A Compact Rectangular Patch Ultra Wideband Antenna with WLAN and ITU Band Rejections

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Abstract— A simple and compact ultra-wideband (UWB) antenna integrated with dual band-notched and desirable gain characteristics is presented in this article. The proposed antenna consists of a rectangular-shaped radiator with a partial ground plane and fed by a 50 Ω microstrip line. By inserting two altered H-shaped slots on the proposed radiator, dual band-notch are created to eliminate the wireless local area network (WLAN) and the International Telecommunication Union (ITU) 8-GHz band interfering signals. The presented structure gives an impedance bandwidth ranges from 2.6 to 10.8 GHz while demonstrating the band rejection performance in the targeted frequency band of 5.15 to 5.85 GHz and 8.025 to 8.4 GHz. The proposed antenna has a compact size of 23.5 × 21 mm2. Time domain analysis of the designed antenna indicates stable signal transmission confirming its suitability for short-range UWB impulse radios. This proposed antenna can be used to overcome the coexistence issues caused by the spectrum overlapping between wideband system and other narrowband systems.

Keyword- Compact Antenna, Frequency Notched, Time-domain Analysis, Ultra-wideband

I. INTRODUCTION

Ultra-wideband (UWB) technology has been rapidly advancing as a promising solution for future wireless technology with its appealing features, such as high transmission data rate, low cost, and low power consumption. UWB technology has been authorized the unlicensed use of bandwidth from 3.1 GHz to 10.6 GHz by the Federal Communications Commission (FCC) in 2002 [1]. However, a number of other established narrowband applications also operate within the allocated wide spectrum to UWB technology such as the wireless local area network (WLAN) for IEEE 802.11a operating at 5.15 – 5.825 GHz and the International Telecommunication Union (ITU) 8-GHz band operating at 8.025 – 8.4 GHz [2]. The operation of UWB radios is almost "invisible" for other applications, attributable to the significant low emitted power from UWB radios (EIRP -41.3 dBm/MHz) [3]. Nevertheless, strong signals from other narrowband systems may cause severe electromagnetic interference that can overload the UWB receiver. This condition could affect the overall performance of UWB communication systems in terms of increasing pulse distortion and bit error rate.

One of the key components in the UWB system is an antenna with wideband impedance matching. In order to overcome this unwanted setback, the system needs to be equipped with filtering property. However, the addition of filters will increase the size, weight and complexity of the UWB system and thus lead to increase in cost. For that reason, it is preferable to design UWB antennas with band-notched function in the affected frequency bands.

Numerous researchers have proposed various antenna designs and methods to achieve band-notched characteristic. Among the most popular methods is by embedding complementary resonance elements into either the radiating plane, ground plane or the feed line of the antenna. Some examples of this technique are by inserting slots on the ground plane [4], or embedding slots in the radiating patch [5], or using parasitic strip [6]. Nevertheless, all of the proposed designs above are able to notch only one frequency band. Several band-notched antenna designs with dual band-notch at the WLAN band and the ITU 8.0 band have been reported recently. As an example, a variation of dielectric loading sandwich technique is used to create dual notched band [7]. It is done by gluing a padding patch printed on a single layer substrate on the radiating element of an UWB antenna. However, this method will increase the antenna size in terms of its thickness, thus limits its applications in a compact UWB system. Another approach is to use different resonators to block the unwanted bands [8]. The proposed antenna is a coplanar waveguide (CPW) fed circular slot antenna. The dual band-notched characteristic is realized by inserting a T-shaped resonator inside the circular patch and etching a parallel resonator in the CPW transmission line. Nevertheless, the proposed structures produced an insufficient rejection bandwidth covering more than the targeted band. Consequently, some useful frequencies may have been wasted and can affect the antenna performances in time domain.

In this article, a simple rectangular shaped UWB antenna with a dual band-notched function in the WLAN band and the ITU 8 band is proposed. The antenna has a compact size of 23.5 × 21 mm2 with wideband impedance matching from 2.6 GHz to 10.8 GHz covering the whole UWB spectrum. By etching two altered H-shaped slots on the radiating patch, the targeted frequency band-notched at 5.15 – 5.825 GHz and 8.0 – 8.4 GHz is accomplished. The presented design structure of the band-notched mechanism can be easily extended to other planar UWB antennas. The article is organized in the following sections. Section II presents the geometry of the proposed antenna and its parametric studies. Details of the simulation results and measurement results are discussed in Section III. The time domain characteristic of the radiator is investigated in section IV. Finally, the conclusions are summarized in Section V.

