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REVIEW

Multislot microstrip antenna for ultra-wide band applications

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Abstract In this paper designs of both planar ultra-wide band (UWB) antenna and UWB antenna with two rejected bands are given. The antenna consists of a rectangular patch etched on FR4-substrate with 50 Ω feed line. The rectangular patch has one round cut at each corner with one slot in the ground plane. The simulated bandwidth with return loss (RL) ⩾ 10 dB is 3.42–11.7 GHz. The rejected bands are the WLAN and X-bands, achieved by inserting slots in the patch and the feed. The simulated results of the proposed antenna indicate higher gain at the passbands while a sharp drop at the rejected bands is seen. The radiation pattern is of dipole shape in the E-plane and almost omnidirectional in the H-plane. The high frequency structure simulator (HFSS) is used to design and simulate the antennas behavior over the different frequency ranges. Measurements confirm the antenna characteristic as predicted in the simulation with a slight shift in frequencies.

Contents

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1. Introduction

The rapid growth in wireless communication systems created huge demands for wide band antennas to satisfy high gain and large bandwidth covering all frequency ranges for these systems. In 2002, FCC approved the UWB technology in the frequency range of 3.1–10.6 GHz with maximum radiated power −41.3 dBm/MHz and data rate between 110–200 Mbps within 10 m distance (FCC, 2002). The advantages of the UWB technology are high data rate, less interference, secure, low cost and low complexity. It is used in different applications such as radar, imaging in medicine and military communication. UWB patch antennas could be designed with different geometries; i.e. triangular, circular disk, strip loop and square (Lin et al., 2005; Jin-Xiang et al., 2010; Sameena et al., 2009; Mohammed and Mohammed, 2011). Several methods are used to enhance its bandwidth (BW) by using parasitic structures and other different arrangements (Ojaroudi et al., 2011; Chen et al., 2011; Rahayu et al., 2010).

Recently, researches focus on designing UWB antenna with band rejection characteristics to eliminate any interference from narrowband wireless applications. This is achieved by adding slots with different shapes in the patch, feed and ground plane (Choi et al., 2005; Eshtiaghi et al., 2010; Ali et al., 2012; Li et al., 2011; Ahmed and Abdel-Razik, 2009), or using defected ground structures (DGS) (Soltani et al., 2011) or by inserting quarter wavelength open ended slits (Yoon et al., 2005). In this paper the UWB antenna is presented in Section 2 and the UWB antenna capable of rejecting two bands is given in Section 3. Measurement results for these antennas are given in Section 4. Finally the paper is concluded in Section 5 with acknowledgement and references respectively.

2. UWB rectangular patch antenna design

The proposed rectangular microstrip patch antenna, shown in Fig. 1(a) and (b), is built on FR4 substrate with $\varepsilon_r = 4.4$ and $\tan\delta = 0.02$. The antenna dimensions (in mm) are: the substrate has $W_{sub} = 30$, $L_{sub} = 35$ and $h = 1.6$, the rectangular patch has width $W = 15$ and length $L = 14.5$, the microstrip feed line has $W_f = 2.85$ and $L_f = 13.5$, the partial ground plane has width $W_g = 30$ and length $L_g = 12.5$.

To improve the antenna BW and matching, round steps are added to the lower and upper corners of the patch besides adding the ground slot. Cutting steps at the bottom of the radiator increases the distance between the patch and the ground plane, which tunes the capacitive coupling between them (Mohammadirad et al., 2010), cutting steps in the upper corners of the patch tunes the inductive part of the antenna that neutralizes the capacitive coupling between the ground and the patch to get pure resistive input impedance (Yu and Chunhua, 2009), while the ground slot neutralizes the capacitive effects through the inductive nature of the patch to get nearly pure resistive input impedance (Liu et al., 2011). The simulated RL results show better impedance matching and wider BW when adding one lower round step rather than two, a small enhancement in the impedance matching when adding one upper round step compared to that without upper steps over the whole frequency range, while adding ground slots improve the impedance matching at the higher frequency band more than the lower band.

