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COMPACT DUAL BAND-REJECT UWB ANTENNA WITH SHARP BAND-EDGE FREQUENCY

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Abstract—A microstrip line fed dual band-reject ultra wideband antenna with sharp band edge frequency of 3.1–10.6 GHz is presented. The antenna consists of a rectangular patch on the front side and a partial ground plane at the rear. A step is cut on the bottom edge of the patch for impedance matching. A split ring slot etched on the radiating patch rejects WiMAX (3.3–3.8 GHz) band, and a pair of inverted S-shaped slot in the partial ground plane rejects WLAN (5–6 GHz) band. In order to eliminate the radiation outside the FCC specified 3.1–10.6 GHz band, a rectangular slot is etched on the ground plane below the feed line. The antenna exhibits UWB band width of 109% except for the notch band. The radiation characteristics are consistent throughout the band. The performance of the antenna is analyzed both in the frequency domain and time domain to assess its suitability for ultra wideband communication. Pulse distortion of the antenna is investigated for both Rayleigh and Gaussian source pulse excitation.

1. INTRODUCTION

The FCC (Federal Communications Commission) allocated 7.5 GHz (3.1 GHz–10.6 GHz) for UWB indoor applications [1]. One of the challenges for the implementation of UWB system is the development of compact antenna with linear phase characteristics, high radiation efficiency and omnidirectional pattern [2]. Broadband monopole antennas are attractive owing to large bandwidth, omnidirectional radiation pattern, compact size and ease of design. Various monopole antennas have been investigated and reported in literature [3–5].

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To prevent interference with the existing wireless networks such as WiMAX (3.3–3.8 GHz) and WLAN (5.15–5.35 GHz and 5.725–5.825 GHz) band, UWB system with stop band characteristics are required. However, the use of additional filter would increase the complexity of UWB systems. To tackle this problem, several novel UWB antennas with band-notched characteristics have been presented [6, 7]. The most popular and easiest technique is to embed a U, C, V-slot or slit in the radiator or ground plane. However, most of these designs have only single band-notched characteristic because, either the space occupied by these slots or slit is very large or notch bandwidth exceeds 2 GHz band. The main problem of the frequency rejected design is the difficulty of controlling the width of the notch band within a limited space. Therefore, obtaining an efficient band-notched characteristic is a challenging issue and is difficult to implement. A few papers address the dual or multiple band-notch design [8, 9]. It has to be noted that most of the presented works focus on the rejection of a single band within the 4.9–5.9 GHz. These works have paid no attention to the FCC recommendation that the radiation from the UWB transmitters should be eliminated or reduced outside the specified 3.1–10.6 GHz band [10].

UWB communication systems are based on the exchange of very fast time domain pulses between transmitter and receiver. Their time domain studies are of intense significance for high speed pulsed communication. Time domain characteristics of the antenna have also been addressed [11–18].

In this paper, a UWB antenna with dual band reject characteristic and sharp band edge frequency is presented. The antenna consists of a rectangular radiator in the front side with single step and a partial ground plane at the back. A pair of S-shaped slots cut in the ground plane rejects the WLAN (5–6 GHz) band and a split ring slot etched on the radiating patch rejects WiMAX (3.3–3.8 GHz) band. The size and location of the S-shaped slot and ring slot is optimized to control the width and length of the notched band according to the practical requirements. Furthermore a rectangular slot is etched on the ground plane to eliminate the frequency outside 3.1–10.6 GHz. The performance of the antenna is analyzed both in frequency domain and time domain.