II. Antenna Configuration And Design

The geometry and configuration of the proposed UWB antenna is shown in Fig 1. The antenna is located in the x-y plane and the normal direction is parallel to the z-axis. The antenna is printed on a standard Taconic TLC–30 substrate with a thickness of 1.575 mm, a relative dielectric constant of 3.0 and a loss tangent of 0.003. The antenna consists of a rectangular patch fed by a microstrip line and printed on a partial grounded substrate. The microstrip line feed is designed using standard design equations [9] to match a 50 Ω characteristic impedance. Simulations of the antenna were performed with Computer Simulation Technology (CST) Microwave Studio software. For this proposed model, the optimization was carried out to achieve the best impedance bandwidth. The impedance matching of the proposed antenna is enhanced by correctly adjusting the dimension of the feeding structure and the patch size. In addition, the design and optimization of the ground plane for a compact UWB antenna is critical for the overall antenna performance [2]. Therefore, a rectangular slit is added on top of the ground plane to further enhance the impedance bandwidth of the antenna. As a result, this antenna (will be referred to as Antenna 1 in this article) has a good impedance bandwidth covering the entire UWB frequency range. The optimized parameters of this structure are tabulated in Table I.

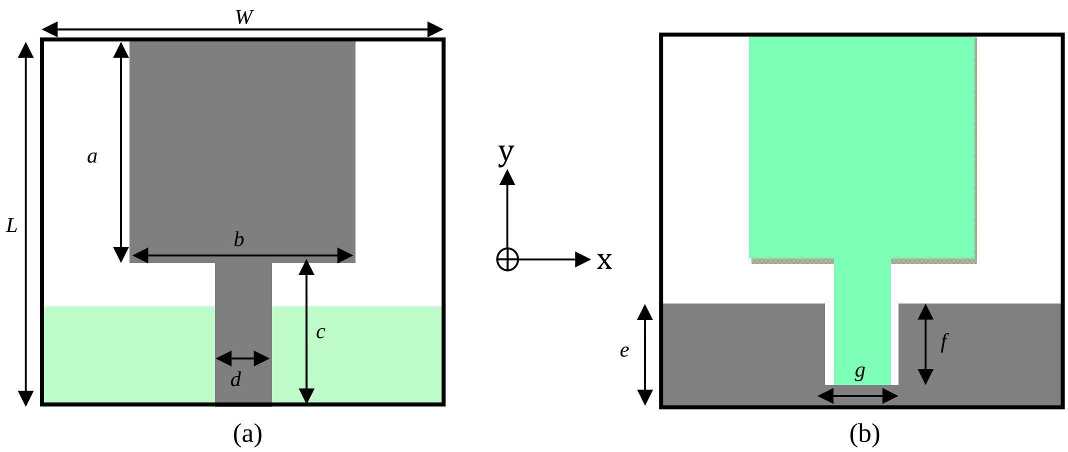


Fig. 1. Geometry of the printed UWB antenna; (a) front view (b) back view

TABLE I. Parameter Value of the Designed Antenna

Parameter	*W*	*L*	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Value (mm)	23.5	21	11.5	13.5	9.5	4.3	6.8	6.3	4.7

The conventional and easy way to achieve band-notched function is by embedding slots on the radiating patch or the ground plane, which results in the changed in the surface current distributions. In this paper, two altered H-shaped slots are etched on the proposed UWB antenna. The geometry and dimensions of the antenna with band-notched design (will be referred to as antenna 2) is illustrated in Fig. 2. The first notch at 5.5 GHz is produced by the outer H-shaped slot while the inner slot created the notch at 8.3 GHz. The previously optimized design parameters of the UWB antenna need no additional retuning work when the band-notched design is applied.

