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A SIMPLE AND COMPACT PLANAR ULTRA WIDE-BAND ANTENNA WITH SINGLE OR DUAL BAND-NOTCHED CHARACTERISTICS

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Abstract—A printed monopole ultra wideband (UWB) antenna with frequency band-notched characteristics is proposed and investigated. The antenna consists of a half-disk shaped structure combined with an inverted isosceles trapezoid structure. To achieve the frequency band notched characteristics, an open-ended thin slit with a length of about one quarter guided wavelength is inserted on the radiator. Multiple slits can be employed to realize multiple frequency band notched characteristics. To validate the concept, two prototypes are designed, fabricated and tested. The first is a single band notched UWB antenna whereas the second is a dual band notched UWB antenna. The simulated and measured results of both antennas are presented shown a reasonable agreement between them. The results also confirm the proposed UWB antenna design can achieve superior dual band-notch performance at desired frequency bands.

1. INTRODUCTION

Ultra wideband (UWB) communications systems have drawn increasing attention in the past decade. It has now become a promising technology offering high performance for both the indoor and outdoor wireless communication systems, which allow low cost, low power consumption and high data rate. For many years, UWB technology was a widely applied technology for radar and remote sensing applications [1, 2]. In

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2002, the Federal Communication Commission (FCC) has allocated frequency band from 3.1 to 10.6 GHz for commercial UWB communication systems [3]. The research on wireless communications systems using UWB technology has become a popular topic since then. However, the design of a UWB antenna with a small size, low cost and high performance is still a challenging task.

The UWB antenna is required to achieve impedance matching over a UWB frequency range, stable radiation patterns, and linear phase. Many UWB antennas, which fulfill these design requirements, have been reported in the literature [4]. Generally speaking, printed type of UWB antennas are the dominating type among most of studies so far reported, in addition to the type of three dimensional designs using metallic plates [5]. This is because printed antennas may have good advantages such as small size, easy fabrication and they can be made compatible to the rest of the RF front ends and be implemented on the same PCB circuitry, which results in reducing the cost of the antenna fabrication.

In recent years, a new challenge in UWB antenna designs is to realize frequency band-notched characteristics. This is for eliminating possible interference between 5 to 6 GHz (5.15–5.35 GHz and 5.725–5.825 GHz), that is already reserved for the existing Wireless Local Area Network (WLAN) communications systems. This type of interference problem can be eliminated by adding extra filters, which will increase the size and cost; however, on the other hand, it is desirable to have a small-size UWB antenna with frequency band notched characteristics. Several methods have been developed to achieve UWB antennas with band-notched characteristics in which they have included: different shapes of slots (ex. U-shaped, V-shaped, arc-shaped, or ring-shaped) are inserted on the printed antenna or its associated ground plane to obtain a notched frequency band [6–11]; adding parasitic elements near the printed antenna [12–15]; using defected ground structure (DGS) [16] or electromagnetic band-gap (EBG) [17]; introducing simple open-end slits on the antenna structure, which are usually quarter wavelength in length, frequency notches can therefore be obtained [18]. Moreover, dual band-notched frequency can be realized by adopting and combining the foregoing methods [19–21].

In this paper, a simple, compact and uniplanar printed monopole antenna operated with single or multiple band-notched characteristics is proposed and discussed. The antenna configuration employs a combination of circular-shaped structure of an inverted isosceles trapezoid structure, in order to realize good impedance matching over the UWB frequency range. The technique of slits loading on the radiator is applied to achieve single or multiple frequency band notched characteristics. Two prototypes are designed and developed, to confirm the operation of single-band-notched and dual-band-notched responses. Finally, analysis of the calculated and measured results of the two prototypes are presented and discussed.

2. DESIGN OF UWB ANTENNA WITH SINGLE BAND-NOTCHED CHARACTERISTICS

The proposed printed monopole UWB antenna with single band notched characteristics is illustrated in Fig. 1. Firstly, a UWB antenna covering 3.1–10.6 GHz is realized; then the band-notched function is considered by adding a single slit on the radiator.

The structure of the antenna consists of two portions: a sectored circular disc shape of an inverted isosceles trapezoid, which is combined as the antenna configuration in this study. The antenna is fed by 50 Ohm microstrip line; it is printed on one side of the dielectric substrate. The width w_1 (see Fig. 1) of the feeding microstrip line is set to have 50 Ohm impedance. The antenna associated ground plane with an appropriate length is printed on the other side of the substrate. The ground plane is virtually shared by both the antenna and its feedline. The shape of sectored circular disc was chosen as the main radiator because of its feature with achievable broadband impedance matching [22]; the structure of the inverted isosceles trapezoid is adopted for the purpose of allowing the control of the impedance matching for the proposed design.

