Controllable Band-Notched Slot Antenna for UWB Communication Systems

Weerathep Kueathaweekun, Noppin Anantrasirichai, Chawalit Benjangkaprasert, Jintana Nakasuwan, and Toshio Wakabayashi

We propose a slot antenna consisting of a rectangular slot on the ground plane, fed by a microstrip line with a rectangular-ring-shaped tuning stub that can be deployed in ultra-wideband (UWB) communication systems to avoid interference with wireless local area network (WLAN) communication. Our antenna can achieve a single band-notched property from the 5 GHz frequency to the 6 GHz frequency owing to a controllable band notch that uses L- and J-shaped parasitic elements. The antenna characteristics can be modified to tune the band-notched property (4 GHz to 5 GHz or 6 GHz to 7 GHz) and the bandwidth of the band notch (1 GHz to 2 GHz). Furthermore, the shifted notch with enhanced width of the band notch from 1 GHz to 1.5 GHz is described in this paper. The UWB slot antenna and L- and J-shaped parasitic elements also provide the band-rejection function for reference in the WiMAX (3.5 GHz) and WLAN (5 GHz to 6 GHz) regions of the spectrum. Experiment results evidence the return loss performance, radiation patterns, and antenna gains at different operational frequencies.

Keywords: UWB antenna, band-notched, dual band-notched, parasitic element, rectangular-ring tuning stub.

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I. Introduction

Ultra-wideband (UWB) is specified in the Federal Communications Commission (FCC) [1] as the frequency band that ranges from 3.1 GHz to 10.6 GHz, which is a 7.5 GHz bandwidth (BW). The UWB antenna design includes a simple structure, compact sizes, low cost, easy fabrication, and band notch characteristics to avoid interference from other narrowband wireless communication systems. For instance, Worldwide Interoperability for Microwave Access (WiMAX) operates at 3.5 GHz (3.40 GHz to 3.69 GHz) while wireless local area networks (WLANs) operate at 5.2 GHz (5.15 GHz to 5.35 GHz) and 5.8 GHz (5.725 GHz to 5.825 GHz). Now, many systems operate across several frequency bands, requiring a band-notched or band reject function. Thus, it is desirable to design UWB antennas with band notch characteristics to avoid potential interference from the other frequency bands.

Some UWB antennas have been reported in the literature [2]-[5], but most are rather large. The researchers in [6] and [7] have focused only on the compact size of UWB. Because there is no attention paid to the band rejection in WLAN and WiMAX applications, interference will affect the frequency range for UWB systems with the existing wireless communication systems. Some researchers presented a UWB antenna with a rejection band or band notch in the 5 GHz to 6 GHz frequency range by using an insertion strip or slot in the antenna [8]-[10]. However, these papers proposed only a single band notch design. A reported UWB antenna [11] was designed by embedding a U-shaped parasitic strip and a pair of T-shaped stubs in wide slots to obtain dual-band stops around 3.5 GHz and 5.5 GHz. The authors in [12] designed a UWB antenna with a dual band-notch for WLAN that covers the frequency ranges of 5.09 GHz to 5.36 GHz and 5.72 GHz to 5.825 GHz. In [13], the authors presented a novel dual band-notched monopole antenna at 3.5 GHz (WiMAX) and 5.5 GHz (WLAN); however, the results do not show the shifted band-notched frequency with enhanced BW of the band notch. Moreover the geometry of this antenna is relatively complex. In the future, we expect that the shifted band-notched frequency and enhanced band-notched BW may be both important and useful in wireless communication systems. Therefore, the aim of our research is to design a UWB slot antenna using a simple structure and independent control width of the band notch and shifted band-notched frequency. The technique of designing single and dual band-notched UWB slot antennas with controllable band-notched frequency and the BW of the band notch is proposed in this paper.

We propose a rectangular slot antenna with a rectangular-ring tuning stub for UWB applications. By inserting a simple parasitic strip (two types: L-shaped and J-shaped), single band-notched characteristics from 5 GHz to 6 GHz can be easily obtained. By inserting two different parasitic elements into a slot radiator, a dual band notch successfully filtered from a 3.25 GHz to 3.69 GHz band and 5.01 GHz to 6.11 GHz band can be created to reduce the potential interference between the UWB system and other communication systems. The characteristics of our UWB antenna with a single or dual band-notched design can be modified to tune the band-notched frequency and the BW of the band notch by varying the total length of the parasitic elements.

II. UWB Slot Antenna Design and Result

1. Geometry of the Proposed UWB Antenna

Figure 1 shows the geometry and configuration of a UWB slot antenna. The antenna consists of a wide rectangular slot etched out of a ground plane and a microstrip feed line with a rectangular-ring-shaped tuning stub for excitation. The antenna is fabricated on the FR4 substrate with a thickness (h) of 0.8 mm, relative permittivity (ε_r) of 4.5, and loss tangent (δ) of 0.02.

2. Simulated Return Loss of the Proposed UWB Antenna

The return loss of the proposed UWB antenna is simulated using an IE3D software package [14]. The antenna is designed with geometric parameters and adjusted carefully to achieve the first edge frequency at around 3 GHz. Finally, the parameters of the slot antenna are LL=33 mm, WW=27 mm, L=23 mm, W=14 mm, W_m=1.5 mm, S_1=12 mm, S_2=8 mm, S_3=7.65 mm, S_4=5.65 mm, S_5=0.55 mm, and L_m=5.55 mm, where W_m corresponds to the 50 Ω of the transmission line. The simulated return loss of the proposed UWB slot antenna

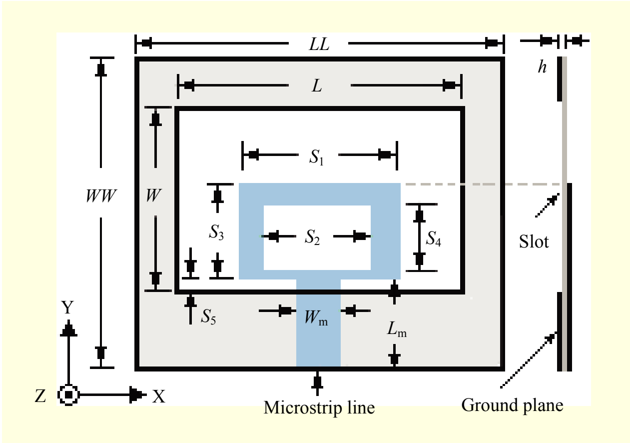


Fig. 1. Geometry of proposed UWB antenna.

