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An Ultra-Wideband Twin-Patch Monopole Antenna with Band-Rejection Characteristic

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Abstract—To suppress electromagnetic interference at 5.5-GHz WLAN (5.15–5.825 GHz) band operation, a novel ultra-wideband (UWB) design of a slotted twin-patch monopole antenna with a band-rejection characteristic is presented. The proposed antenna with a simple structure has a large impedance bandwidth, defined by 10-dB return loss, covering the range from 2.95 to 10.85 GHz, and a tunable cutoff band from 5.18 to 6 GHz for band-operation suppression. Measured monopole-like radiation pattern and in-band average gain of about 2.3 dBi have also been obtained, simultaneously, with good agreement to the simulated results.

1. INTRODUCTION

Recently, interest of the ultra-wideband (UWB) communication technology has rapidly increased due to their many advantages including low-spectral-density radiated power, low cost and complexity, and potential for accommodating higher data rate. The UWB system has been allocated to the frequency band of 3.1–10.6 GHz. However, within this band, the 5.15–5.825 GHz frequency band is used by IEEE 802.11a wireless LAN (5.5-GHz WLAN) system and, thus, any electromagnetic interference caused from the use of 5.5-GHz WLAN system should be avoided to ensure the UWB transmitter performance. So far, several UWB antennas with the rejected band of 5.15–5.825 GHz have been reported, which applied different techniques including use of the parasitic element [1], shaped slotted-patch [2–6], resonator element [7, 8], defected ground structure [9–11], and distorted patch or strip [12–15]. However, most of them are not only with a complex or larger structure but also with a difficult fabrication process resulting from achieving the band-rejection function by inserting slot or additional control element into the antenna.

In this paper, a novel design of a printed twin-patch monopole antenna with a band-rejection characteristic is proposed for UWB communication. Compared to lots of reported designs with similar band-rejection function, the proposed design with not only an overall size of only $18 \times 23 \times 1.6\,\mathrm{mm}^3$ but also a stable radiation characteristic is practically compact and applicable. The parameters which affect the band-rejection characteristics of the antenna were investigated both theoretically and experimentally. It has been demonstrated that the optimal design of this type antenna can yield a very large bandwidth with a tuneable cutoff frequency band by properly assembling the structure and adjusting dimensions of the proposed slotted twin-patch monopole.

2. DESCRIPTION OF THE ANTENNA DESIGN

Figure 1 shows the geometry of the proposed printed UWB slotted twin-patch monopole antenna. The detailed dimensions of the proposed antenna were presented in Table 1. It is fabricated on an FR4 epoxy substrate with thickness 1.6 mm and relative permittivity 4.4. The top and bottom conductors

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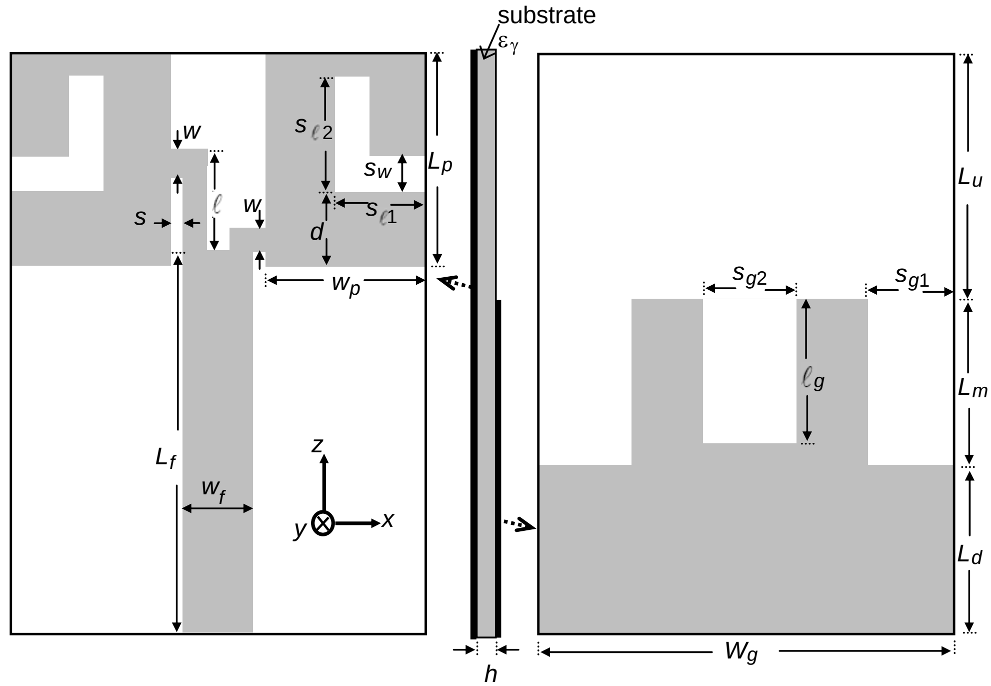