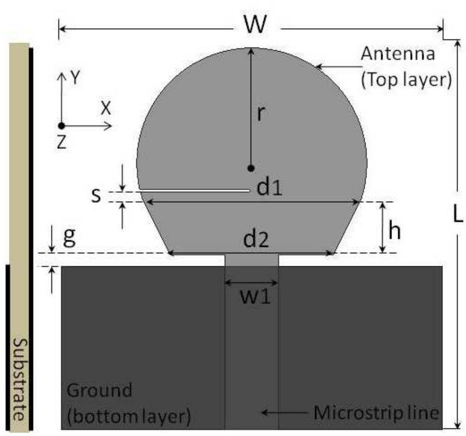


Figure 1. Antenna configuration of the printed UWB monopole with frequency-notched characteristics.

The proposed compact printed monopole UWB antenna (without a band notch) is successfully developed. Subsequently, a method of producing band-notched characteristics is introduced, by inserting a horizontally open-ended thin slit with approximated length about one quarter-wavelength guided wave at the desired notched frequency (f_{notch}). The position of this slit is placed near the area of the inverted isosceles trapezoid. This is due to the fact that most of surface current is mainly distributed around the area between the antenna ground plane and the lower area of the inverted isosceles trapezoid. The first resonant frequency (f_{low}) at the lower edge of operating band is related to the vertical length $(r + h)$ of the proposed antenna, which can be approximately calculated by Equation (1). Moreover, the notched-band frequency (f_{notch}) of the inserted quarter wavelength open-ended slit resonator is given by Equation (2).

$$f_{low} = \frac{c}{4(r+h)\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$f_{notch} = \frac{c}{4l_s\sqrt{\varepsilon_{eff}}} \tag{2}$$

where c is the speed of light, r and h are shown in Fig. 1, l_s is the length of the open-ended slit and ε_{eff} is defined as [7]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{3}$$

The antenna is simulated and designed using Ansoft HFSS [23].

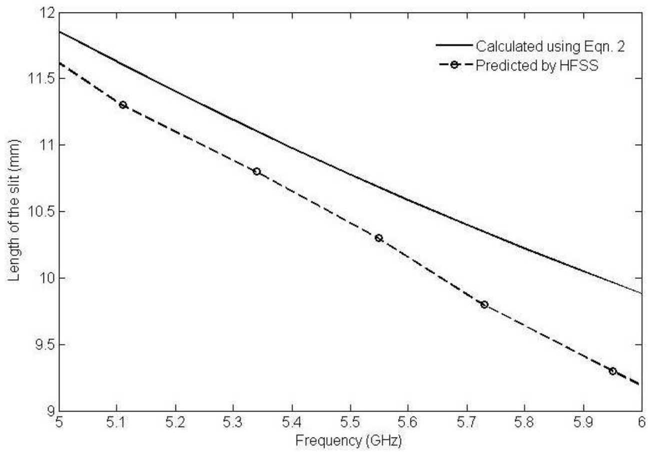


Figure 2. Comparison of calculated and predicted length of the resonator slit corresponding to the notch frequency.

Table 1. Dimensions of the antenna parameters of the proposed design.

	Parameters									
	W	L	w_1	d_1	d_2	l_s	h	g	r	s
Dimensions (mm)	35	35	4.9	15	20	10.1	5	1	14	0.8

The relationship between the predicted notch frequency and the corresponding quarter wavelength resonator slit length is studied first. The results predicted by the HFSS simulator are compared to the ones calculated by the Equation (2), as shown in Fig. 2. As can be seen, the curves from two sets of results show similar slope tendency against the frequency, but different in the slit length corresponding to each frequency. This is mainly because the approximation adopted when calculating the relative dielectric permittivity in Equation (2). Nevertheless, it is noted that the parameter l_s is found to be 10.1 mm in order to obtain a notched frequency at 5.59 GHz. Other parameters, including r, s, d_2 and l_s are also important parameters in the design. Table 1 presents the detailed dimensions of each antenna parameters of the final design.

3. RESULTS ANALYSIS FOR SINGLE BAND-NOTCHED DESIGN

The proposed antenna with single band-notch characteristic is firstly studied by simulation and then in a hardware realization. For fabrication, prototypes of the proposed design with optimized key parameters (e.g., r, s and d_2), including the design with and without frequency notch respectively, are built up on the Duroid 5880 substrate with dielectric constant of 2.2 and thickness of 1.575 mm. In this section, the characteristics of the proposed design is analysed in terms of antenna voltage standing wave ratio (VSWR), input impedance, radiation patterns, power gain and group delay, in addition to the results in time domain analysis. The measured results of the fabricated prototype is presented and compared with the theoretical predictions.