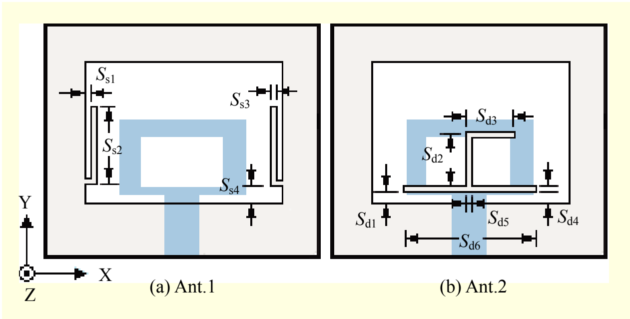


Fig. 2. Geometry of UWB antennas with single band-notch.

shows the BW of 115.6% or 7.84 GHz from the frequency range of 2.86 GHz to 10.7 GHz, as shown in Fig. 12.

III. Single Band-Notched UWB Antenna Design and Result

1. Geometry of Single Band-Notched UWB Antenna

The band-notched function is desirable in UWB systems for the purpose of reducing interference with IEEE 802.11a and HIPERLAN/2 WLAN systems operating in the 5 GHz to 6 GHz frequency band. To implement this design requirement, a narrow rejection band structure is added to the original UWB antenna area. Two types of single band-notched designs using the parasitic strip in a slot excitation scheme are presented to demonstrate the band-notched features of the proposed antenna. Figure 2 shows two types of geometry of our UWB antenna, which exhibits a single band-notch design filtering property in the 5 GHz to 6 GHz frequency band. The first design is a UWB antenna with a single band notch formed by inserting two L-shaped parasitic elements (Ant.1) into the slot radiator, as shown in Fig. 2(a). The second design is a UWB antenna with a single band notch formed by inserting a J-shaped parasitic element (Ant.2), as shown in Fig. 2(b). The design resonant length of the parasitic L-shaped and J-shaped elements relates to the guide wavelength (λ_g) at a notch frequency of 5.5 GHz. In this case, half of the perimeter (half of the total length) of the L-shaped parasitic element (H_{TL}: S_{s1}+S_{s2}+S_{s3}) compensated for by S_0 is about $\lambda_g/4$ of the center frequency of the band notch of the form given by (1). Similarly, half of the perimeter of the parasitic J-shaped element (H_{TJ}: S_{d2}+S_{d3}+S_{d4}−S_{d5}+S_{d6}) compensated for by S_0 is about $3\lambda_g/4$ of the center band-notched frequency, as given by (2). In both (1) and (2), S_0 is determined by the mean error between the simulation and the calculation for half of the total length of the parasitic strip at different frequencies.

To achieve the band-notched characteristic at 5.5 GHz, H_{TL} and H_{TJ} can be found from

$$(S_{s1} + S_{s2} + S_{s3}) - S_0 \approx \lambda_g/4, \quad (1)$$

$$(S_{d2}+S_{d3}+S_{d4}-S_{d5}+S_{d6}) - S_0 \approx 3\lambda_g/4. \quad (2)$$

Hence,

$$\lambda_g = \frac{c}{f_{\text{notch}}\sqrt{\varepsilon_{\text{eff}}}}, \quad (3)$$

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_m}\right]^{-\frac{1}{2}}, \quad (4)$$

where the guide wavelength (λ_g) at the center frequency of the notched band, 5.5 GHz, is 29.61 mm.

The length (S_{s2}) and width (S_{s3}) of the L-shaped strip are related to the notched frequency and affect the shift and enhance the BW of the band notch.

2. Simulated Return loss of Single Band-Notched Antenna

The individual strip sizes of the L-shaped element are S_{s1}, S_{s2}, and S_{s3}. In this paper, S_{s2} is the main factor to achieve the notch frequency, while S_{s1} and S_{s3} will affect the matched impedance at the notch frequency and the tuned width of the band notch, respectively. In this case, S_{s1} and S_{s3} are significantly smaller than S_{s2}. For the J-shaped strip design, S_{d2} and S_{d3} are major adjustments of notch frequency, while S_{d6} is a minor adjustment of notch frequency. The parameters S_{d4} and S_{d5} are adjusted for tuning the width of the band notch.

The dimension parameters of our UWB antenna with a single band notch in the L-shaped and the J-shaped design at frequency 5.5 GHz are to be S_{s1}=0.45 mm, S_{s2}=8.33 mm, S_{s3}=0.5 mm, S_{s4}=1.5 mm, S_{d1}=0.25 mm, S_{d2}=4.8 mm, S_{d3}=4.05 mm, S_{d4}=0.5 mm, S_{d5}=0.5 mm, and S_{d6}=15 mm, respectively. It is decided from the simulation result that the compensated parameter should be S_0=1.8 mm. The simulated return loss of the single band-notched slot antenna from Ant.1 with two L-shaped parasitic inserts and from Ant.2 with a J-shaped parasitic insert is shown in Fig. 13. Both band-notched designs successfully filter the 5 GHz to 6 GHz range and still exhibit good impedance matching at other UWB frequencies.

