Compact Multiband Planar Antenna for 2.4/3.5/5.2/5.8 GHz Wireless Applications

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***Abstract*— A low-profile planar monopole antenna is proposed to operate within WLAN and WiMax frequency bands. The antenna is composed three radiating elements together with an additional strip to control the antenna performance. An electromagnetic (EM) model of the proposed antenna is developed in CST Microwave Studio for numerical analysis and optimization. The principle of operation and parametric study on the antenna performance are provided. Two dual-band and triple-band antennas are fabricated and experimental results are presented.**

***Index Terms*— Compact antenna, multiband antennas, wireless local area network (WLAN), worldwide interoperability for Microwave Access (WiMAX).**

I. Introduction

RECENTLY wireless local area networks (WLAN) and the worldwide-interoperability-for-microwave-access (WiMAX) technology have been extensively used in commercial, medical and industrial applications. The allocated spectrum for these WLAN systems is centered at 2.4, 5.2 and 5.8 GHz and for WiMAX at 3.5 GHz. There are many reported antenna designs for wireless systems, but the most are single-band or dual-band [1]-[5]. One simple way to cover all frequency bands is using wideband antennas. However, in order to avoid interfering with nearby communication systems, we need to design an antenna that can operate only at the desired frequency bands. There are a few designs to operate over all four wireless frequency bands [6]-[8]. In most cases the antenna size is large and the geometry of the antenna is complicated. In some cases, although the antenna is compact, it shows a quite high level of cross polarization [8].

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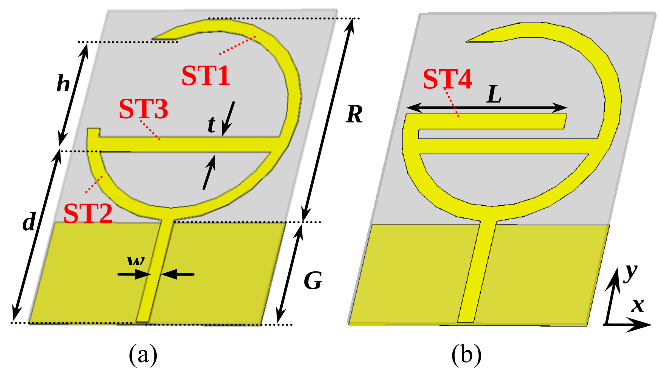


Fig. 1. Proposed multiband antenna : (a) dual-band, (b) triple-band design.

The size and weight of the antenna are important for the antenna to be practical. A small-size, simple multi-band antenna covering all four wireless frequency bands is desirable. Moreover, it is demanding to be able to control the antenna bandwidth over different frequency bands independently.

Recently, we introduced a compact multiband antenna and the antenna performance was studied numerically [9]. The antenna operates at the wireless frequencies of 2.4, 3.5, 5.2 and 5.8 GHz. The antenna is composed of a short and a long circular radiating element to cover the 2.4 GHz and the 5.2 and 5.8 GHz bands. An additional strip is used as an interconnection between the two circular elements to control the 5.2 and 5.8 GHz performance. An extra radiating element is then added to allow the antenna to cover WiMAX band at 3.5 GHz, as well as WLAN bands. The antenna bandwidth can be also independently adjusted at different resonant frequencies by just tuning different parts of the antenna.

In this letter, two antennas, dual- and triple-band designs, are realized and the performance of the antenna such as impedance bandwidth, radiation pattern (both co- and cross polarizations), and gain are experimentally addressed. Moreover, since the antenna will be integrated in a microwave device, the housing effect is also investigated by locating the antenna in the vicinity of a metallic sheet. The organization of this letter is as follows. In Section II, the antenna structure and the detailed principle of operation are addressed. The experimental results of the fabricated profiles are presented in Section III. Finally, Section IV contains conclusions.