2. ANTENNA DESIGN

The geometry and configuration of the proposed antenna is shown in Figure 1. The antenna is printed on a FR4 substrate with a dielectric constant of 4.4, loss tangent of 0.021. The length of the feed line is

$0.5\lambda_g$ and width is 3 mm for a line impedance of $50\,\Omega$. The patch is a rectangular radiator with a single step cut in the lower edge of the radiator. The steps cut in the radiating patch plays an important role in achieving wide bandwidth. The notch cut at the lower edge of the radiator introduces a capacitive reactance which counteracts the inductive reactance of the feed. The antenna impedance bandwidth is further broadened by optimizing the location of the feed point. The

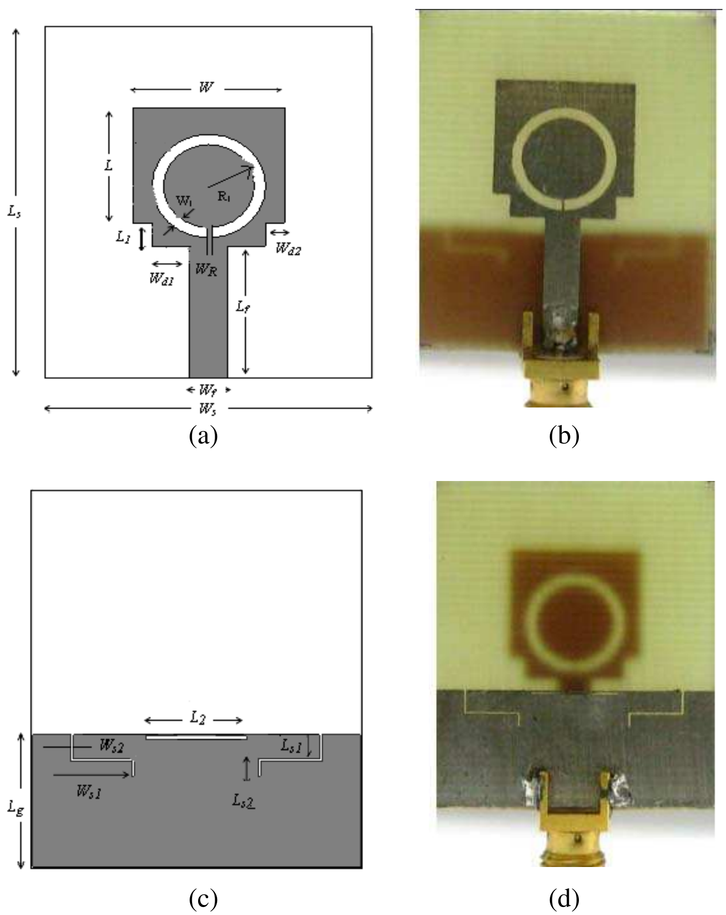


Figure 1. Geometry of the proposed antenna: (a) Front view, (b) front view of fabricated antenna, (c) back view, (d) back view of fabricated antenna. ($W_s \times L_s = 26 \times 30\,\text{mm}^2$, $W_f = 3\,\text{mm}$, $L_f = 11\,\text{mm}$, $W \times L = 12 \times 10.5\,\text{mm}^2$, $W_{d1} = 3\,\text{mm}$,, $L_1 = 2\,\text{mm}$, $W_{d2} = 1.5\,\text{mm}$, $W_1 = 0.5\,\text{mm}$, $W_R = 0.6\,\text{mm}$, $R_1 = 4.5\,\text{mm}$, $L_g = 10.5\,\text{mm}$, $W_{s1} = 4.95\,\text{mm}$, $W_{s2} = 0.2\,\text{mm}$, $L_{s1} = 2.2\,\text{mm}$, $L_{s2} = 1.4\,\text{mm}$, $L_2 = 8\,\text{mm}$).

coupling between the ground plane and feed is adjusted appropriately, thereby providing wide impedance bandwidth. The length of the monopole antenna is determined from [5].

$$f_L = \frac{7.2}{L + r + g}\,\text{GHz}$$

f_L is the lowest resonant frequency (GHz),

L is the length of the planar monopole antenna in cm,

r is the effective radius of the equivalent cylindrical monopole antenna, cm,

g is the gap distance in cm.