The simulated RL which is equal to –S11 (scattering parameter), shown in Fig. 2, for the proposed antenna shown in Fig. 1(c), shows that with RL $\geqslant$ 10 dB the antenna has BW 3.42–11.7 GHz with minimum RL of 17 dB. The best dimensions (in mm) for the proposed antenna are

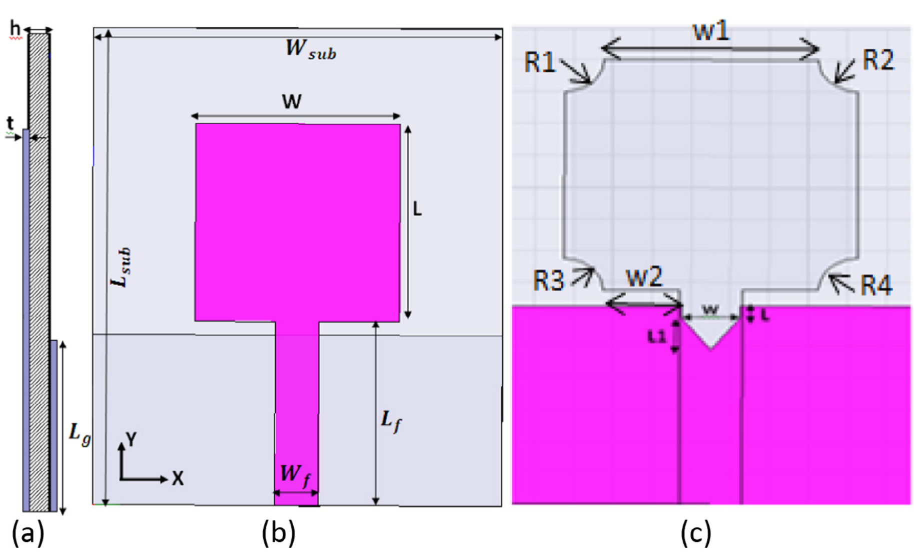

Figure 1 The proposed antenna: (a) side view, (b) without modifications, (c) final design.

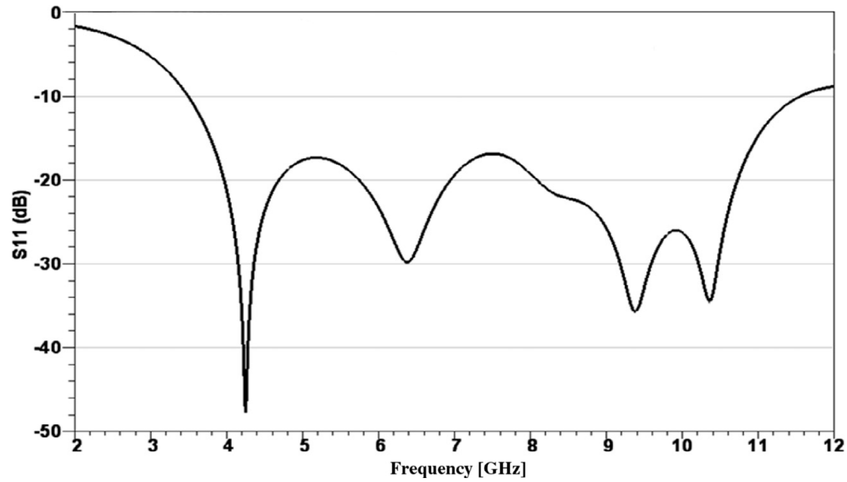

Figure 2 The simulated S11 for the proposed antenna shown in Fig. 1 (c).