Table 1. Optimized dimensions of L-shaped element for shifted band notch.

Designs	Parameters (S_{s3} = 0.5 mm, S_{s4}=1.5 mm, S_0=1.8 mm)				
	S_{s1} (mm)	S_{s2} (mm)	H_{TL}−S_0 (mm)	f_c (GHz)	BW (GHz)
Sn.1	0.45	8.33	7.48 (0.252λ_g)	5.5	1.0
Sn.2	0.47	10.30	9.05 (0.250λ_g)	4.5	1.0
Sn.3	0.50	6.75	5.95 (0.237λ_g)	6.5	1.0

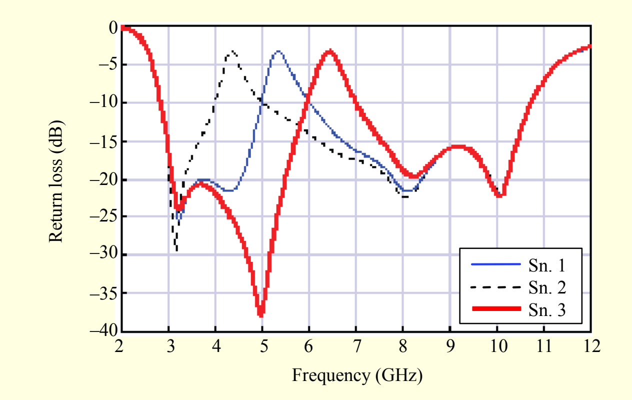


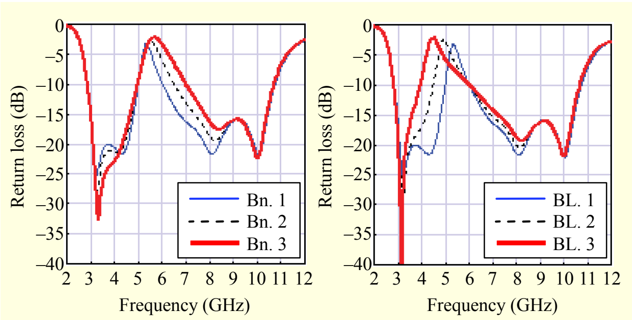
Fig. 3. Simulated return loss profile, illustrating shifted band-notch UWB antenna (Ant.1).

One of the characteristics of a UWB antenna with a single band notch is readily apparent. We can control a shifted band-notched frequency and the enhanced width of the band notch by varying the length of the parasitic strip (two L-shaped and one J-shaped). To prove that this is the case, we present only the characteristic of return loss of a UWB antenna that features two parasitic L-shaped inserts (Ant.1). The filtering frequency band can straightforwardly be controlled by tuning the total length of the parasitic L-shaped inserts to the dimension parameters of S_{s1}, S_{s2}, and S_{s3}. We present three designs of the shifted band-notch, namely, Sn.1, Sn.2, and Sn.3. The values of the parameters S_{s1} and S_{s2} of the three designs with the notched BW, the center frequency of the band notch (f_c), and H_{TL} compensated by S_0 (H_{TL}−S_0) are listed in Table 1.

Figure 3 shows the simulated return loss (S_{11}) of Ant.1 for giving the different total lengths of the two parasitic L-shaped elements, as listed in Table 1. The filtering frequency band can be controlled by tuning the total length of the parasitic L-shaped insert. The simulation results of Sn.1, Sn.2, and Sn.3 show rejection-based filtering of the frequency bands at 5 GHz

Table 2. Optimized dimensions of L-shaped element for BW enhancement of choice 1 and choice 2.

Designs		Parameters (S_{s4}=1.5 mm)				
		S_{s1} (mm)	S_{s2} (mm)	S_{s3} (mm)	f_c (GHz)	BW (GHz)
Choice1	Bn.1	0.45	8.33	0.50	5.5	1.0
	Bn.2	0.50	8.25	0.89	5.75	1.5
	Bn.3	0.50	8.20	1.40	6.0	2.0
Choice2	BL.1	0.45	8.33	0.50	5.5	1.0
	BL.2	0.49	9.20	0.81	5.25	1.5
	BL.3	0.49	10.3	1.20	5.0	2.0



(a) Choice 1, fixed lower frequency edge at 5 GHz

(b) Choice 2, fixed higher frequency edge at 6 GHz

Fig. 4. Simulated return loss profile, illustrating enhanced width of band notch of Ant.1.

to 6 GHz, 4 GHz to 5 GHz, and 6 GHz to 7 GHz, respectively. Thus, if we require a shift in the band-notched frequency, it is sufficient to vary only the total length of the parasitic L-shaped insert.

Similarly, we design the notch frequency at 5.5 GHz using (1) and the enhanced band notch by adjusting the dimension of the L-shaped strip. Optimized dimensions of the L-shaped element are shown in Table 2 and Table 3. There are two choices for enhancing the width of the band notch from 1 GHz up to 2 GHz; one is band rejection from 5 GHz up to 7 GHz and other is band rejection from 6 GHz down to 4 GHz. Herein, each choice allows three designs, namely Bn.1, Bn.2, and Bn.3 for choice 1 and BL.1, BL.2, and BL.3 for choice 2; the optimized dimensions of the L-shaped element, the notched BW, and the f_c are listed in Table 2.

Figure 4 shows the simulated return loss of the six designs of choice 1 and choice 2. The implication of Bn.1 and BL.1 is that these design filters can cover the frequency band from 5 GHz to 6 GHz. Design filters Bn.2 and BL.2 exhibit a BW enhancement of 1.5 GHz.