3.1. Analysis in Frequency Domain

The antenna input matching of the fabricated prototype is evaluated at the defined UWB frequency band. The measured and simulated VSWR of the proposed antenna with frequency band-notched feature is presented in Fig. 3, where their VSWR was compared to those of the design without band-notch. As can be seen in Fig. 3, the proposed antenna exhibits ultra wideband impedance behavior, the measured and simulated results agreed well in both cases. Moreover, a clear notched frequency appears at frequency of 5.6 GHz with measured peak VSWR of over 7, which suggests a good rejection level at this frequency.

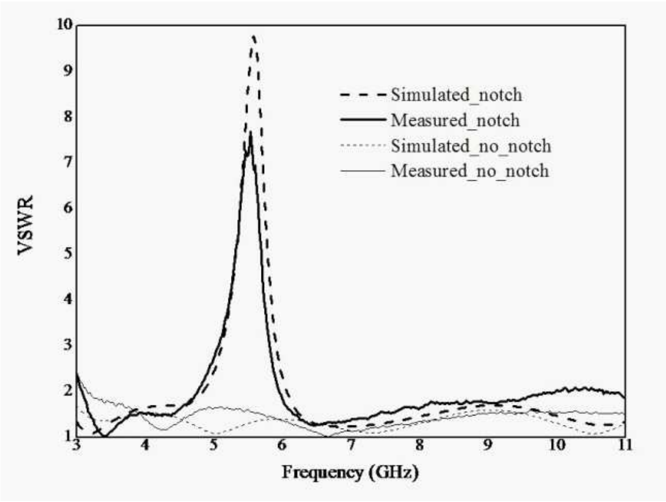


Figure 3. Comparison of simulated and measured antenna VSWR for single notched-band design.

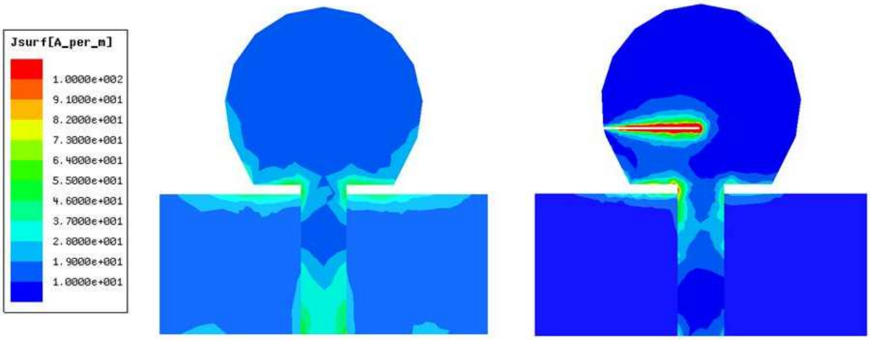


Figure 4. Comparison of simulated surface current distribution for the antenna with and without frequency-notched feature.

The surface current distribution at the notched frequency of the proposed design is examined, as presented in Fig. 4. As can be seen, the surface current distributes over the antenna and the ground plane for the antenna without notch band, whereas, the amplitude of surface current is increased dramatically for the band-notched design. It is notable that the surface current is mainly concentrated around the region of the slit on the antenna. This implies the band rejection effect due to the fact that the standing wave is realized. As a result, the slit effectively reflects back the RF signal to the antenna input port. Thus, the radiation of the proposed antenna is effectively suppressed at the notched frequency. In addition, current distributions at other UWB