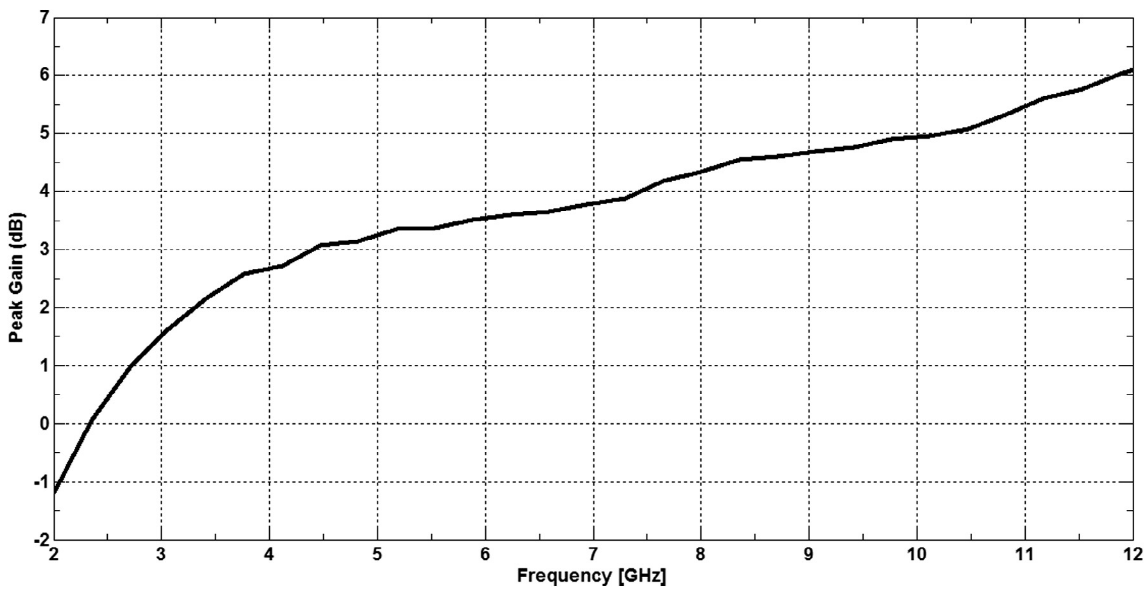

Figure 3 The Simulated peak gain of the proposed antenna.

$R1 = R2 = R3 = R4 = 2$, $w1 = 11$ and $w2 = 6.075$. The suggested ground slot combines the square and triangle slot shapes with $w = 3$, $L = 0.75$ and $L1 = 1$.

The simulated peak gain, presented in Fig. 3, indicates an increase in the gain with increasing frequency reaching 6 dBi at 11.7 GHz. The radiation patterns for the proposed antenna are presented in Fig. 4, where the E and H planes are the yz plane ($\varphi = 90^{o}$ and $0° < \theta < 180°$) and the xz ($\varphi = 0°$ and $0° < \theta < 180°$) respectively, at different frequencies: 5, 6 and 7.8 GHz. Radiation patterns in the E-plane are about the same as that of a dipole antenna, the number of lobes rises with the increase in frequency due to the existence of higher order modes. The radiation patterns in the H-plane are nearly omni-directional at lower frequencies.

Comparing the proposed antenna with other works, the proposed design has one round step at each corner of the patch while the antenna in (Mohammadirad et al., 2010) has six rectangular steps and a wide rectangular ground slot. The proposed antenna has higher BW than that in (Mohammadirad et al., 2010; Dargar et al., 2013; Kasi et al., 2011). The proposed design has the lowest RL in dB compared to (Dargar et al., 2013; Vuong et al., 2007).

3. Band rejection using slots

Two rejected bands are achieved, the WLAN and X bands, by introducing slots in the antenna patch and the feed line.