Figure 1. Geometry of proposed band-rejection UWB antenna.

Table 1. Detailed dimensions of the proposed antenna.

parameters	w_f	L_f	w	ℓ	s	w_p	L_p	$s_{\ell 1}$	$s_{\ell 2}$	d
value (mm)	3	15	1	4	0.5	7	8.5	4	4.5	3
parameters	s_w	W_g	L_u	L_m	L_d	s_{g1}	s_{g2}	ℓ_g	ε_γ	h
value (mm)	1.5	18	10	6.5	6.5	4	4	5.5	4.4	1.6

distributed on the substrate are the radiating structure and ground plane, respectively. Initially, the radiating structure has twin patches and each with dimensions of width 7 mm and length 8.5 mm, while the ground plane has a size of 18 mm in width and 13 mm in height. The twin patches are respectively connected to the feeding line with a width 3 mm and length 15 mm by an inverted-L shaped strip with fixed width of 1 mm. Here, the vertical sections of the two shaped strips have different lengths of 4 and 1 mm to thus resemble the antenna in an asymmetrical structure and therefore, effectively increase the operation bandwidth, while length of the horizontal section for both strips is 1.5 mm. As for the ground plane, it was defected by inserting three rectangle notches from its upper edge at the middle and the two side locations. The size for the middle and each of the two side notches are $4 \times 5.5\,\text{mm}^2$ and $4 \times 6.5\,\text{mm}^2$, respectively. Here, defection on the ground was found an effective way to significantly improve matching condition and thus largely increase the bandwidth.

Meanwhile, as each of the twin patches was inserted with an equal-size L-shaped slot at the location of 3 mm away from bottom of the patch, the band-rejection function can be realized. The size for such a slot was optimally obtained as 4 and 4.5 mm in its horizontal and vertical sections, respectively, and 1.5 mm for its width, s_w. These geometric dimensions were optimally obtained via iterative simulation with the aid of the commercially available simulator, HFSS. The simulated frequency response of impedance match for the proposed optimal prototype, as depicted in Table 1, was shown in case (iv) of Figure 2. Obviously, according to the multi-resonance excited at 3.42, 4.8, 6.2 and 8.2 GHz, the proposed slotted twin-patch antenna provides a sufficiently wide impedance bandwidth (10-dB return loss) of 8 GHz (3.07–11.07 GHz) for requirement of the entire UWB operation and has a frequency notch of 720 MHz (5.14–5.86 GHz) for band rejection of the 5.5-GHz WLAN frequency band.

For examining the effects of notching the ground, asymmetrically feeding the radiating patches, and inserting slots to the patches, the evolution process of impedance match for the proposed antenna is also shown in Figure 2. For the antenna denoted as case (i), it is the initial prototype and excites a resonant mode at around 4.8 GHz. The produced impedance bandwidth for this prototype is 1.4 GHz across the operating band from 4 to 5.4 GHz. As the ground is defected with three rectangle notches (i.e., case (ii)), the matching condition is found to be not only much improved but also shifted toward a higher