The simulation results for these designs show a rejection band from 5 GHz to 6.5 GHz and 4.5 GHz to 6 GHz for choice

Table 3. Optimized dimensions of parasitic L-shaped insert for shifted band notch of BW 1.5 GHz.

Designs	Parameters (S_{s4}=1.5 mm)				
	S_{s1} (mm)	S_{s2} (mm)	S_{s3} (mm)	f_c (GHz)	BW (GHz)
Bs.1	0.50	8.25	0.89	5.75	1.5
Bs.2	0.48	10.28	0.81	4.75	1.5
Bs.3	0.50	6.63	0.95	6.75	1.5

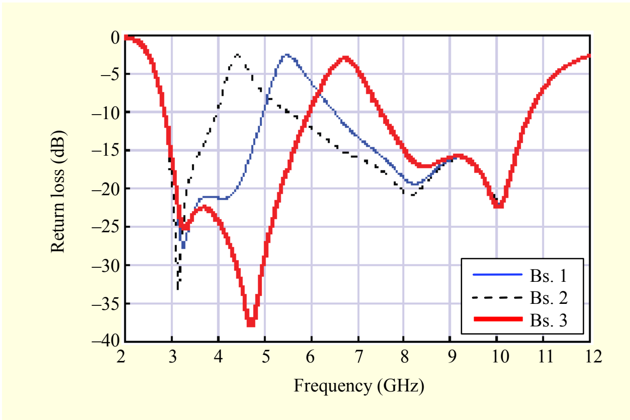


Fig. 5. Simulated return loss profile, illustrating shift and enhanced width of band notch of Ant.1.

1 and choice 2, respectively. The simulated return losses of Bn.3 and BL.3 in Fig. 4(a) and (b) clearly show that the BW is 2 GHz that the band rejection is from 5 GHz to 7 GHz and 4 GHz to 6 GHz for the final design of choice 1 and choice 2, respectively. The UWB antenna with a single band notch of Ant.1 can be tuned to control the center band-notched frequency shift from 5.5 GHz by controlling the width of the band notch from 1 GHz up to 1.5 GHz by changing the total length and width of two parasitic L-shaped inserts. The three design cases, namely Bs.1, Bs.2, and Bs.3, with a shift in the band-notched frequency and a notch BW of 1.5 GHz are shown in Fig. 5. The parameters of the L-shaped element, the notched BW, and the f_c are listed in Table 3.

From the simulation results, it is clear that the rejection band for the three designs are 4 GHz to 5.5 GHz, 5 GHz to 6.5 GHz, and 6 GHz to 7.5 GHz. Thus, this single band-notched UWB antenna can filter out bands other than the 5 GHz to 6 GHz range to avoid interfering with other UWB frequencies.

IV. Dual Band-Notched UWB Antenna Design and Result

1. Geometry of Dual Band-Notched UWB Antenna

Both WLAN and WiMAX communication systems operate

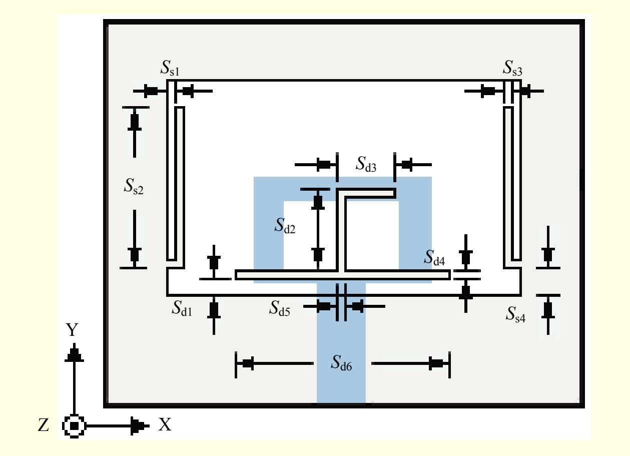


Fig. 6. Geometry and configuration of UWB antenna with dual band-notched design.

in the UWB frequency range. We can develop a UWB antenna from a single band notch to dual band notch design by inserting two different parasitic strips (L-shaped and J-shaped) in the slot to reduce interference with the WiMAX (3.5 GHz) and HIPERLAN/2 (5 GHz to 6 GHz) bands. In this case, the L-shaped and J-shaped elements are designed for operation at 3.5 GHz and 5.5 GHz, respectively. It is possible to control the shifted band-notch frequency and the enhanced notch BW more than 1 GHz by varying the total length of the parasitic element inserts.

The geometry and configuration of a UWB antenna with a dual band notch design is shown in Fig. 6. The half total length of the L-shaped element and J-shaped element at the center band-notched frequency of 3.5 GHz and 5.5 GHz, respectively, is determined by (1) and (2).

2. Simulated Return Loss of Dual Band-Notched UWB Antenna

The optimized values of the parasitic elements for the dual band-notched UWB antenna design are S_{d1}=0.4 mm, S_{d2}=4.9 mm, S_{d3}=4.05 mm, S_{d4}=0.5 mm, S_{d5}=0.5 mm, S_{d6}=15 mm, S_{s1} =0.25 mm, S_{s2}=12.9 mm, S_{s3}=0.3 mm, and S_{s4} =0.4 mm. The simulation return loss of our dual band-notched UWB antenna successfully filters frequencies from 3.24 GHz to 3.70 GHz and from 4.98 GHz to 6.0 GHz. This result still performs desirable impedance matching (defined by $S_{11}<-10$ dB) at frequencies from 2.87 GHz to 11.12 GHz, as shown in Fig. 14.