3.1. Rejection of the WLAN frequency band

Four slot shapes (M, inverted-U, inverted-E and H) which are symmetrical around the vertical central axis are inserted in the patch to reject the WLAN (5.15–5.825 GHz) band. The slot length is half a wavelength at the central frequency with the effective dielectric constant $\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}$ (Gupta et al., 1996;

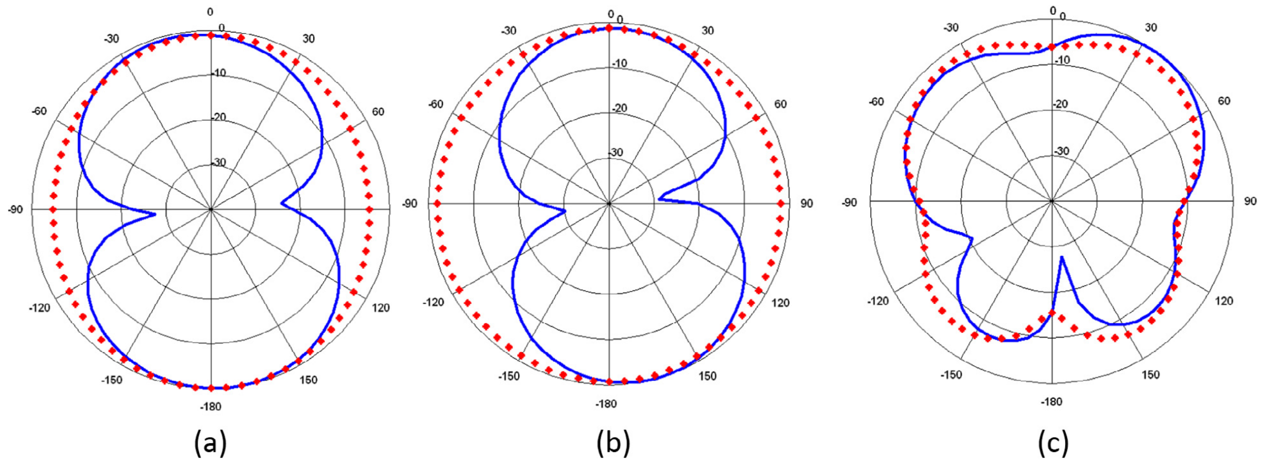

Figure 4 The Simulated radiation pattern, _____ E-plane and - - - - H-plane, for the proposed antenna; (a) f = 5 GHz, (b) f = 6 GHz, (c) f = 7.8 GHz.

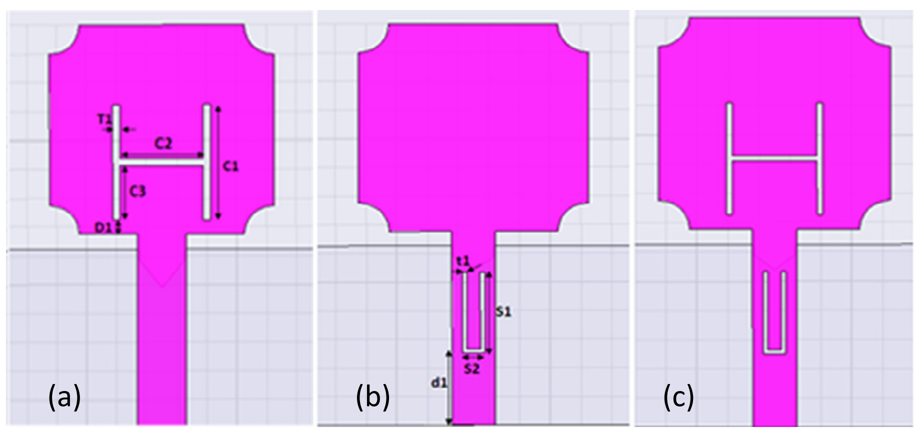

Figure 5 (a) H-slot in the patch, (b) U-slot in the feed line and (c) Multi-slot H–U proposed antennas.

Kumar and Ray, 2002). To study the effect of the slot parameters on the RL, parametric study was performed on the H-shape slot components $T1$, $C1$ and $C2$ shown in Fig. 5(a). Low values of $T1$ cause a narrow rejection bandwidth and high RL values at the center frequency of the rejected band, while high values of $C1$ and $C2$ cause a decrease in the center frequency of the rejected band with lower RL values. The best slot dimensions (in mm) which are used to reject the 5–6 GHz band are given by $C1 = 7.77$, $C2 = 5.7$, $C3 = 3.8$, $D1 = 1$ and $T1 = 0.37$.