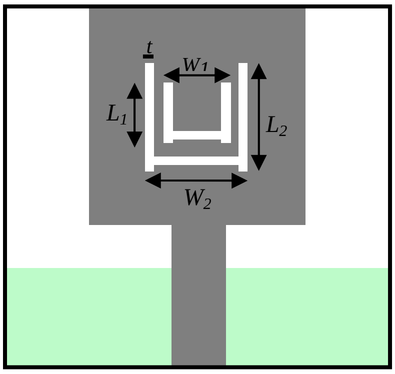


Fig. 2. Geometry of the proposed UWB antenna with H-shaped slots

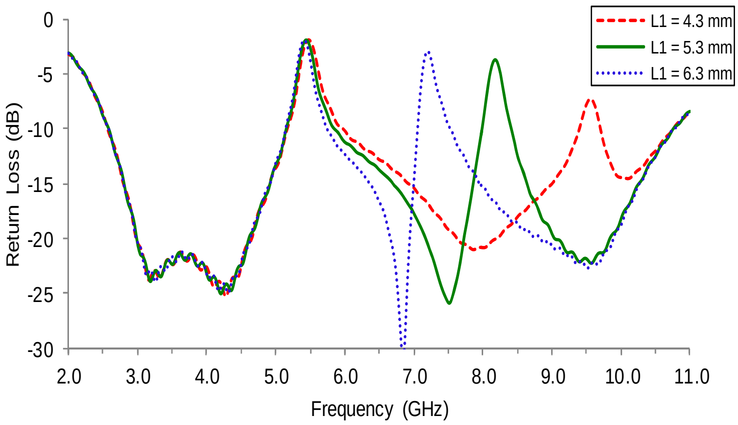
In general, the design concept of the notch function is to adjust the total length of the slot to be approximately half-wavelength at the desired unwanted frequency [10]. As presented in [10], the notch frequency given the dimensions of the band-notched feature can be postulated as in Equation (1)

$$f_{notch} = \frac{c}{2L\sqrt{\varepsilon_{eff}}} \quad (1)$$

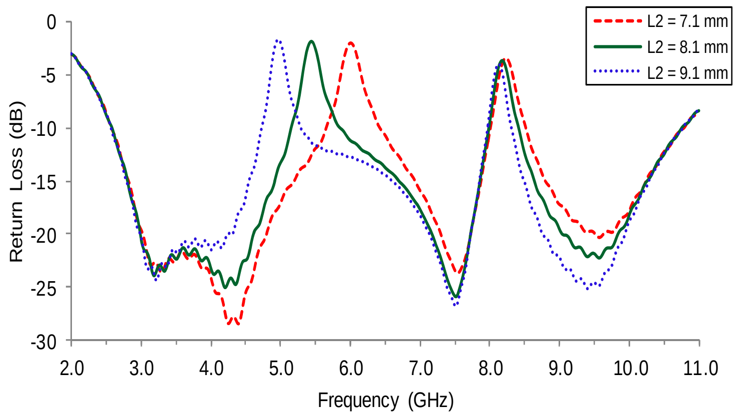
Where L is the total length of the slot, εeff is the effective dielectric constant and c is the speed of light.

Equation (1) is used to acquire the initial total length of a single H-shaped slot at the beginning stage of the design. The analysis of the notched design with different parameters of the slots are performed to get the optimized parameters. From the analysis, it is discovered that the created notched bands are significantly dependent on the length and the width of the H-shaped slots. To gain further understanding on the effects of these parameters to the notch band characteristics, a parametric study has been conducted. In the simulations, the parameter of interest is varied while the other parameters are kept constant.