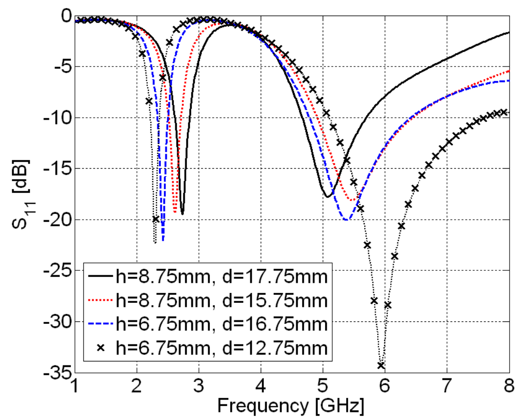
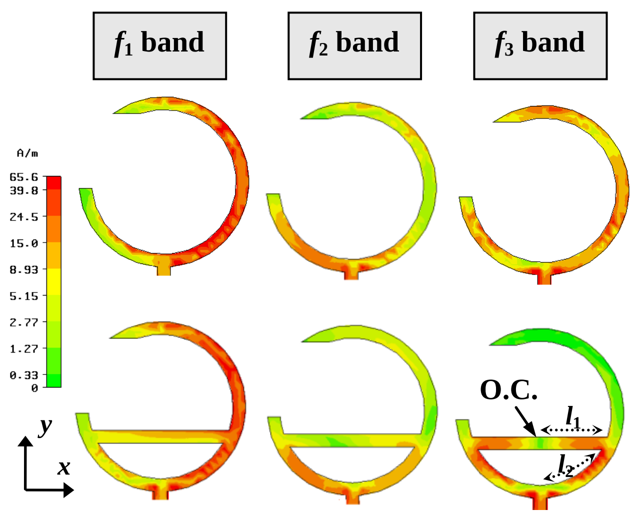
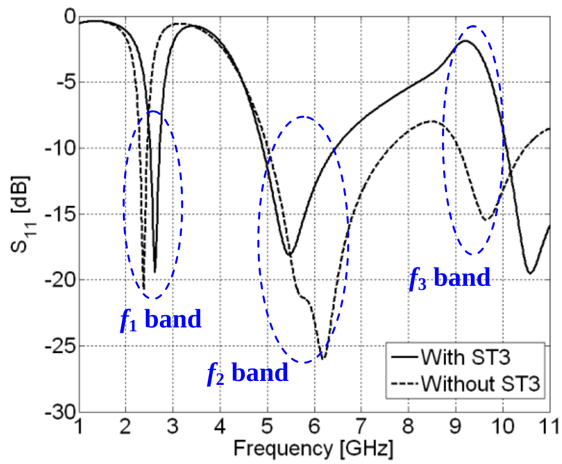


Fig. 2. S_{11} of the dual-band antenna for R = 20 mm, t = 1.5 mm, G = 8 mm and w = 1.5 mm



(a)



(b)

Fig. 3. (a) Surface current distribution at three frequency bands, (b) S_{11} of the antenna with and without ST3 strips.

II. Antenna Geometry and Principle of Operation

Fig. 1 shows the geometry of the proposed multiband antenna. The antenna is printed on 0.508 mm-thick Rogers RT Duroid 3003 (ε_r =3, tanδ = 0.0013) substrate with the size of 22×29 mm^2. The radiating element of dual-band design is composed of three strips, the long strip (ST1), the short strip

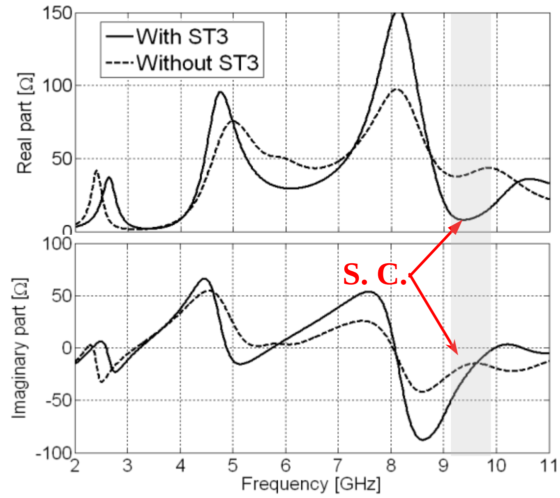
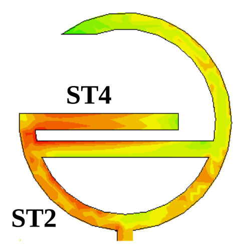
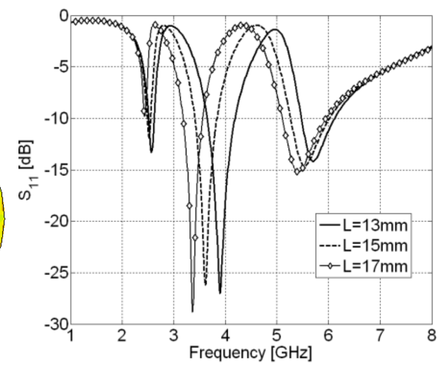


Fig. 4. Input impedance of the antenna with/without ST3 strip.