Figure 7 shows the simulated surface current distribution of the UWB antenna with a dual band notch design at 3.5 GHz and 5.5 GHz by using two L-shaped strip inserts and one J-shaped strip insert, respectively. It can be observed that the surface current is distributed on the L-shaped strip at 3.5 GHz but not on the J-shaped strip, as shown in Fig. 7(a). Similarly,

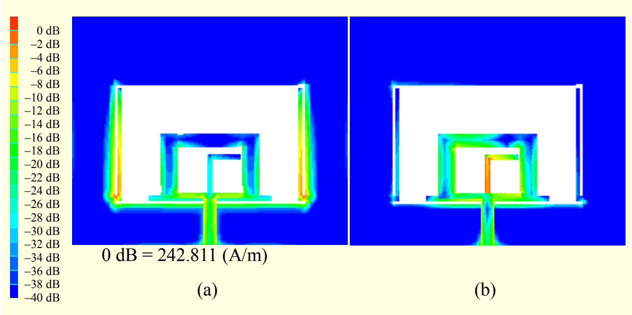


Fig. 7. Simulated surface current distribution of dual band-notched antenna: (a) at 3.5 GHz and (b) at 5.5 GHz.

Table 4. Optimized dimensions of L-shaped element for shifted notch frequency at first notch.

Designs	Parameters		
	S_{s2} (mm)	f_c (GHz)	BW (GHz)
Sw.1	12.90	3.47	0.46
Sw.2	12.15	3.67	0.46
Sw.3	11.48	3.87	0.46

the surface current distribution increases markedly on only the J-shaped strip at 5.5 GHz, as shown in Fig. 7(b). In this case, the impedance acutely changes at the strips and the high return loss leads to impedance mismatching at the desired notched frequency. Therefore, the antenna efficiency and gain decrease at these notched frequencies. The beneficial characteristics of our UWB antenna are apparent. We can independently control a shift of the band-notch and enhance the width of the band notch at the first and second notch by varying the length of the parasitic strip (two L-shaped and one J-shaped).

A. Characteristics of 3.5 GHz Band-Notched UWB Antenna

To study the characteristics of a 3.5 GHz band-notched UWB antenna that features two parasitic L-shaped element inserts, we must consider the shift and the enhanced band-notched function. In this case, we present three design cases, namely Sw.1, Sw.2, and Sw.3 by fixing S_{s1} = 0.25 mm, S_{s3} = 0.3 mm, and S_{s4} = 0.4 mm. The parameters in Table 4 show that the 3.5 GHz band-notched characteristics can be obtained by changing only vertical length (S_{s2}) of the L-shaped element. Table 4 shows the simulation of the notched BW and the f_c.

Tuning the shifted band-notched frequency around the 3.5 GHz band without changing the characteristic of the 5.5 GHz band-notched frequency can be achieved as shown in Fig. 8. Figure 8 shows the simulated return loss (S_{11}) of the dual band-notched antenna for different given lengths S_{s2} of the parasitic L-shaped elements. The filtering frequency band can simply be

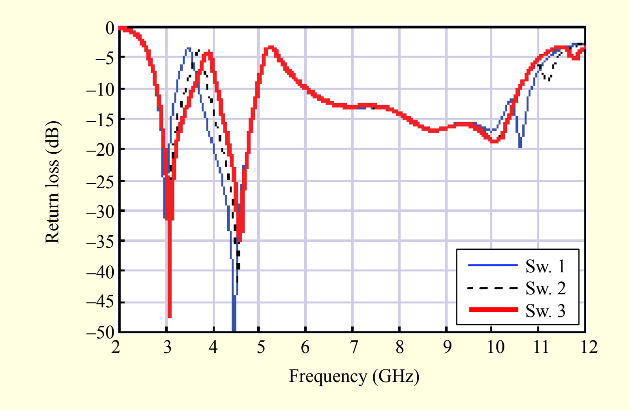


Fig. 8. Simulated return loss of dual band-notched antenna, illustrating shifted band-notch at first notch.

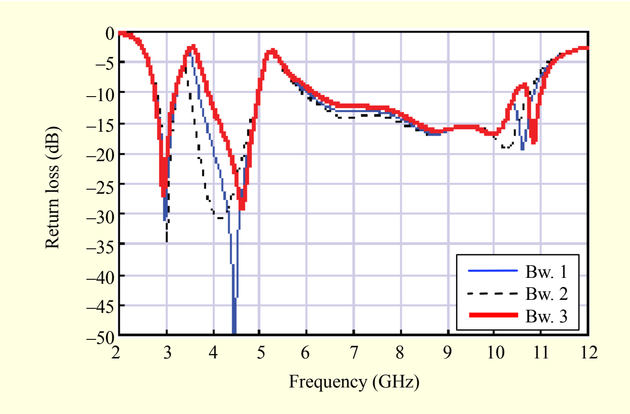


Fig. 9. Simulated return loss of dual band-notched antenna, illustrating enhanced band-notch at first notch.

controlled by tuning the total length of the parasitic L-shaped insert. The simulation results of Sw.1, Sw.2, and Sw.3 show rejection-based filtering of the frequency bands from 3.24 GHz to 3.7 GHz, 3.44 GHz to 3.9 GHz, and 3.64 GHz to 4.1 GHz, respectively, by adjusting only S_{s2}. Thus, when we require a shift in the first band-notched frequency, the vertical length (S_{s2}) of the parasitic L-shaped insert is varied as shown in Table 4.

Similarly, we can control the BW of the band notch by varying the dimension parameters of the parasitic L-shaped elements without changing the lower edge frequency of the first notch and the BW of the second notch, as shown in Fig. 9. The three design cases, namely Bw.1, Bw.2, and Bw.3, are presented for the enhanced BW of the notch. Figure 9 shows that the filtered frequency band can clearly be controlled by tuning the dimension of the parasitic L-shaped element and fixing S_{s4} = 0.4 mm. The three parameters S_{s1}, S_{s2}, and S_{s3} with the results of the notched BW and the f_c are listed in Table 5.