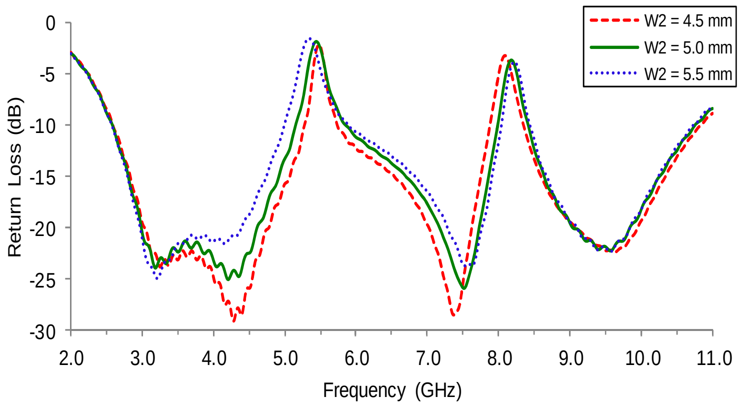
Fig. 3 depicts the simulated return loss for varied values of L1, L2 and W2. L1 is the length of the inner slot, L2 is the length of the outer slot and W2 is the width of the outer slot. The width of the inner slot, W1 is not considered in this analysis since its value is limited by the value of W2. From Fig. 3(a), it is observed that the centre frequency of the upper band notched shifted toward lower frequencies as the value of L1 increased while the lower notched band remains unaffected. On the other hand, the centre frequency of the lower band notched is influenced by the value of L2 as it shifted towards the lower frequency as L2 increased as can be seen in Fig. 3(b). The increment of L2 has no significant effect to the second notched band at the upper frequency. Meanwhile, in Fig. 3(c), it is observed that the bandwidth of the first notched band for WLAN is slightly increased as W2 increased. It is interesting to note that the centre frequency and the second notched band for ITU-band remains unaffected.



(a)



(b)



(c)

Fig. 3. Simulated return loss for different values of (a) L1 (b) L2 and (c) W2

From the above parametric study, it can be stated that the centre frequency for both notched bands is greatly influenced by the length of the corresponding slot. As the length increases, the centre frequency shifted towards the lower frequency. Additionally, the bandwidth of the notched band also can be changed by varying the width of the slot. In this structure, the bandwidth will slightly increase as the slot becomes wider. Therefore, it can be concluded that the band-notch characteristics can be controlled by properly adjusting the length and width of the H-shaped slot. These properties offer a great freedom to properly define the centre frequency and bandwidth of the desired notched band. The final design parameters of the altered H-shaped slot are tabulated in Table II.

TABLE III. Parameter Value of the Band Notched Antenna

Parameter	W_1	L_1	W_2	L_2	t
Value (mm)	3.0	5.3	5.2	8.1	0.6

III. Results And Discussions

The results from frequency domain analysis such as return loss, radiation characteristics and gain of the proposed notched band antenna are presented and discussed in this section.

A. Return Loss

The simulated return loss of the proposed antenna with and without slots are illustrated in Fig. 4. From Fig. 4, it can be seen that the calculated return loss for the antenna without slot (Antenna 1) is less than -10dB from 2.6 GHz to 10.8 GHz. The result indicates that the total bandwidth of the antenna is 8.2 GHz, covering the entire UWB frequency range. There are few resonance frequencies which are in the vicinity of 4.4, 7.6 and 10.1 GHz within the UWB spectrum.

On the other hand, the band-notched characteristic is clearly demonstrated in the return loss curve for the antenna with slots (Antenna 2). Two significant notched bands can be observed in the figure at the targeted WLAN band from 5.15 to 5.85 GHz with a peak at -1.8 dB and the ITU band from 8.025 to 8.4 GHz peaking at -3.6 dB. This result gives a clear indication that by adding the H-shaped slots on the radiating plane, the desirable notched band characteristic can be created.