3.2. Rejection of the X-band frequency range

To reject the X-band downlink 7.25–7.75 GHz and uplink 7.9–8.4 GHz frequency ranges, slots are inserted in the microstrip feed line. Two slot shapes U and J are proposed as shown in Fig.5(b). Parametric study is done for the U-shape slot parameters, and it was found that varying them will affect mainly the location of the central frequency of the rejected band. The optimized values of the slot parameters (in mm) are $S1 = 5.63$, $S2 = 1.45$, $t1 = 0.31$ and $d1 = 5$.

3.3. Rejection of both WLAN and X bands

After investigating various slot shapes, in the patch and the feed line, and observing their performance with regard to the UWB antenna requirements, we combine the two slot types in the proposed antenna to form an antenna which rejects two bands as shown in Fig. 5(c). The simulated RL results for the H–U multi-slots antennas show that the rejection bands are narrow enough to reject the desired interferences from the WLAN and the X-band frequency ranges. RL curves for the proposed antennas without slots, with U-slot in feed only, with H-slot in the patch only and with multi-slots (H–U) are shown in Fig. 6.

The simulated peak gain for the H–U multi-slot antenna is shown in Fig. 7, where it varies between 2.2–5.6 dBi in the pass band frequency ranges. A significant reduction in gain occurred at the two central frequencies of the rejected bands.

The radiation patterns for the H–U multi-slots antenna are presented in Fig. 8, where the E and H planes are the yz plane ($\varphi = 90°$ and $0° < \theta < 180°$) and the xz ($\varphi = 0°$ and $0° < \theta < 180°$) respectively at 4.1 GHz, 6.5 GHz and 9.5 GHz. Radiation patterns in the E-plane are about the same

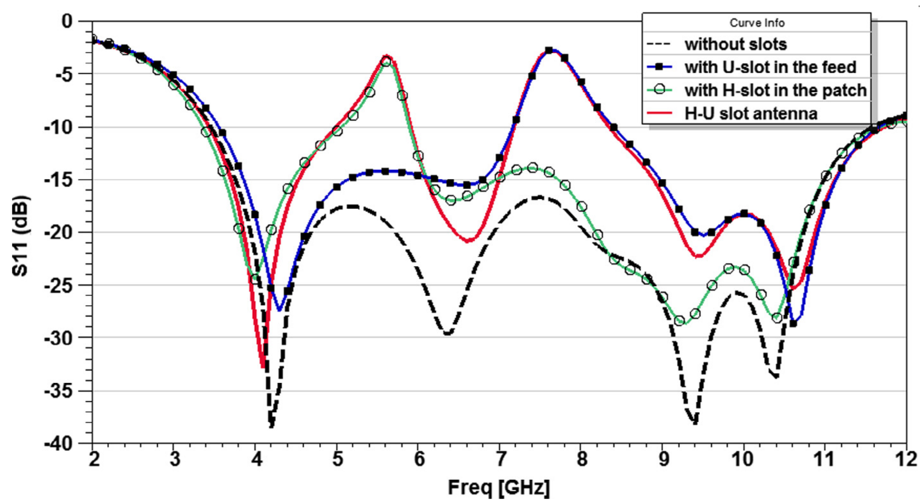

Figure 6 The simulated S11 curves for the antenna without slots, with U-slot in feed only, with H-slot in the patch only and with multi-slots H–U.