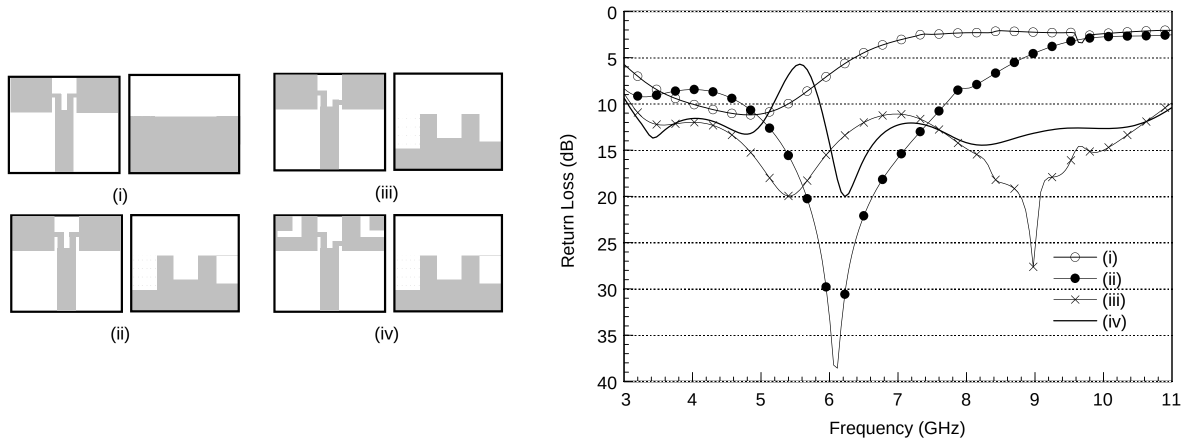

Figure 2. Simulated return loss against frequency of the proposed antenna with different structures.

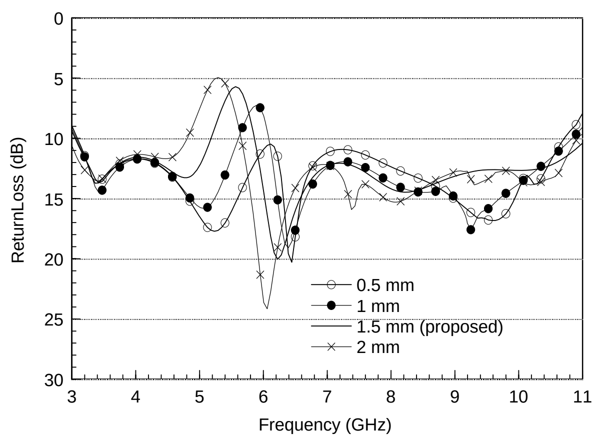

Figure 3. Simulated return loss against frequency of the proposed antenna with $s_w = 0.5$, 1, 1.5 and 2 mm.

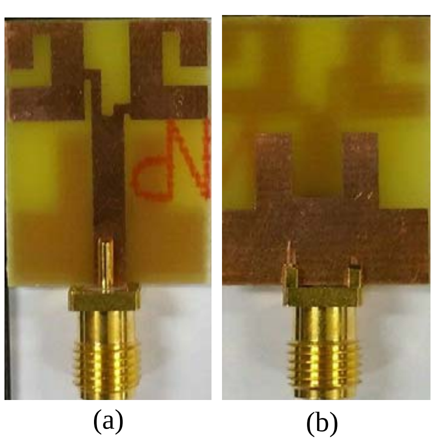

Figure 4. Photo of the fabricated antenna: (a) top face; (b) bottom face.

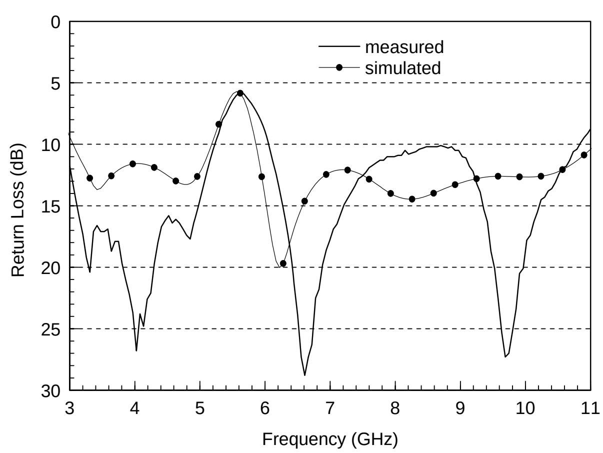

Figure 5. Measured and simulated return loss against frequency for the proposed band-rejection UWB antenna.

frequency at about 6.1 GHz, accompanied with a much wider bandwidth of about 3 GHz (4.7∼7.7 GHz). Thereafter, the two stripes used for connecting the twin patch radiators to the feeding line were adjusted with difference in length as that shown in case (iii). The radiator becomes asymmetrical, and triple