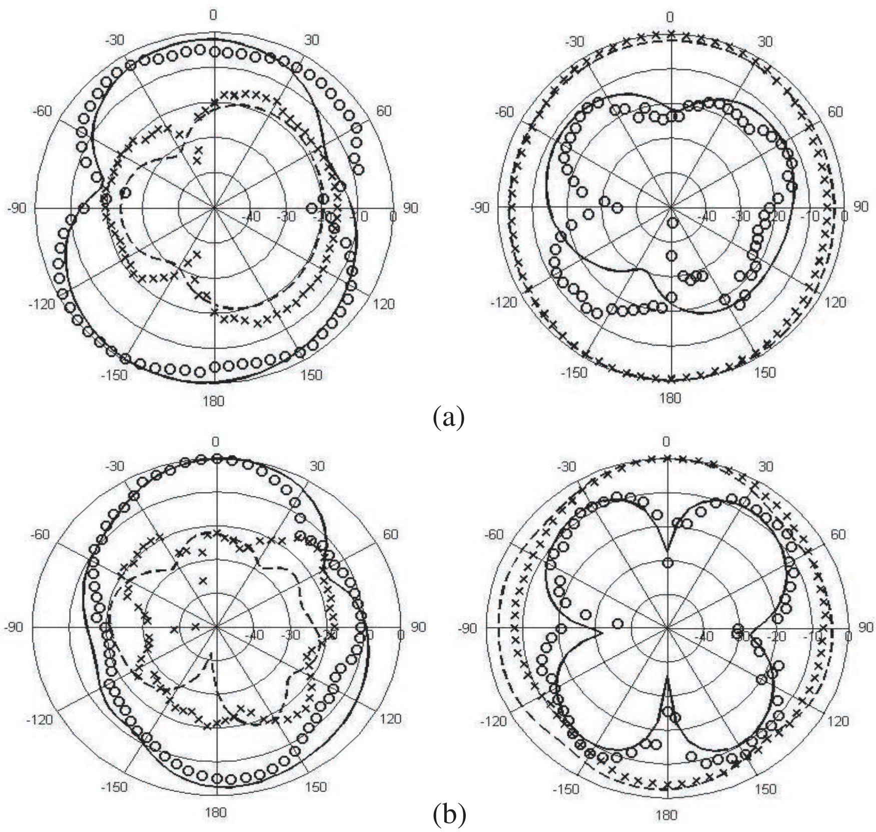


Figure 5. Radiation patterns of the proposed antenna for (a) E plane and (b) H plane at $f = 4\,\text{GHz}$ and $f = 8\,\text{GHz}$ ('ooo' represents measured E_θ, '—' simulated E_θ, 'xxx' measured E_ϕ and '- - - -' simulated E_ϕ).

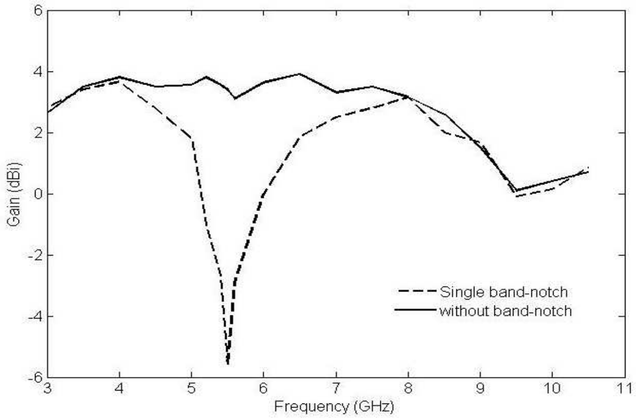


Figure 6. Measured peak gain in y-z plane of the proposed UWB antenna with a single band notch.

frequencies are also examined. It is found that relatively weak current distribution around area of the slit is observed, which suggests the slit does not have major perturbation on the antenna performance except for the notched frequency.

Measurements of the radiation patterns of the prototype were carried out in a far-field anechoic chamber using an elevation-over-azimuth positioner, with the elevation axis coincident with the polar axis ($\theta = 0°$) of the antenna's co-ordinate system. The azimuth drive thus generates cuts at constant ϕ. The elevation positioner (i.e., θ) was rotated from $-180°$ to $180°$ with an increment of $5°$ for principal plane measurements. Two principal-plane pattern cuts (i.e., y-z and x-z planes) were taken for the frequencies of interest. Fig. 5 presents the simulated and measured normalised far field radiation patterns in the y-z (E-plane) and x-z (H-plane) planes for the proposed antenna at two different frequencies of 4 GHz and 8 GHz. It is observed that the measured patterns exhibits a relatively omidirectional radiation in the x-z plane at these frequencies; whereas, measured patterns in the y-z plane illustrates the radiations, like E-plane radiation pattern of a vertical dipole.

Measurements of antenna gain for UWB band across frequencies from 3 GHz to 11 GHz are investigated. The measured peak gain in the y-z (E-plane) plane across the frequency bands of interest are shown in Fig. 6. A rejection level of -5.6 dB is observed at the notch frequency of 5.6 GHz, which implies the effectiveness of band-notched feature of this proposed design.

3.2. Analysis in Time Domain

Group delay is an important parameter to characterize the degree of distortion of the pulse signal for UWB impulse-based system. It is desired that the group delay response is stable over the UWB frequency band. In addition, the shape of the transmitted pulse should not be distorted by the antenna.

The measured group delay between the two identical antennas, oriented face to face, in this study is performed. The corresponding result is illustrated in Fig. 7. As can be seen, the measured group delay is almost smooth with the variation less than 0.5 ns over the frequency range from 3–11 GHz expect for the notched frequency band at 5 GHz, which indicates the proposed antenna should possess good transient performance with a small pulse distortion.