The simulation results suggest that the three design cases can filter in the frequency bands of 3.24 GHz to 3.7 GHz,

Table 5. Optimized dimensions of L-shaped element for enhanced band-notch at first notch.

Designs	Parameters				
	S_{s1} (mm)	S_{s2} (mm)	S_{s3} (mm)	f_c (GHz)	BW (GHz)
Bw.1	0.25	12.90	0.30	3.47	0.46
Bw.2	0.15	13.20	0.17	3.37	0.26
Bw.3	0.25	12.79	0.60	3.57	0.66

Table 6. Optimized dimensions of J-shaped element for shifted notch frequency at second notch.

Designs	Parameters			
	S_{d2} (mm)	S_{d3} (mm)	f_c (GHz)	BW (GHz)
Sh.1	4.90	4.05	5.49	1.02
Sh.2	5.20	2.50	6.01	0.98
Sh.3	4.40	3.08	6.50	1.0

3.24 GHz to 3.5 GHz, and 3.24 GHz to 3.9 GHz. Thus, this dual band-notched UWB antenna can filter out bands other than the 3.4 GHz to 3.69 GHz (WiMAX 3.5 GHz) range to avoid interference with other UWB frequencies.

B. Characteristics of 5.5 GHz Band-Notched UWB Antenna

Similarly, the 5.5 GHz second band notch is achieved by inserting a parasitic J-shaped element in the slot radiator. Three design cases for a shifted band notch, namely, Sh.1, Sh.2, and Sh.3, are presented. The filtering frequency bands of the three design cases can be controlled by tuning the total length of the parasitic J-shaped insert. The parameters S_{d1}, S_{d4}, S_{d5}, and S_{d6} are fixed to 0.4 mm, 0.5 mm, 0.5 mm, and 15 mm, respectively. In this case, the parameters S_{d2} and S_{d3} are adjusted to achieve the results of the notched BW and the f_c, which are shown in Table 6.

Figure 10 shows the simulated return loss (S_{11}) of the dual band-notched antenna. The band-notched frequency is shifted by different given total lengths of a parasitic J-shaped element without changing the characteristic of the 3.5 GHz band notch. The simulation results suggest that Sh.1, Sh.2, and Sh.3 filter the frequencies in the 4.98 GHz to 6 GHz band, the 5.52 GHz to 6.5 GHz band, and the 6 GHz to 7 GHz band, respectively.

In addition, the UWB slot antenna with a dual band notch can be tuned to adjust the frequency of the band notch and widen the BW to more than 1 GHz by changing the total length and width of the parasitic J-shaped insert. The three design cases of the J-shaped element, namely, Bh.1, Bh.2, and Bh.3, with BW enhancements of nearly 1 GHz, 0.5 GHz, and

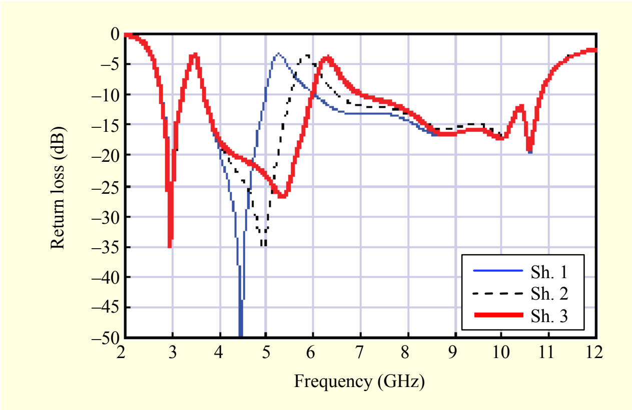


Fig. 10. Simulated return loss of dual band-notched antenna, illustrating shifted band-notch at second notch.

1.5 GHz, respectively, are presented. We let S_{d4} = 0.5 mm and S_{d6} = 15 mm and adjust other dimension parameters, and the results of the notched BW and f_c are listed in Table 7.

The simulation results in Fig. 11 suggest that these designs can filter the frequencies in the bands of 4.98 GHz to 6 GHz, 5 GHz to 5.52 GHz, and 5 GHz to 6.52 GHz. Thus, the dual band-notched UWB antenna can filter out bands other than the 5 GHz to 6 GHz range so as to avoid interference with other UWB frequencies.

Table 7. Optimized dimensions of J-shaped element for enhanced band-notch at second notch.

Designs	Parameters					
	S_{d1} (mm)	S_{d2} (mm)	S_{d3} (mm)	S_{d5} (mm)	f_c (GHz)	BW (GHz)
Bh.1	0.40	4.9	4.05	0.5	5.49	1.02
Bh.2	0.40	3.2	5.50	0.5	5.26	0.52
Bh.3	0.35	5.4	4.95	2.0	5.76	1.52

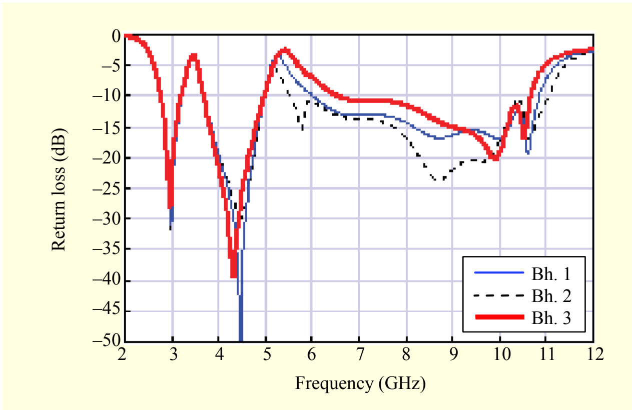


Fig. 11. Simulated return loss profile, illustrating enhanced band-notch at second notch.