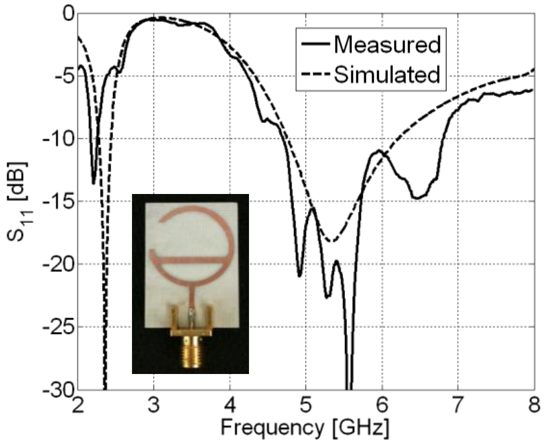
(a)



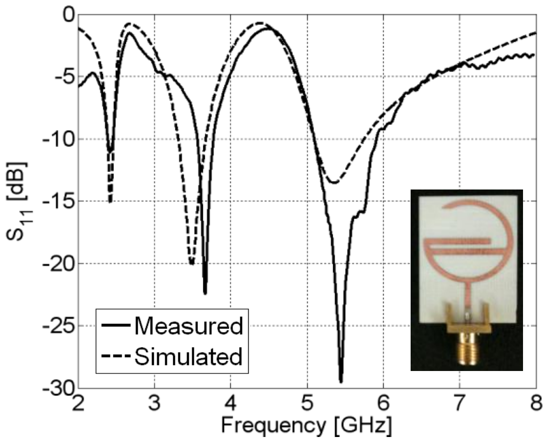
(b)

Fig. 5. (a) Current distribution at the second resonate frequency, (b) S_{11} parameter of the triple-band antenna.

(ST2), and the interconnecting strip (ST3) between the ST1 and the ST2 strips. The computed reflection coefficient of the antenna using CST MWS software [10] is shown in Fig 2. The lower and upper resonant frequencies can be adjusted by changing the length of ST1 and ST3, respectively. It is observed that the antenna covers the 2.4 GHz band and the 5.2 and 5.8 GHz bands and the resonant frequency and bandwidth are adjustable by changing the parameters h and d. For example, by choosing R = 20 mm, t = 1.5 mm, G = 8 mm, w = 1.5 mm, h = 8.75 mm and d = 15.75 mm, the antenna has a satisfactory S_{11} from 2.4 to 2.6 GHz and from 5.0 to 6.3 GHz. Modifying the surface current distribution on ST1 and ST2, the strip ST3 is used to adjust the antenna bandwidth over the 5.2 and 5.8 GHz range. The effect of strip ST3 is explained by evaluating the antenna surface current distribution at the resonant frequency as displayed in Fig. 3 (a). The S_{11} of the antenna with and without ST3 strip is shown in Fig. 3 (b). It is observed that the antenna operates over f_1 and f_2 frequency bands with or without using ST3 strip. Without using ST3 strip, the bandwidth in the "f_2" band is widened, and a new "f_3" pass band, not used in the current application, is introduced between 9 and 10 GHz. Fig. 3(a) shows that the "f_3" band is due to the higher order mode of ST1 strip so that by introducing ST3 strip, the current on ST1 is shorted out and



(a)



(b)

Fig. 6. Fabricated antennas along with the associated S_{11} parameter, (a) dual-band (b) triple-band antenna.