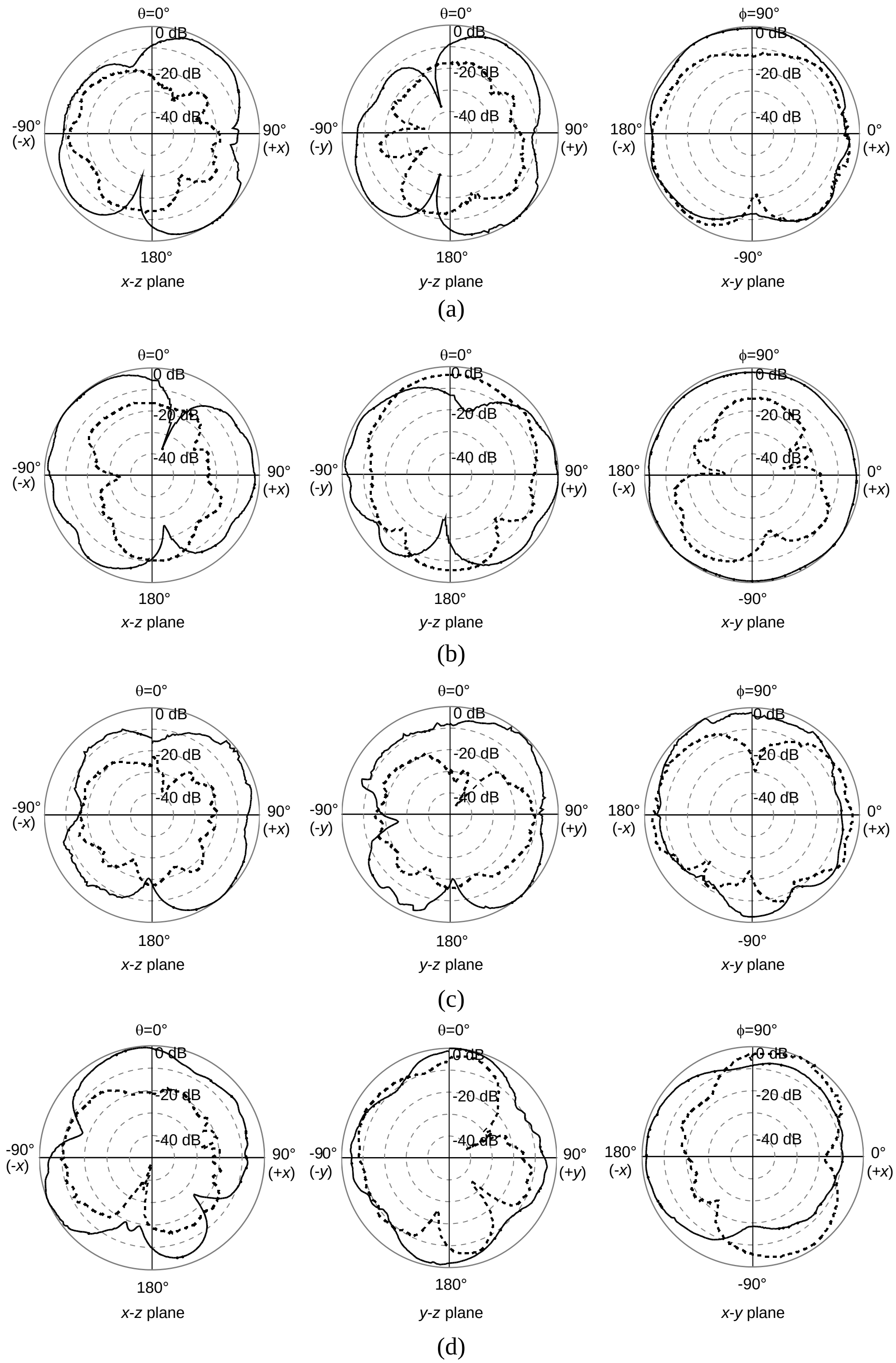

Figure 6. Measured radiation patterns for the proposed antenna at (a) 4 GHz, (b) 5.5 GHz, (c) 6.8 GHz, and (d) 9 GHz. (E_θ: —; E_ϕ: - - -).

resonant modes at 3.6, 5.4, and 9 GHz were excited. Thus the bandwidth of the designed antenna was immensely increased to reach as large as 7.9 GHz (3.1–11 GHz), which sufficiently covers the requirement of UWB operation. Finally, each of the twin patch radiators was further inserted with an L-shaped slot as that shown in case (iv). It is clearly seen that with such a slot the patch radiator does effectively provide a band-rejection function for this UWB antenna prototype. The mechanism of achieving such a band-rejection function can be attributed to the collapse of the resonant mode initially excited at 5.4 GHz band when inserting the slots into the patch. Addition of the embedded slots practically affects the path of surface current flow and thus results in a mismatching condition across the 5.4 GHz band.