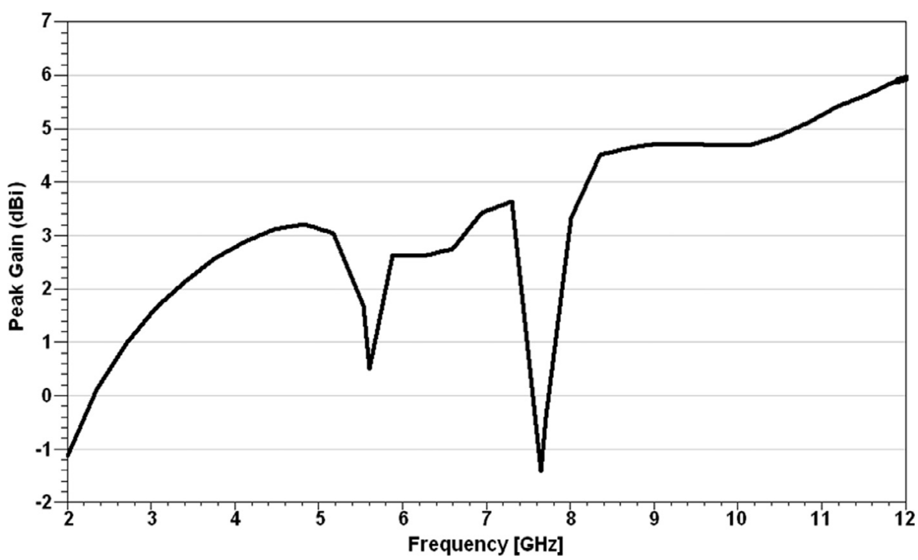

Figure 7 The Simulated peak gain of H–U multi-slot antenna.

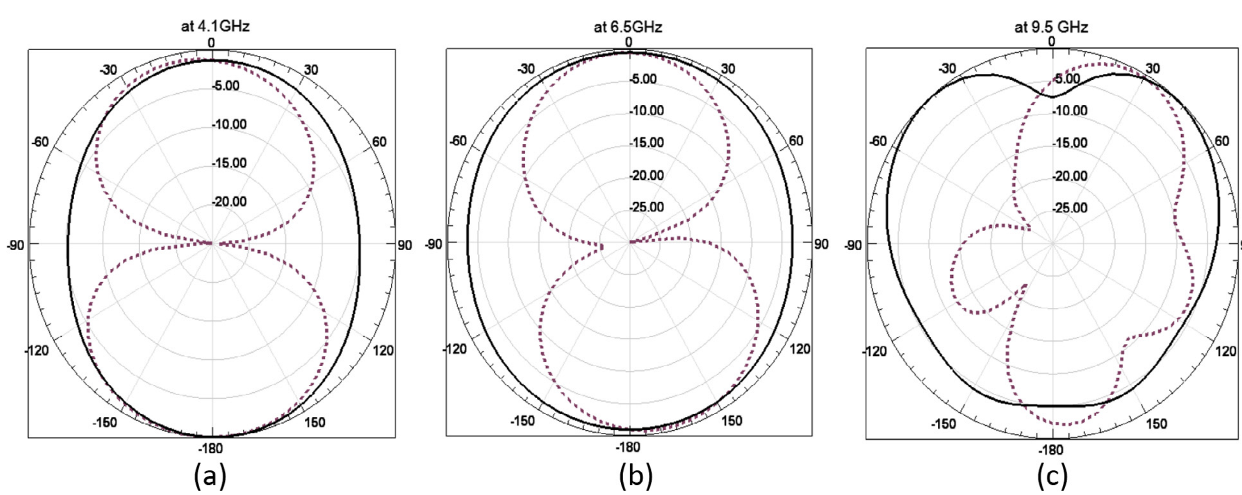

Figure 8 Simulated radiation pattern, - - - - E-plane and _____ H-plane for the H–U multi-slots antenna; (a) f = 4.1 GHz, (b) f = 6.5 GHz and (c) f = 9.5 GHz.