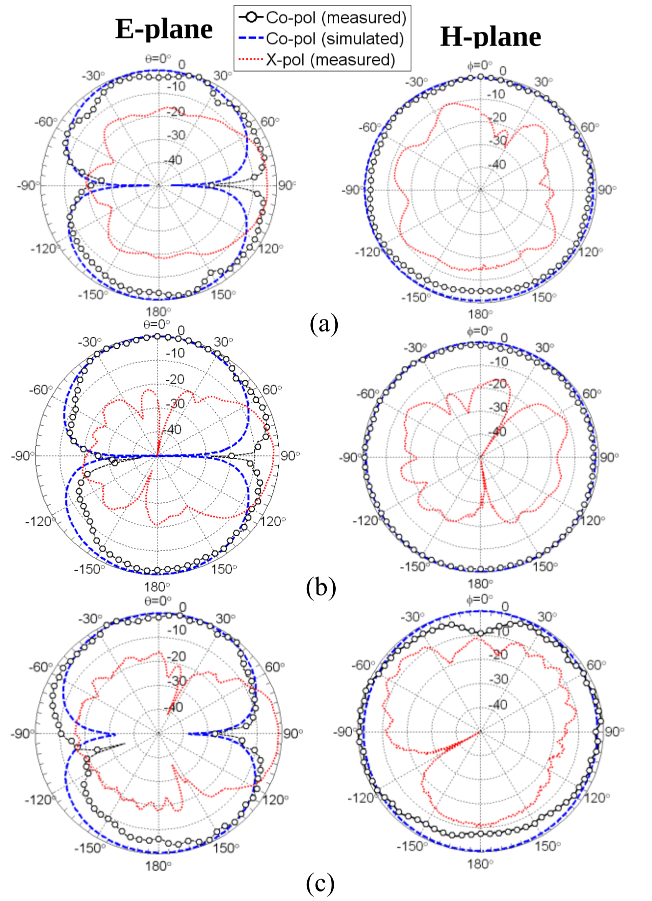


Fig. 7. The normalized radiation pattern of the triple-band design at: (a) 2.4 GHz, (b) 3.6GHz, and (c) 5.4 GHz.

the antenna does not radiate over f_3 band. It is observed that at f_3 band, the current mainly flows in ST3 with very weak magnitude at the middle point of ST3 strip, which could be also considered as an open circuit (O.C.) point. The combination of l_1 and l_2 transmission lines, $l_1 + l_2 = 17$ mm, acts as a $3\lambda_{eff} / 4$ open circuit stub, which leads to a short circuit (S.C.) impedance behavior at the input port of the antenna at about 9.37 GHz ($\lambda_{eff} = 22.6$ mm). Fig. 4 shows the input impedance of the antenna, both real and imaginary parts. As expected, the impedance is low over f_3 frequency band, leading to such stop band behavior at f_3 band as displayed in Fig. 3(b). Therefore, the antenna bandwidth can be controlled over f_2 frequency band using ST3 strip with different lengths. Note that the ST3 strip slightly shifts the resonant frequency of the antenna over f_1 band; however, it could be easily compensated by tuning the length of ST1 strip.

By adding an extra radiating element to the antenna geometry, strip ST4 in Fig. 1(b), the 3.5 GHz WiMAX frequency band can be covered by the proposed antenna, as well as WLAN frequencies. Fig. 5(a) shows the surface current distribution at the resonant frequency of 3.6 GHz. It is observed that the combination of strips ST2 and ST4 is a half-wave resonator at 3.6 GHz. The reflection coefficient of the antenna is displayed in Fig. 5(b). The resonant frequency in the WiMAX band can be adjusted by changing the length of ST4.

III. Experimental Results

Two dual-band and triple-band antenna prototypes were fabricated on 0.508mm-thick Rogers RT Duroid 4003 (ε_r =3.38, tanδ = 0.0027) substrate. The substrate size is 22×29 mm^2. Using HP8720 network analyzer, the S_{11} parameter of the antennas is measured as shown in Fig. 6. The discrepancy between simulation and measurements could be due to the effect of connector and manufacturing tolerance. Moreover, since the antenna prototype is small, the coupling between the connector and various parts of the antenna may slightly affect the performance.

The radiation pattern of the proposed antenna at resonant frequencies is measured in anechoic chamber. Fig. 7 shows the normalized radiation pattern of the triple-band design at three resonant frequencies of 2.4, 3.6, and 5.4 GHz. Showing the almost low level of cross polarization, the antenna has a dipole shape radiation pattern at the E-plane and omnidirectional radiation pattern at the H-plane. A quite high cross polarization in the direction of $\theta = 90^{\circ}$ at E-plane is observed, which is due to the contribution of the x-components of the surface current on the antenna [4, 8]. It should be noted that good polarization purity is not normally required for handheld

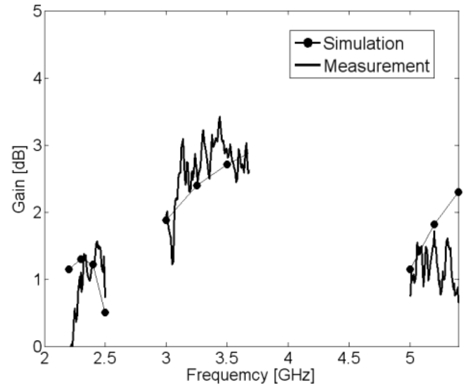


Fig. 8. The realized gain of the triple-band antenna.

devices. The antenna peak gain is also measured over the frequency bands of interest as shown in Fig. 8.