The case for the inserted L-shaped slots with different widths, s_w, was also analyzed and shown in Figure 3. Obviously, the notch frequency can be adjusted by changing the width of the L-shaped slots. The wider the slot width is, the lower the center frequency of the notched band is. For that the 5.5-GHz WLAN band is desired to reject, and the case of $s_w = 1.5$ mm is therefore selected as the optimal value.

3. EXPERIMENTAL RESULTS AND DISCUSSION

To validate the performance of the proposed antenna, a prototype, as shown in Figure 4, is fabricated and tested. Figure 5 presents the measured return loss against frequency for the proposed antenna with optimal structure as that shown in Figure 1. For comparison, the simulated result is also included in this plot. The obtained experimental bandwidth is from 2.95 to 10.85 GHz with a notch band of 820 MHz, ranging from 5.18 to 6 GHz. Clearly, the measurement agrees well with the simulation except a slight frequency shift, which is mainly caused by the use of SMA connector. The normalized far-field radiation patterns from measurement for the proposed band-rejection UWB antenna in two orthogonal planes at 4, 5.5, 6.8 and 9 GHz are plotted in Figure 6. Clearly, the H-plane (x-y plane) patterns are close to omnidirection, while those in the E-plane (x-z and y-z planes) are monopole-like except having a slight asymmetry, which should be due to the effect caused by the asymmetrical feeder. Meanwhile, significant difference between E_θ and E_ϕ is seen for the proposed antenna to show that the linear polarization in radiation characteristic is seen for the proposed antenna. Figure 6 presents the frequency responses of the measured and simulated antenna gain across the operating band. Obviously, the result obtained from experiment is in good agreement with that achieved from simulation, and both have a significant gain decrease over the notched band. The average gains across the operating band, excluding the notch band, are about 2.3 and 2.1 dBi for measurement and simulation, respectively, whereas over the notch band, the gain decrease is about 3 and 2 dB for measurement and simulation, respectively. In addition, the radiation efficiency of the proposed antenna is also simulated and shown in Figure 7. It is seen that the antenna shows a good and stable efficiency throughout the operation band except having a drastic decrease at the notched band. From the above results, the proposed antenna has shown itself a good candidate for UWB communication application without interference from the 5.5-GHz WLAN frequency band.

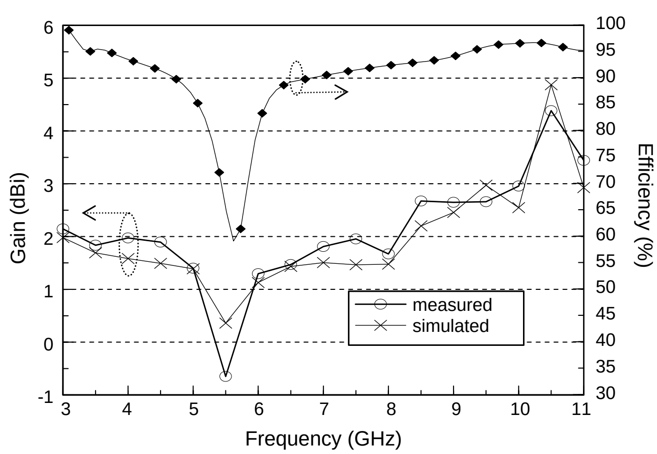

Figure 7. Antenna gain and efficiency for proposed band-rejection UWB antenna across the operating band.

4. CONCLUSION

A band-rejection UWB monopole antenna with experimental and numerical results has been presented. By simply asymmetrically feeding the twin patches as well as embedding L-shaped slot to each of them, the proposed design can reveal not only good UWB performance in impedance bandwidth, radiation pattern and gain, but also a band-rejection function to restrict interference caused from the 5.5-GHz WLAN.

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