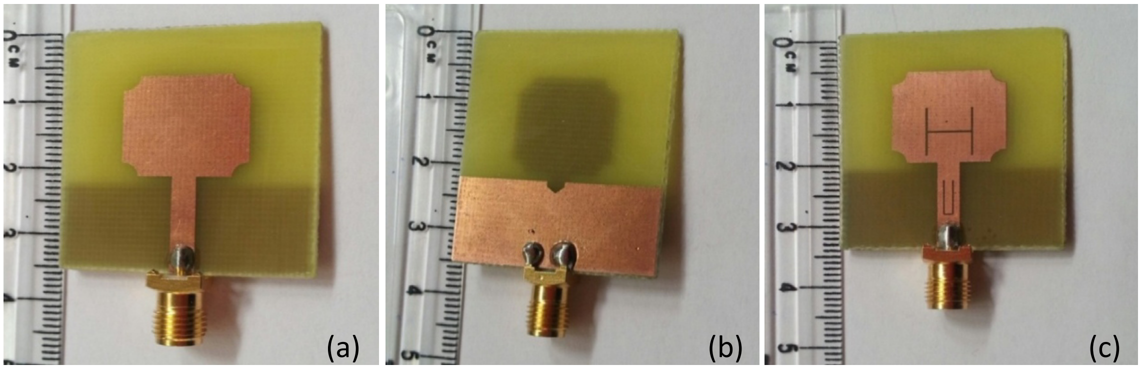

Figure 9 Prototype of the proposed antenna, (a) without slots (b) multi-slot antenna and (c) bottom view.