The dimension of the substrate is $30 \times 26\,\text{mm}^2$ and that of partial ground plane is $10.5 \times 26\,\text{mm}^2$. Notched band can be generated by etching slots with different shapes. The slot can be placed either horizontally or vertically and is determined by the shape and size of the patch or the ground plane. Due to limited size of ground plane, two $\lambda/4$ S-shaped slots are positioned symmetrically on either side of the feed line on the ground plane to reject 5–6 GHz band. A circular ring slot is etched on the radiator to reject WiMax band. A narrow rectangular slot is etched on the ground plane beneath the microstrip feed line to eliminate the frequency outside 3.1–10.6 GHz. The optimal dimension of the antenna and the photograph of the fabricated antenna are shown in Figure 1.

2.1. Parametric Analysis

It has been observed that the operating bandwidth of the antenna critically depends on the width and length of the steps cut in the radiator and the gap between radiator and ground plane. The critical dependence of the width and length of the antenna is optimized for maximum bandwidth. The parametric study is carried out to design and optimize the antenna for wide impedance bandwidth and band reject performance using commercial simulation tool CST which is based on the Finite Integration Technique. The results of this parametric study as seen in Figures 2–7 are summarized as follows:

i. Variation of reflection coefficient of the antenna for different width $W_{d1} = 1$, 2, 3 and 4 mm is shown in Figure 2. Further increase in W_{d1} varies the lower band frequency leading to the reduction in upper operating band of the antenna. The optimum performance of the antenna is obtained for $W_{d1} = 3\,\text{mm}$.

ii. Another important factor affecting the bandwidth performance of the antenna is length L_1. Figure 3 depicts the reflection coefficient of the antenna for different length $L_1 = 1$, 2 and 3 mm and an optimal width $W_{d1} = 3$ mm. When L_1 increases beyond 2 mm impedance matching worsen in the mid band at 6 GHz, hence optimum length L_1 is found to be 2 mm.

iii. The simulated reflection coefficient for different width $W_{d2} = 1$, 1.5 and 2 mm is shown in Figure 4. It is clear from the figure that variation of W_{d2} degrades the mid frequency at 6 GHz and an optimum value of W_{d2} is found to be 1.5 mm.

iv. Another factor affecting the matching and bandwidth of the antenna is the gap g between the monopole and ground plane. Variation of reflection coefficient for different gap spacing g ($g = 1$, 1.5 and 2 mm) is illustrated in Figure 5. Low value of g affects the matching in midband and high value of g widens the impedance bandwidth beyond the specified frequency. Optimum value of g is found to be 1.5 mm.

v. Figure 6 illustrates the variation of reflection coefficient with different ground slot width and length. It is clear from the figure that without the slot, bandwidth exceeds the specified frequency of 3.1–10.6 GHz. Parametric study reveals that the optimum value of ground slot length for eliminating the frequency outside 3.1–10.6 GHz frequency is $0.186\lambda_m$ and $0.069\lambda_m$, where λ_m is the mean frequency.

vi. The simulated reflection coefficient of circular slot and split ring slot is shown in Figure 7. It can be observed that a spurious notch band occurs in the vicinity of 5.5 GHz increasing the notch frequency band beyond the desired band of 6 GHz up to 8 GHz. The spurious band notch characteristic of circular slot is reduced by employing split ring slot resonator structure which has high Q factor at microwave frequency. The split ring resonant structure rejects 3.3–3.83 GHz due to its property of high Q factor and a pair of slits in the ground plane rejects the WLAN 5–6 GHz band.

3. RESULT AND DISCUSSION

The proposed optimized antenna was fabricated and the return loss characteristics were measured using Agilent N5230A network analyzer. A sharp increase in reflection coefficient is observed at notched frequency band of 3.3–3.83 GHz and 5–6 GHz as shown in Figure 8. The simulated and measured results were in close agreement. Measured results shows that the impedance bandwidth is 7.5 GHz stretching over the frequency range from 3.125 GHz to 10.625 GHz for $S_{11} < -10$ dB.