The normalised received signal in comparison of the excited pulse is shown in Fig. 8. This result is obtained for two identical antennas with a distance of 20 cm in a face-to-face orientation and a UWB signal source (i.e., the differential Gaussian pulse) is adopted from the author's previous study in [24] as an excitation signal. A comparison of excited and received pulse signal is shown in Fig. 8, where the two signals are deliberately superimposed (i.e., received delay was deleted). As can be seen, the maximum amplitude of the received pulse is almost level to the one of excited pulse. It is notable that the ripple of the received pulse is mainly caused by the introduction of the open-ended slit on the antenna structure.

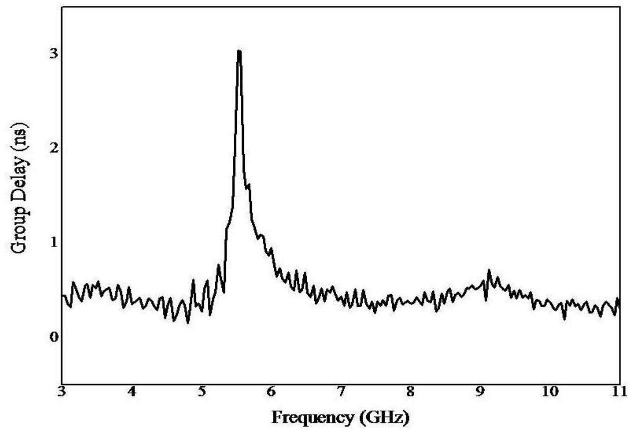


Figure 7. Measured group delay for the proposed band-notched antenna.

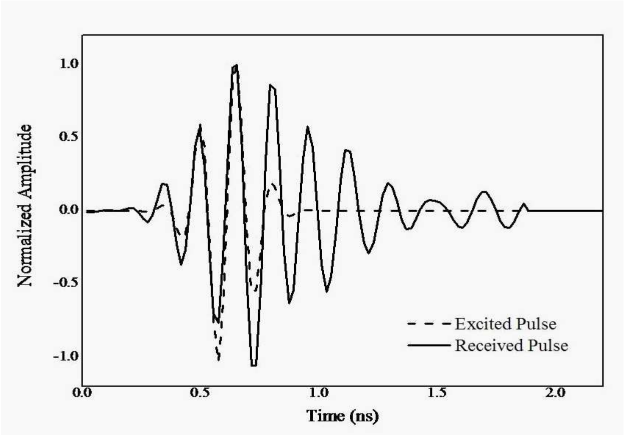


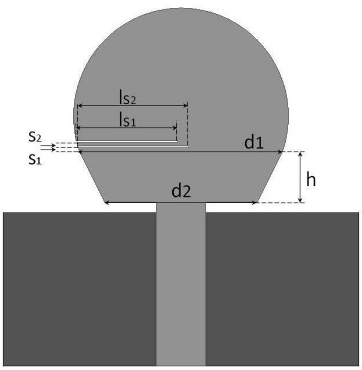
Figure 8. The measured normalised source and received signal.

4. DESIGN AND ANALYSIS OF UWB ANTENNA WITH DUAL-BAND NOTCHES

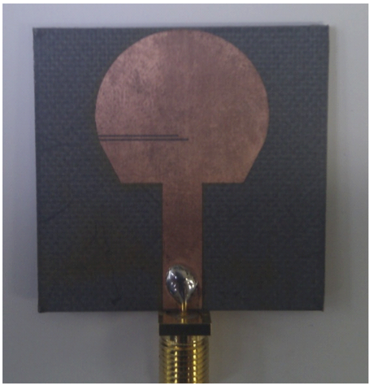
4.1. Dual Notched-band Design

The single band-notched UWB antenna proposed in Section 3 can be easily extended to the design of UWB antenna with multiple notched bands. The motivation of this study is to obtain dual band-notch behavior, working at lower and upper frequency bands (i.e., 5.15–5.35 GHz and 5.725–5.825 GHz) for WLAN. The antenna design should result in better performance on the level of radiation suppression at each notched frequency band.

This dual notched-band design can be realized as follow-on to the foregoing single notched-band antenna structure by providing an additional quarter wavelength open-ended slit. The position of the second slit is closed placed below the existing one. This newly-added slit can work independently to achieve another notched-band depending on the length of the slit. In this exercise, the length of the two slits should be adjusted in correspondence to the central frequency of lower (at 5.3 GHz) and upper (at 5.8 GHz) 5 GHz WLAN bands. Fig. 9 presents the geometry including the important dimensions of the dual notch-band design. It should be noted that the geometry of the radiator remains the same after adding the second slit. The two slits act as two resonators in series and can be controlled independently for the desired notched frequency.