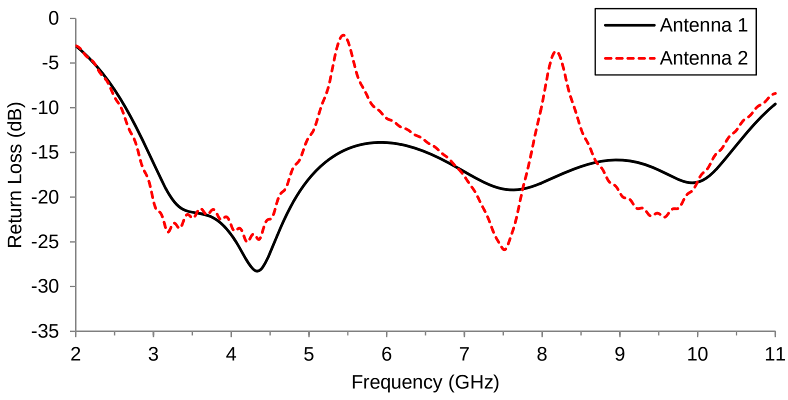


Fig. 4. Simulated return loss of the proposed antennas

The proposed Antenna 2 is fabricated on Taconic TLC-30 substrate with a dielectric constant of 3 and with thickness of 1.575 mm as shown in Fig. 5. The return loss of the fabricated antenna is measured using a calibrated Rhode and Schwarz ZVL vector network analyzer. Fig. 6 illustrates the comparison between the simulated and measured return loss of the band notched antenna. It can be noted that a relatively good agreement is achieved between the measured and simulated results at both of the targeted notched bands. This proposed antenna model has successfully filtered out the WLAN band from 5.3 to 6.0 GHz and the ITU band from 8.0 to 8.4 GHz. However, the depth of return loss at other pass band is marginally reduced in the measurement result. This discrepancy from the simulation result might be due to the effect of imperfect soldering and fabrication tolerance.

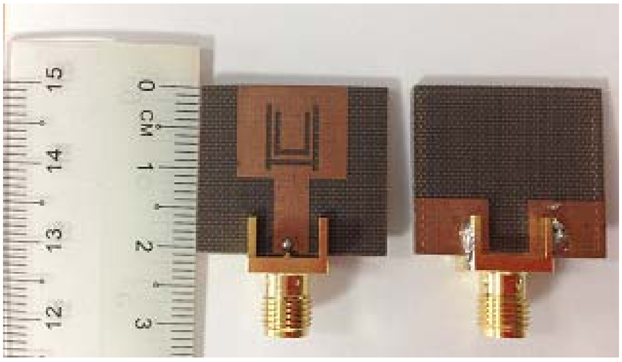


Fig. 5. Photograph of the fabricated Antenna 2

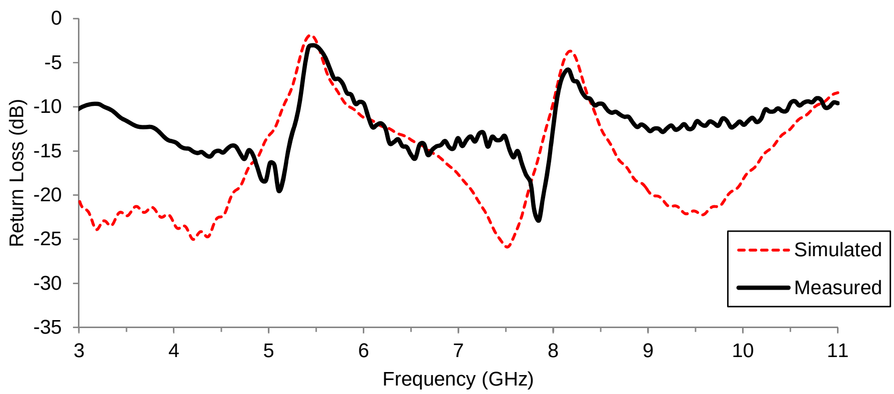


Fig. 6. Measured return loss of the proposed UWB antenna

B. Radiation Patterns

The normalized radiation patterns of the notched band antenna in the E-plane and the H-plane at 3.5 GHz, 5.5 GHz and 7.5 GHz are depicted in Fig. 7. The selection of these frequencies is made in order to demonstrate any degradation in the radiation pattern of the antenna when the frequency notch occurred (5.5 GHz). E-plane is the y-z plane and H-plane is the x-z plane with reference to the antenna orientation.

As can be seen in Fig. 7, the patterns obtained are typical of those for monopole antennas. In the H-plane the pattern is quite omnidirectional while the bidirectional pattern can be observed in the E-plane for all chosen frequencies. Nevertheless, a slight distortion can be noticed in the radiation pattern for the band notch frequency. The radiated field intensity degradation at 5.5 GHz can be justified by the decrease of radiation pattern coverage in both planes. The degradation of radiated field can be further verified by the simulated gain result presented in Fig. 8. Based on the results, it can be stated that the presence of the slot does not initiate any undesirable effect to the radiation pattern performance of the antenna outside the band notch range.

