-shaped monopole and the two orthogonal line currents will generate two orthogonal radiations. Additionally, as there will be large phase lag when current flows through long monopole, combined with the F-shaped strip on the wide-slot ground, the current phase of the horizontal direction should lag behind that of the vertical direction. There will be right hand circular polarization (RHCP) in far field. Now, the vital parameters are analyzed for further investigation on resonant frequency and AR

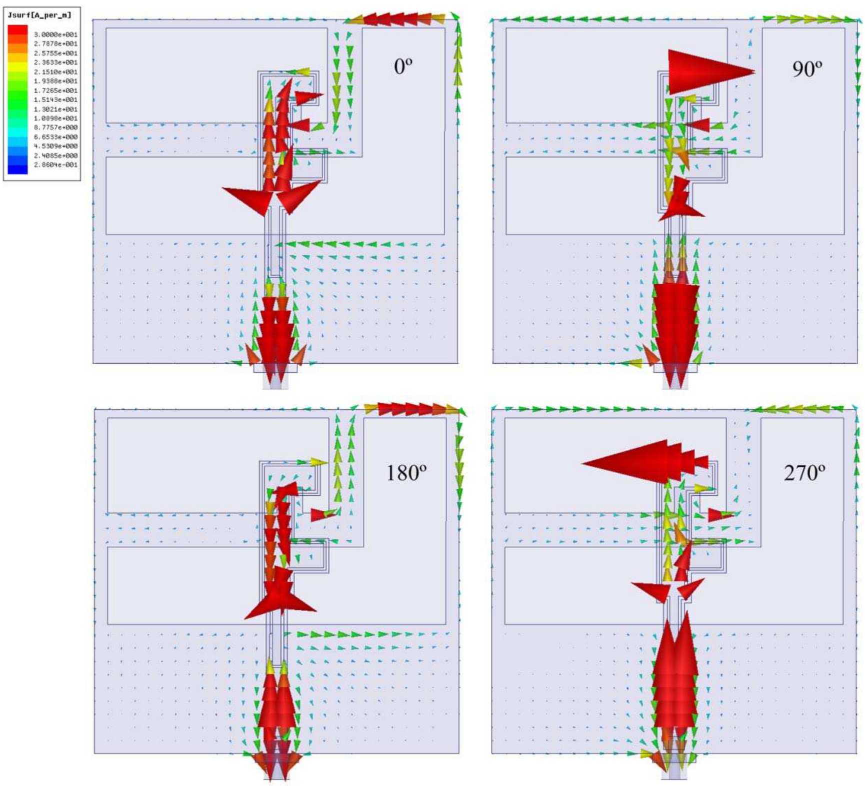


Figure 7. Distribution of the surface current on the feed and ground of the proposed antenna at 3.5 GHz in 0°, 90°, 180°, and 270° phase.

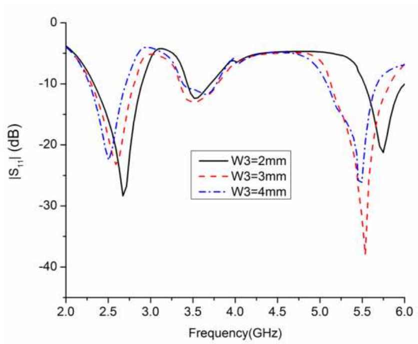


Figure 8. $|S_{11}|$ for different iterations of W_3.

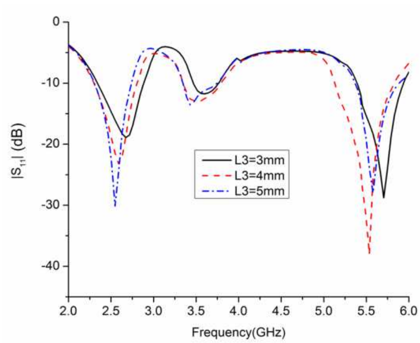


Figure 9. $|S_{11}|$ for different iterations of L_3.

bands. Simulated $|S_{11}|$ curves for different values of W_3, W_4, W_6 and L_3 are shown in Figures 8–12. With the length and width W_3, L_3, W_4 decreased, their corresponding lower, medium and upper resonant

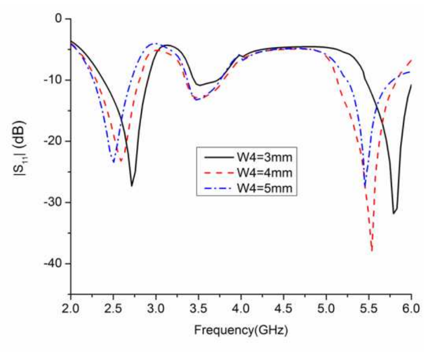


Figure 10. $|S_{11}|$ for different iterations of W_4.