V. Experiment Results of UWB Antenna and Band-Notched UWB Antennas

The UWB slot antenna experiment is conducted using an Agilent E8363B network analyzer. The antenna is fabricated on an FR4 epoxy substrate with h = 0.8 mm and ε_r = 4.5. All radiation patterns are measured in a far-field anechoic chamber.

1. Result of UWB Antenna

Figure 12 shows the comparison between the simulated and the measured return loss of the UWB antenna with a rectangular-ring tuning stub. The measured impedance BW of this UWB antenna, around 113.6% or 7.98 GHz ranging from 3.03 GHz to 11.01 GHz, is in compliance with IEEE 802.15a. Thus, this slot antenna can be deployed in UWB applications.

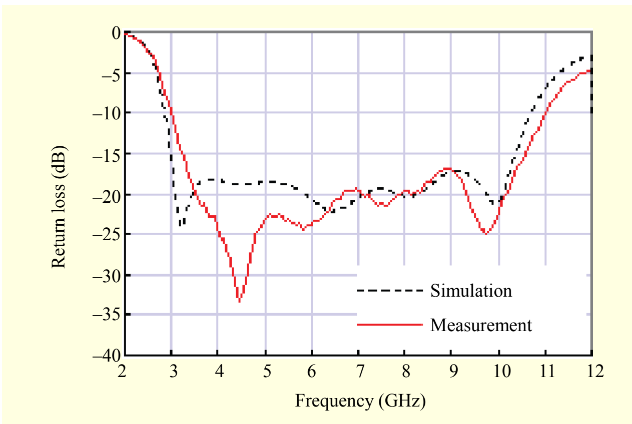


Fig. 12. Comparison between measured and simulated return loss of UWB slot antenna.

2. Results of Single Band-Notched UWB Antenna

The simulated and measured return loss (S_{11}) of the UWB slot antenna with single band notch design is shown in Fig. 13. Results from Ant.1 with two L-shaped parasitic inserts are shown in Fig. 13(a), and results from Ant.2 with a J-shaped parasitic insert are shown in Fig. 13(b). Both band notch designs successfully filter the frequencies in the 5 GHz to 6 GHz range and still exhibit good impedance matching at other UWB frequencies.

3. Results of Dual Band-Notched UWB Antenna

Figure 14 compares the simulated return loss of the dual band notch design with the measured return loss. The

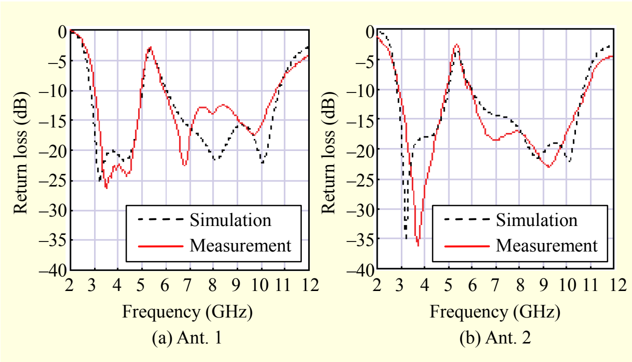


Fig. 13. Comparison between measured and simulated return losses of single band-notched UWB antennas.

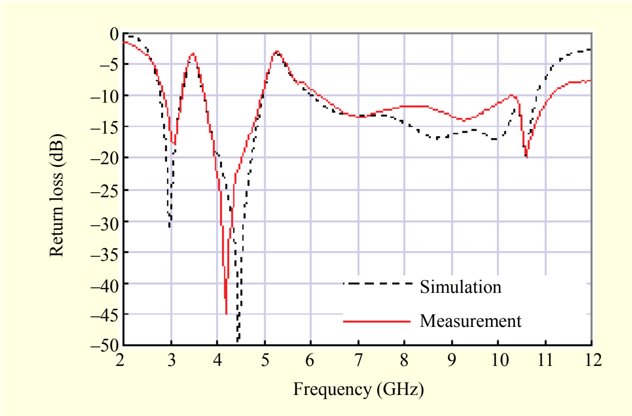


Fig. 14. Comparison between measured and simulated return loss of dual band-notched UWB antenna.

measured result shows that the UWB antenna with a dual band notch successfully filters frequencies from 3.25 GHz to 3.69 GHz and from 5.01 GHz to 6.11 GHz and offers good impedance matching at other UWB frequencies.

The radiation patterns of a dual band-notched UWB antenna are measured in the anechoic chamber at many frequencies ranging from 2.87 GHz to 11.12 GHz. However, for brevity, both co-polarization and cross-polarization within the x-z plane (H-plane) and the y-z plane (E-plane) at frequencies 3.1 GHz, 4.5 GHz, and 7 GHz are illustrated in Fig. 15.

The measured radiation pattern associated with the H-plane is omni-directional, and the pattern for the E-plane is bi-directional. The characteristics of the radiation patterns of the proposed antenna for deployment in UWB applications can be summarized as follows. The direction of maximum radiation is constantly associated with the ± z-axis, which is normal to the slot plane.