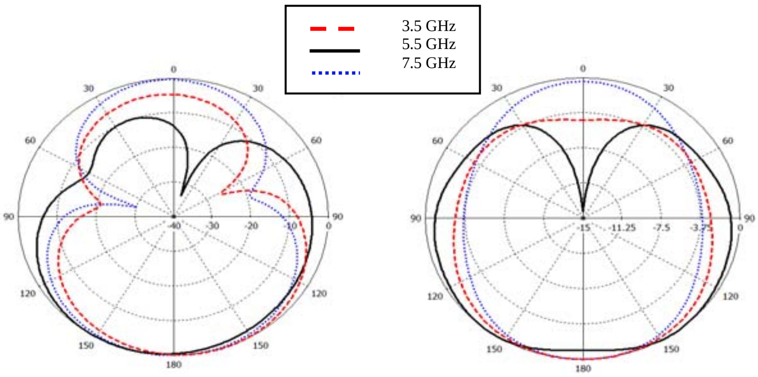


Fig. 7. Simulated E-and H-plane radiation patterns of the antenna at (a) 3 GHz, (b) 6 GHz, and (c) 9 GHz

C. Antenna Gain

Fig. 8 illustrates the variation of gain versus frequency for the notched antenna design. A steady increase in gain can be seen along the frequency and it reaches a peak of approximately 3 dBi at 8 GHz. It is noted that a lower gain causes the radiator to exhibit good omnidirectional characteristics. At the higher frequency band, the gain starting to descend which is expected as it is one of the common feature of UWB monopole planar antenna [11].

On the other hand, a tremendous reduction in the gain plot can be observed at both of the targeted notch bands. The computed peak gain value at 5.5 GHz is –6.6 dBi and a peak gain value of -4.8 dBi is recorded at 8.2 GHz. These values confirmed the expected gain reduction over the targeted notched band and explained the distortion in the radiation pattern at the notch frequency. In addition, the gain plot also validates the antenna's ability to reject the unwanted signal frequencies within the targeted bandwidth.

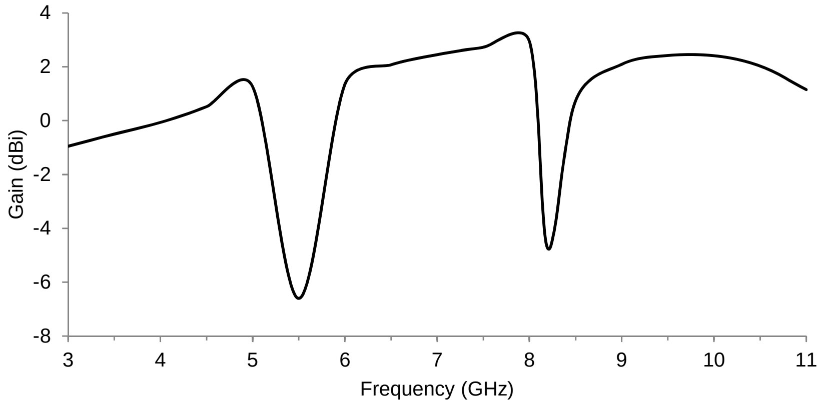


Fig. 8. Simulated gain of the antenna

IV. TIME DOMAIN ANALYSIS

In order to achieve multipath immunity, UWB systems transmit data by using short pulses in large frames. Such a characteristic helps minimizing the inter-symbol interference at the receiving end of the systems. As reported in the previous section, the proposed UWB antenna has a very wide impedance bandwidth. Nonetheless, having a broadband frequency domain response does not guarantee a proper radiated pulse shape signal in time domain. Thus, it is important to evaluate the antenna's performance in the time domain. This analysis is done to ensure that the designed antenna can transmit the UWB pulse signal without deteriorating its pulse shape.

For dispersion analysis in time domain, the fifth-order Gaussian monocycle signal is chosen as the input pulse with mathematical form in Equation 2.

$$s_1(\mathrm{t}) = \mathrm{GM}_5(t) = \frac{\mathrm{e}^{-t^2/2\sigma^2}}{\sqrt{2\pi}}\left(-\frac{t^5}{\sigma^{11}} + \frac{10t^3}{\sigma^9} - \frac{15t}{\sigma^7}\right) \quad (2)$$

This input pulse as illustrated in Fig. 9, is designed to fulfil the limitation set by the FCC and to comply with the specified emission standards for pulse width factor σ = 51 ps. The distortion between source pulse and output pulse can be quantified using the system fidelity index. The definition of the fidelity factor, F is given by Equation 3.