(a)



(b)

Figure 9. (a) Configuration of the proposed dual band-notched UWB antenna (important dimensions: $S_1 = 0.5$, $S_2 = 0.5$, $l_{s1} = 9.9$ and $l_{s2} = 10.9$; unit in mm); (b) a prototype of the proposed design.

4.2. Analysis of Dual Notched-band Design

Performance of the dual-band notched design is predicted and analysed using EM simulator. A prototype of the proposed design is fabricated and tested. Fig. 10 presents the measured antenna VSWR in comparison with the simulation. A good agreement between measured and simulated VSWR results is observed. The prototype antenna exhibits two individual notched bands at the expected notched frequencies with excellent band-notch phenomenon. The effect on the rejection level of the proposed designs, including single and dual notched-band, are compared and summarised in Table 2. It is found that the rejection level of the dual notched-band design outperforms the single notched-band design in terms of antenna VSWR, especially at lower 5 GHz frequency band. This result proves the advantage of the design of the dual notched-band function.

In the proposed antenna, the length of the two slits are found to be 10.9 mm and 9.9 mm in order to realise two targeted resonating notch frequency at 5.3 GHz and 5.8 GHz, respectively. The coupling effect between them is necessary to be investigated since the two slits are placed closed to each other. The surface current distribution at each notch frequency for the proposed dual-notch design is examined, as Fig. 11 presents. As can be seen, the surface current mainly concentrates at the surrounding area of the corresponding slit at the each notch frequency in both cases. This implies that the neighbouring slit has little mutual effect to the other in band-notch performance,

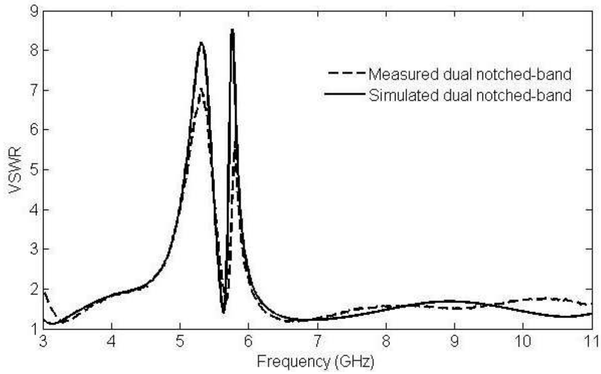


Figure 10. Comparison of simulated and measured antenna VSWR for dual band-notch design.

Table 2. Comparison of the rejection level of the antenna design in terms of antenna VSWR.

	Minimum/Maximum VSWR (frequency range: 5.15–5.35 GHz)	
	Simulated	Measured
Single notched-band design	3.2/5.2	2.9/4.8
Dual notched-band design	6.0/8.0	5.5/7.0

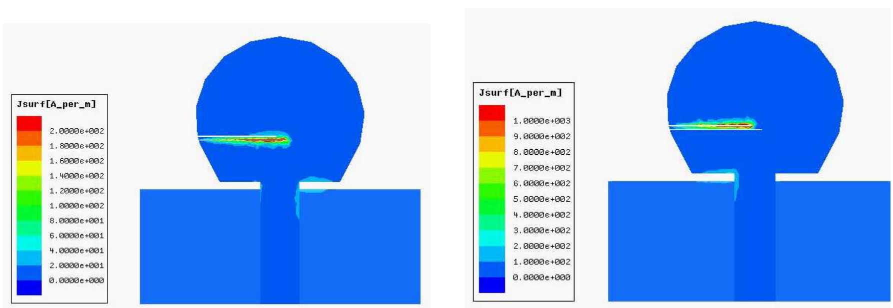
	Minimum/Maximum VSWR (frequency range: 5.725–5.825 GHz)	
	Simulated	Measured
Single notched-band design	4.2/6.5	3.0/5.2
Dual notched-band design	5.8/8.5	3.3/5.7

which indicates that they do not affect the notched frequency of the other slit if one slit length is varied. This is the advantageous feature in this proposed design concept for dual notched-band.

The far field performance of the dual band-notched design is also carried out. The radiation patterns were measured at the whole UWB frequency range, including the intended band-notched frequencies. Fig. 12 presents the far field radiation patterns in the E and H planes for the antenna at two frequencies of 4 GHz and 8 GHz. As can be seen, the simulated and measured normalised antenna patterns are in relatively good agreement. Moreover, it is found that the antenna radiation pattern is similar to the ones of the single notched-band design (see Fig. 5). This confirms that the introduced slits have no effects on the antenna radiation performance other than at band-notched frequencies.