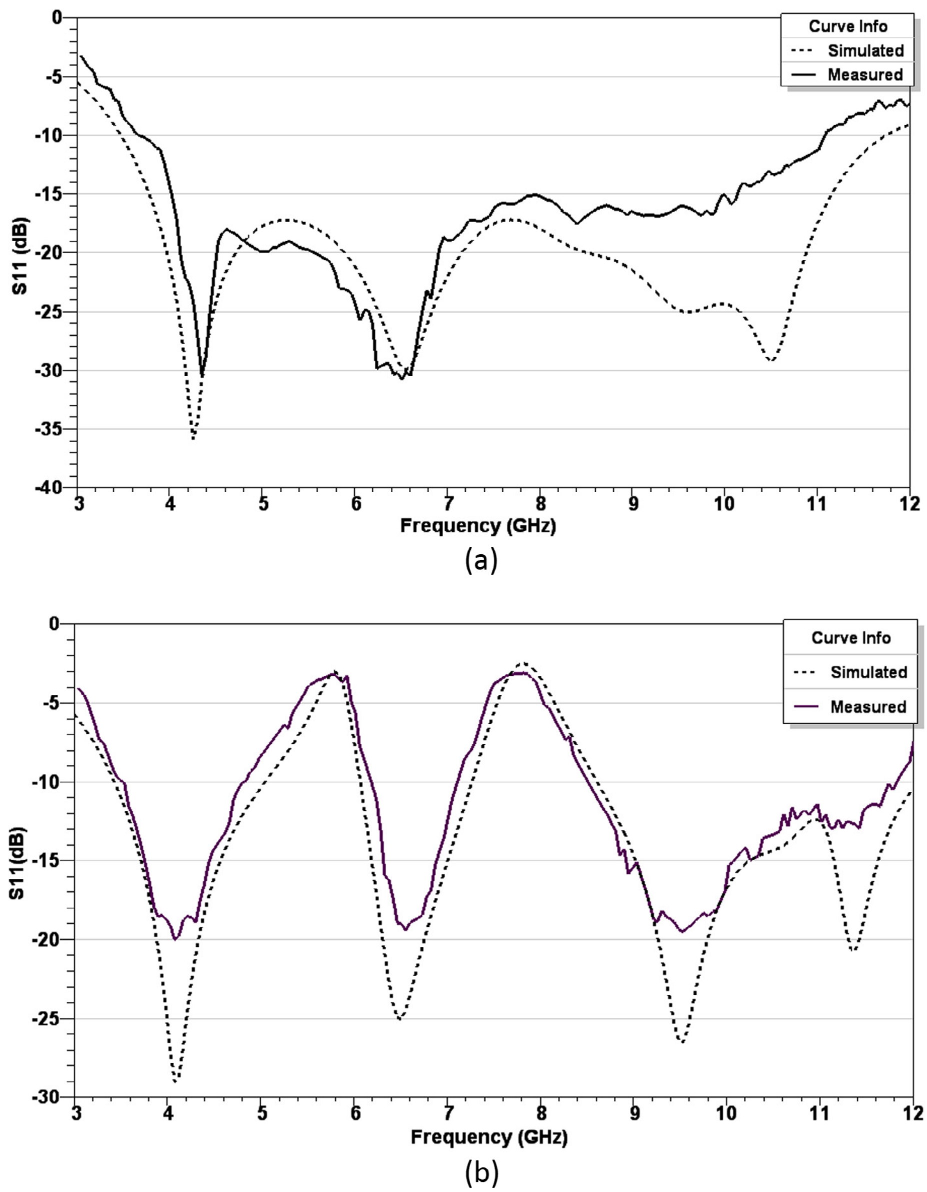

Figure 10 Simulated and measured S11 for the proposed antennas: (a) without slots (b) with H–U slots.

as that of a dipole antenna, while in the H-plane are nearly omni-directional at lower frequencies.

Comparison between the proposed multi-slot antennas in this research to reject WLAN 5.15–5.825 GHz and other reported designs shows that the proposed antennas have a narrow rejection band for the WLAN band. The antennas in (Vuong et al., 2007; Gupta et al., 1996; Kumar and Ray, 2002; Liu et al., 2008) reject part of the WLAN band, while the antennas in (Lu et al., 2008; Hu et al., 2010; Panda and Kshetrimayum, 2011; Zhu et al., 2011) have wider rejection bands compared to our proposed design. The value of the VSWR at the rejection band is between 4.5 and 5.6, while its value for the antenna proposed by (Xu et al., 2012a) is 4.5. The proposed antennas reject the uplink and downlink X-band frequency ranges with a simple design while in (Xu et al., 2012b) a complicated design with five slots is used to reject five sub-bands including WLAN and X-bands.

4. Experimental verifications

The proposed antennas were built on FR4 substrate whose dielectric constant $\varepsilon_r = 4.4$ and thickness $h = 1.5$ mm as shown in Fig. 9. This antenna is tested at the antenna measurement laboratory at King Abdullah Design and Development Bureau (KADDB). The RL and VSWR are measured by using Agilent N5242A network analyzer with SAC-26G-0.5 using 50 Ω cables. The measured and simulated RL curves for the proposed antennas (without slots and with multi-slot H–U) are plotted in Fig. 10. Measurements confirm the UWB characteristic as predicted in the simulation with a slight shift in the lower and upper edge frequencies. The discrepancy between the measured and the simulated results is mostly attributed to the tolerance in fabrication and welding the SMA connector, which are not taken into account through simulation. Besides the dielectric loss tangent of the FR4 substrate is kept constant during simulation, where actually it is a function of frequency.

5. Conclusion

Planar compact multi-slot UWB antennas are designed to satisfy the requirements of the UWB systems and minimize the interferences from WLAN and X-band applications. The UWB antenna consists of simple rectangular patch antenna with 50 Ω microstrip feed line. Investigations have been carried to cut steps in the four corners of the rectangular patch and to add slots in the ground plane. The covered BW at RL $\geqslant$ 10 dB is 3.42–11.7 GHz with good impedance matching. Slots are inserted in the patch and in the feed line to create rejection bands at WLAN and X-band frequency ranges respectively. Almost omnidirectional radiation pattern in the H-plane and dipole shape in the E-plane is achieved with acceptable gain in the pass band frequency ranges. A sharp drop in both gains at the notch frequencies is achieved. The measurement results agree well with the simulation results with a slight shift in the lower and upper edge frequencies.

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