Usually the antenna is integrated in a circuit which includes various components and modules. In mobile and vehicular applications, the antenna could be used in proximity to a variety of materials, such as metal objects or the human body. When the antenna radiates in the vicinity of an object, the backscattered fields produced by the object induce electric current on the antenna, affecting the antenna performance. Therefore, the "housing effect" of such nearby devices on the antenna performance is a critical factor [11]. In [9], the simulation results showed that the orientation of the antenna to a nearby object is critical in maintaining the performance of the antenna. Here, we consider the worst case scenario of housing effect setup so that the antenna is located in the front of the metallic sheet, as shown in Fig. 9(a). A 10 cm × 10 cm copper sheet is placed closely in the front of the antenna with a separation distance of Δ. The reflection coefficient of dual- and triple-band antennas is measured for different separation distances. Figs. 9(b) and (c) show the results for Δ = 3 and 10 mm, respectively. It is observed that even for the small values of Δ, the antennas still operate over 5-6 GHz frequency band. However, the lower bands are affected. The first resonant frequency of both antennas is downshifted to around 2 GHz. At the second resonant frequency of the triple-band design, a slight downshift is observed for Δ = 3 mm and the impedance matching gets worse. We found that for Δ < 2 mm the antenna performance over all frequency bands significantly deteriorates which is due to the adverse effect of the antenna image.

IV. Conclusion

A compact multiband antenna has been proposed to cover the WiMax and WLAN frequency bands centered at 2.4, 3.5, 5.2 and 5.8 GHz. It has been observed that the resonant frequencies of the antenna can be easily adjusted. The impedance bandwidth in the 5.2 to 5.8 GHz range is effectively controlled by using a strip to short out the surface current. The resonant frequencies over 2.4 and 3.5 GHz bands can be easily adjusted by tuning the related strips. The antenna shows a donut-shaped radiation pattern in the E-pane and an omnidirectional radiation pattern in the H-plane for both lower and upper WLAN frequency bands. The housing effect of

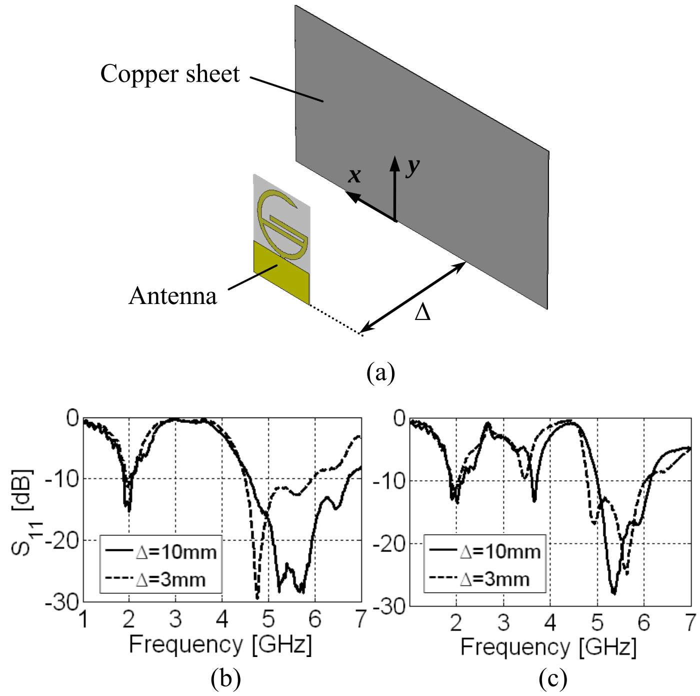


Fig. 9. (a) Housing effect setup, and measured S_{11} of the antennas (b) double-band antenna, (c) triple-band antennas in the vicinity of the metallic sheet.

devices in the vicinity of antenna has also been investigated, and it has been observed that locating the antenna to a nearby metallic objects is critical, affecting the performance of the antenna over lower frequency bands.

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