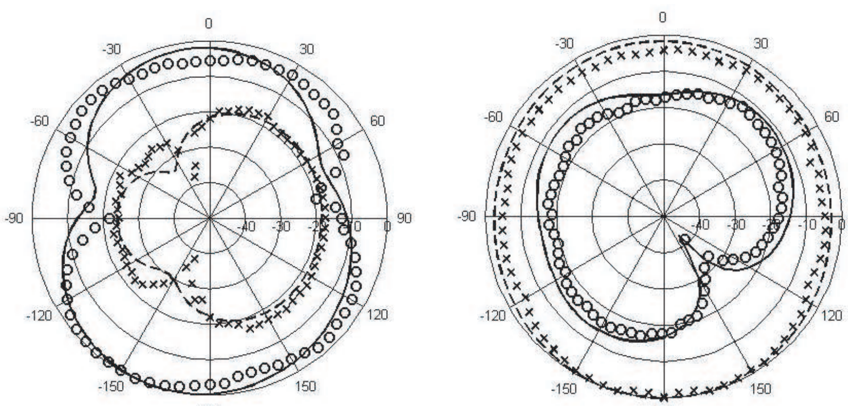
The antenna gain of the proposed design is presented in Fig. 13, and it is also compared with the reference UWB design without band-notched function. The antenna illustrates similar antenna gain outside the notched-band frequency range; whereas two distinguished gain suppression are found with maximum level of -5.2 dB and -2.4 dB at the two designated notched frequency bands.

The group delay of the design is also measured in face-to-face antennas orientations and the corresponding results are presented in Fig. 14. Apart from the notched bands, the group delay shows slightly small variations, showing that the proposed design is suitable for operation over UWB band.



(a) (b)

Figure 11. Comparison of simulated surface current distribution for the antenna with dual-notch frequency feature at (a) $f_1 = 5.36$ GHz and (b) $f_2 = 5.78$ GHz.



(a)

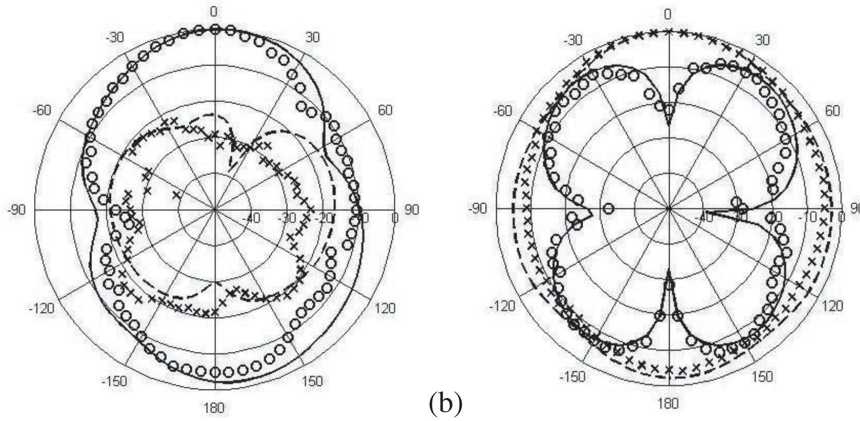


Figure 12. Radiation patterns of the dual band-notched antenna for (a) E plane and (b) H plane at $f = 4\,\text{GHz}$ and $f = 8\,\text{GHz}$ ('ooo' represents measured E_θ, '—' simulated E_θ, 'xxx' measured E_ϕ and '- - - -' simulated E_ϕ).

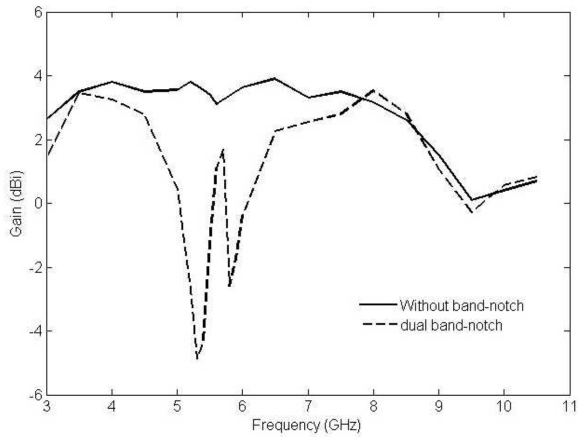


Figure 13. Measured peak gain in y-z plane of the proposed dual band-notched design.