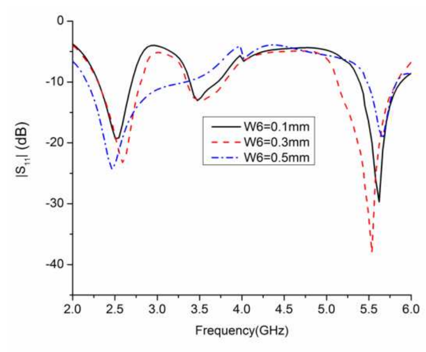


Figure 11. $|S_{11}|$ for different iterations of W_6.

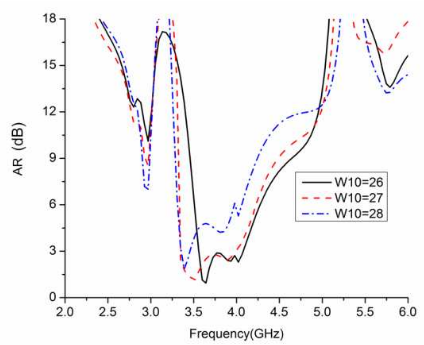


Figure 12. AR for different iterations of W_{10}.

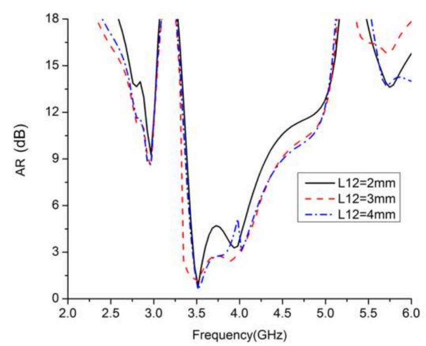
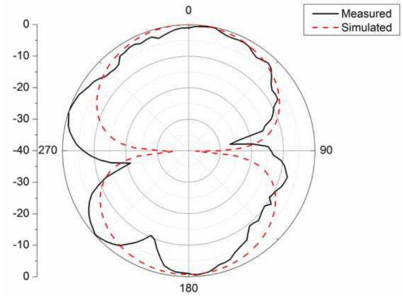
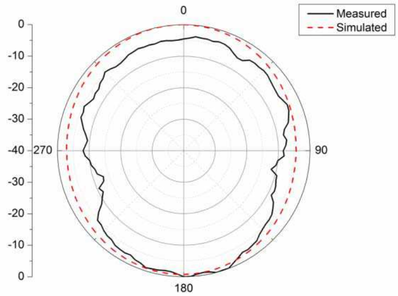


Figure 13. AR for different iterations of L_{12}.