$$F = \max_{\tau}\left\{\frac{\int_{-\infty}^{\infty} s_1(\mathrm{t})s_1(\mathrm{t}-\tau)\mathrm{d}\tau}{\int_{-\infty}^{\infty}\sqrt{s_1{}^2(\mathrm{t})\mathrm{dt}}\int_{-\infty}^{\infty}\sqrt{s_2{}^2(\mathrm{t})\mathrm{dt}}}\right. \quad (3)$$

τ is a delay which is varied to make the numerator in Equation 3 attain a maximum value [11]-[12]. F = 1 indicates that the propagated source signal is undistorted and the received pulse waveform can be characterized completely. The pulse fidelity of the proposed antenna is assessed by placing three virtual probes in the far field region at θ = 0°, 45° and 90°. The corresponding received pulse waveforms as seen by the virtual probes for all scenarios are plotted in Fig. 10.

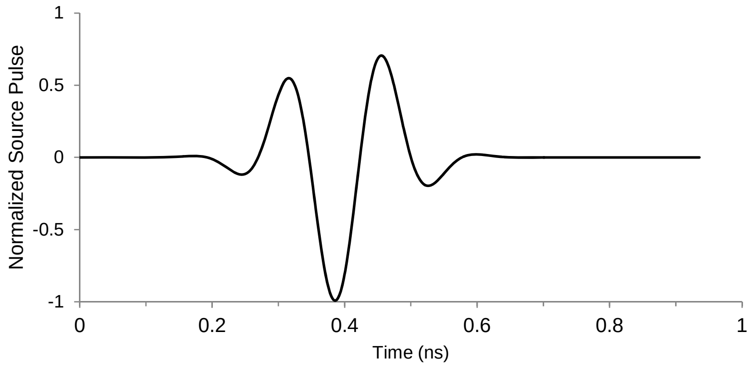


Fig. 9. Normalized antenna input signal

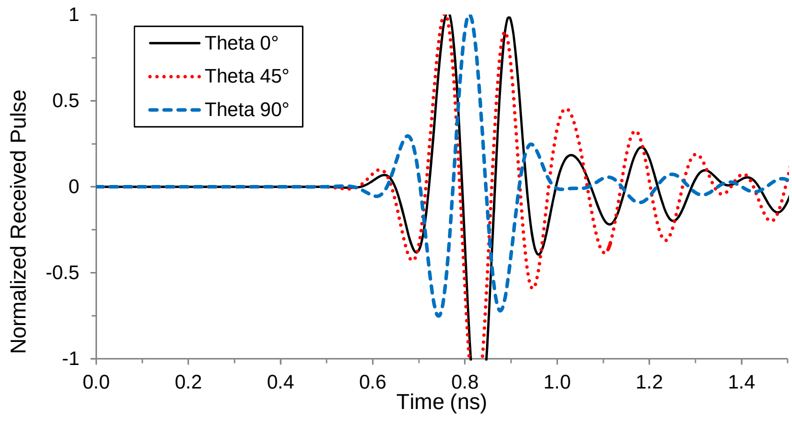


Fig. 10. Received pulse for various elevation angles

From Fig. 10, it can be described that the received pulse waveforms are almost identical for all the designated angles. However, a small ringing effect is observed in the received signal. This is principally due to the energy storage effect of the dielectric substrate. The correlation factors for various elevation angles between the transmitted and received signals are computed and tabulated in Table III. It is found that the fidelity values are more than 0.93 for all angles. These results imply that the proposed antenna can transmit the UWB pulse signal without introducing the dispersion effect.

TABLE IIIII. Fidelity of the Designed Antenna

Angle, θ	0	45	90
Fidelity, F	0.9494	0.9524	0.9356

V. CONCLUSION

A simple rectangular microstrip antenna design for UWB applications is presented and discussed in this article. The impedance bandwidth of the designed antenna ranges from 2.6 to 10.8 GHz. It has adequate impedance bandwidth and stable radiation patterns throughout the UWB spectrum. Dual notched bands are created from 5.15 to 5.85 GHz and 8.025 to 8.4 GHz by etching two altered H-shaped slots on the radiating patch. Time domain studies on the antenna show good performance in the pulse-preserving capabilities. These desirable features make the proposed antenna a suitable candidate to overcome the coexisting issue between WLAN systems and ITU band satellite services with UWB system.

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