4.3. Discussion and Comparison of Dual Notched-band Design

In this study, the simple and compact dual band-notched UWB antenna has been realised using two quarter-wavelength slits, which are placed close to each other with slight difference in length in order to generate band-notched function at the desired WLAN frequency bands. The antenna performances have been characterised in terms

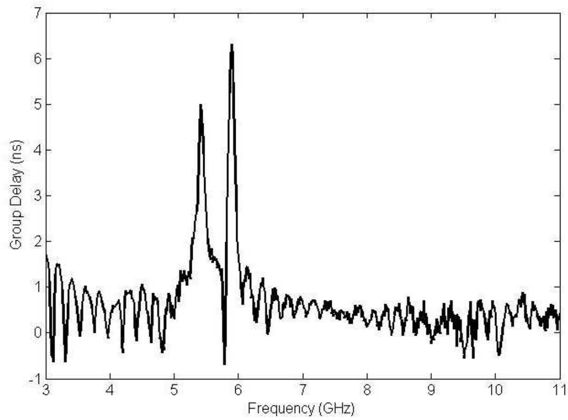


Figure 14. Measured group delay for the proposed dual band-notched antenna.

of VSWR, current distribution at central notch frequencies, antenna radiation patterns and gain.

In the literature, some other techniques have already been successfully demonstrated in achieving the UWB antenna with dual band-notch [25–30]. Thus, it is worthy comparing the proposed design of this work with the published designs reported in open literature. Besides the dual quarter-wavelength slits technique used in this work, the technique of introducing half-wavelength parasitic elements has been reported to provide dual band-notched characteristic on the UWB radiator, like the work in [25] by adding separating strips on the radiator; whereas, crescent-shaped parasitic resonator are employed [26], in which the parasitic elements are short-circuited to connect to the main radiator from the other side of the substrate. Creating half-wavelength resonator slits on the antenna structure or on its associated ground plane is also one of the effective techniques to obtain such a realisation. For example, split ring resonator structures have been adopted in [27, 28]; closed loop ring resonator have been used in [29]; In addition, two resonators of the mushroom-type EBG structure have also been demonstrated for such a purpose in [30].

In order to draw a rational comparison, the rejection levels (or maximum VSWR) of the dual band-notched design at two distinguished band notch frequency bands are chosen for comparison with the existing studies. Generally, the higher of the rejection levels at two WLAN bands for such a design, the better the performance of dual band-notched design should be. The comparison of the simulated and measured peak VSWR at the central notched frequencies of the

Table 3. Comparison of the proposed dual band-notched design with prior to art designs.

		Dual band-notched bands (frequency range: 5.15–5.35 GHz & 5.725–5.825 GHz)			
		This work	**Ref. [25]**	**Ref. [26]**	**Ref. [27]**
Peak VSWR	Simulated	8 & 8.5	6 & 5	6 & 5	10 & 8
	Measured	7 & 5.7	4 & 3.5	4 & 3.5	3.5 & 3
		Dual band-notched bands (frequency range: 5.15–5.35 GHz & 5.725–5.825 GHz)			
		Ref. [28]	**Ref. [29]**	**Ref. [30]**	-
Peak VSWR	Simulated	7 & 6	4 & 3.5	$>$ 10 & 10	-
	Measured	7 & 6	4 & 3.5	4 & 3	-

two notch bands are summarised and presented in Table 3. As can be seen, the proposed design shows reasonably superior performance than most of the existing studies using both simulation and measured data in terms of higher peak VSWR, equally higher rejection levels in two rejection bands. Moreover, in dual or multiple band-notched UWB antennas, it is difficult to develop compact designs when applying multiple $\lambda/2$ slits or parasitic strips on the radiator or ground plane for realising compact UWB antennas. On the contrary, the technique using quarter-wavelength open-end slit has the advantage of possessing smaller dimension than those using half-wavelength technique, which can result in an attractive feature of enabling to achieve simple and compact designs, in addition to have the attribute of the independent operation of the two closely-placed slits. Therefore, the proposed dual band-notched design proves to be a promising design choice for the UWB applications.

5. CONCLUSION

A new printed monopole antenna with a frequency band-notched function for UWB systems has been presented. The proposed antenna design was found simple, compact and easy to fabricate; including its realization of a single band notch and also multiple frequency band notches. To prove the concept, two prototypes including a UWB antenna with single band notch and a UWB antenna with dual band notches are designed, developed and tested. The antennas have demonstrated good performance in terms of VSWR, input impedance, current distribution, radiation pattern, gain and the group delay. The measured results agreed well with the simulation results. The rejection levels of the dual band-notched design have been compared with those available in the literature. The proposed designs are shown to be able to achieve desired band-notched characteristics, making the design an attractive candidate for the UWB system applications.

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