(a) *E*-plane



(b) *H*-plane

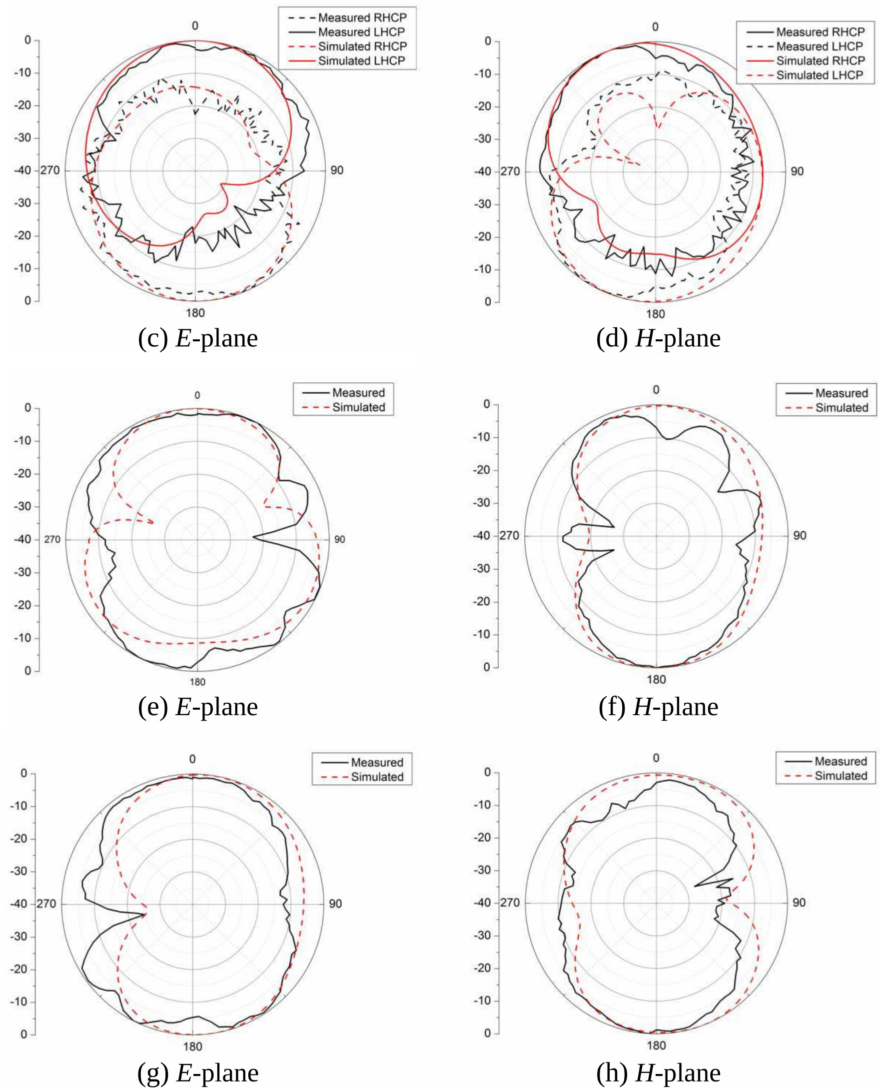


Figure 14. The E- and H-plane radiation pattern of the proposed tri-band antenna at (a)–(b) 2.4 GHz, (c)–(d) 3.5 GHz, (e)–(f) 5.2 GHz, (g)–(h) 5.8 GHz.

frequencies shift. The gap width W_6 determines the coupling strength between the gap and the monopole. So it has an impact on both of the frequency and bandwidth within the three resonant points. The CP characteristic mainly attributes to the F-shaped stub on the wide-slot ground plane. By tuning L_{12} and W_{10}, we can make an agreement between 3 dB ARBW and impedance bandwidth in Figure 13.

The measured and simulated radiation patterns in the E (yz) and H (xz) planes at 2.4, 3.5, 5.2 and 5.8 GHz are shown in Figures 14(a)–(h). Measured RHCP and LHCP radiation patterns and directivity of the antenna at typical frequency of 3.5 GHz are shown in (c), (d). From an overall view of these radiation patterns, the antenna behaves quite similarly to the typical printed monopoles at the frequency of 2.4, 5.2 and 5.8 GHz. And at 3.5 GHz, it is seen that the antenna radiates an LHCP wave in the upper-half space.

The gain of the proposed antenna for frequencies across the triple operating bands is stable and acceptable, as illustrated in Figure 15. For the working band, the peak gain is about 2.35 dBi. So the gain of the proposed antenna within the operating bands satisfies the requirement of many wireless communication terminals.

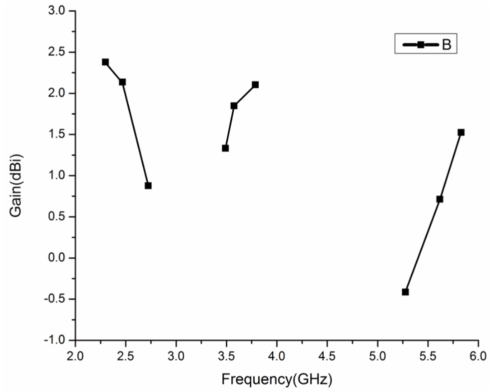


Figure 15. Measured gain versus frequency.

4. CONCLUSION

A triple-band slotted F-shaped antenna with dual-polarization characteristics is presented and investigated. With the design of an F-shaped monopole and a crooked gap, the antenna generates three sufficiently wide bands (2.3–2.8 GHz, 3.3–3.8 GHz, and 5.12–5.87 GHz). In addition, by properly inserting an F-shaped stub on the wide-slot ground plane, the antenna can reach a relatively wide 3 dB ARBW as large as 19% (3.3–4 GHz) and can be completely enclosed by the corresponding impedance bandwidth. Furthermore, the antenna has a compact dimension of $42 \times 40\,\text{mm}^2$. Consequently, the proposed slot antenna design could be promising and suitable for WLAN and WiMAX applications.

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