The simulated and measured peak gains of the UWB antenna with and without notches are presented in Fig. 16. The maximum peak gain of the four UWB antenna designs without notch, with single band notch using L-shaped (Ant.1), with

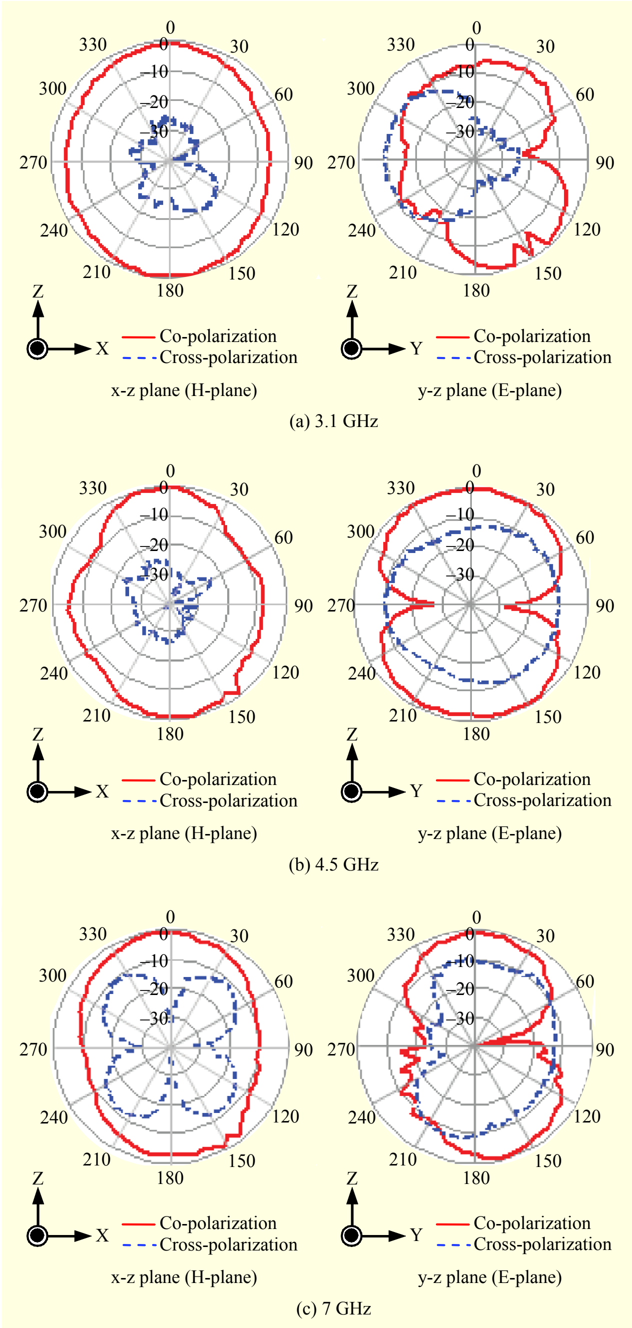


Fig. 15. Measured radiation patterns of dual band-notched UWB antenna.

single band notch using J-shaped (Ant.2), and with dual band notch are 6 dBi, 5.97 dBi, 6.1 dBi, and 6.5 dBi, respectively. It is apparent that the measured peak gain of the dual band-notched UWB antenna decreases in the 3.2 GHz to 3.8 GHz and the 5 GHz to 6 GHz bands and exhibits desirable performance at other frequencies in the UWB band. Figure 17 shows photographs of the proposed antenna. Note that the ground plane dimensions are 33 mm × 27 mm for all samples of the proposed antenna.

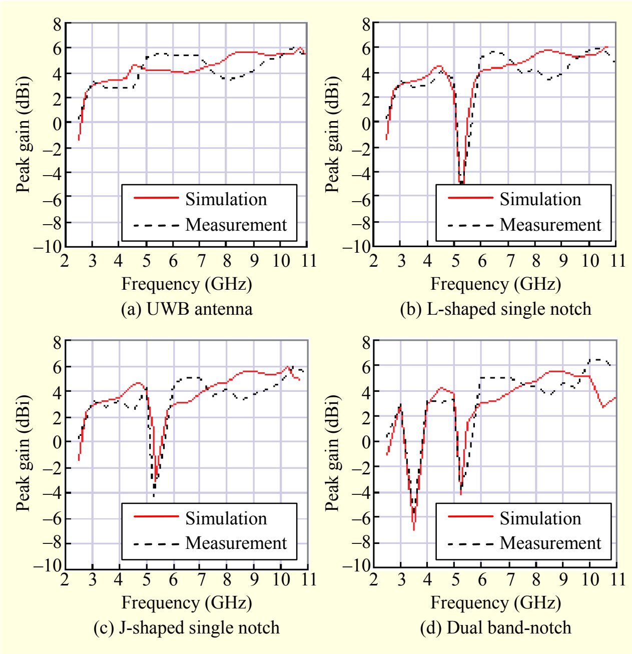


Fig. 16. Simulated and measured peak gain of the single and dual band-notched UWB antennas.

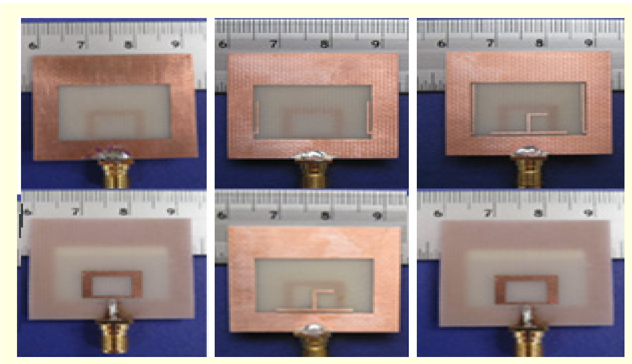


Fig. 17. Photographs of proposed antenna.

VI. Conclusion

The UWB slot antenna and a variety of band notch designs were proposed. These designs created three features by adjusting the dimension parameters of parasitic elements: shifted band-notched frequency, enhanced width of the band notch, and a shifted with the enhanced band-notched frequency. This proposed antenna exhibits a simple structure. This antenna can be used in UWB systems to avoid interference with other wireless communication systems by inserting parasitic elements in the slot antenna to cause rejection in the bands used by communication systems such as WiMAX, WLAN, and HIPERLAN/2. All versions of the proposed antenna can control a shift of the band-notched frequency and the BW of the band notch. The simulated and measured results of the proposed antenna reveal agreement in terms of the return loss, radiation patterns, and gains at different operational frequencies.

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