The radiation characteristics of the fabricated antenna were measured in an anechoic chamber. The measured E-plane and H-plane radiation patterns at 4.5, 6.5 and 8.5 GHz respectively are illustrated in Figure 9. The radiation characteristics are constant through the band with good omnidirectional characteristics in the H-plane and monopole like in E-plane except for the notch band. In general, the simulated and measured results are fairly consistent at most of the frequencies

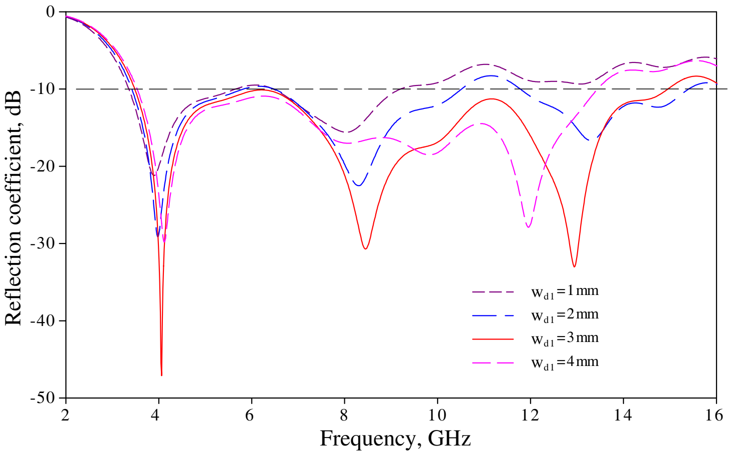


Figure 2. Variation of reflection coefficient of the antenna for different W_{d1}.

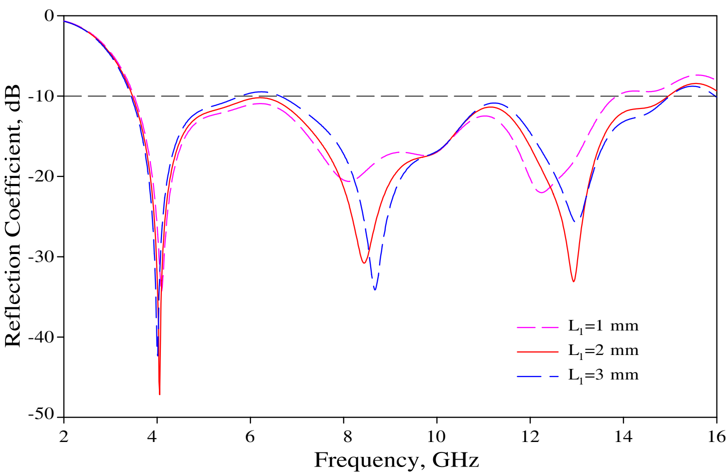


Figure 3. Variation of reflection coefficient of the antenna for different L_1.

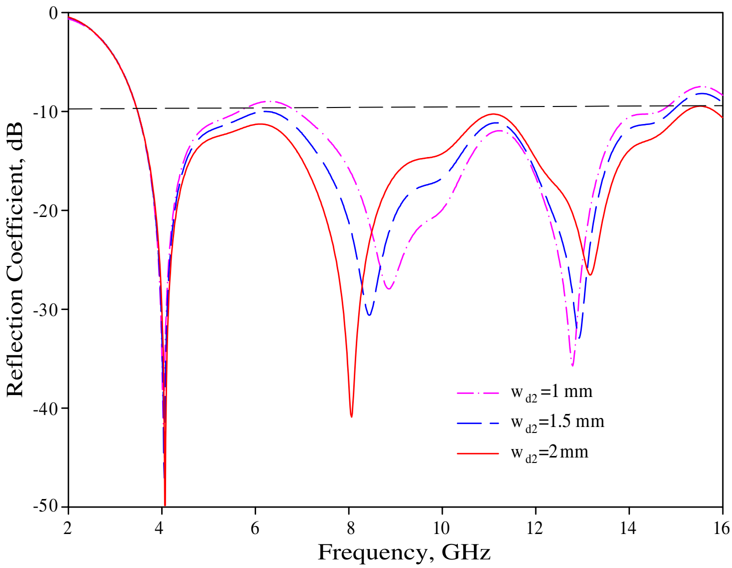


Figure 4. Variation of reflection coefficient of the antenna for different W_{d2}.

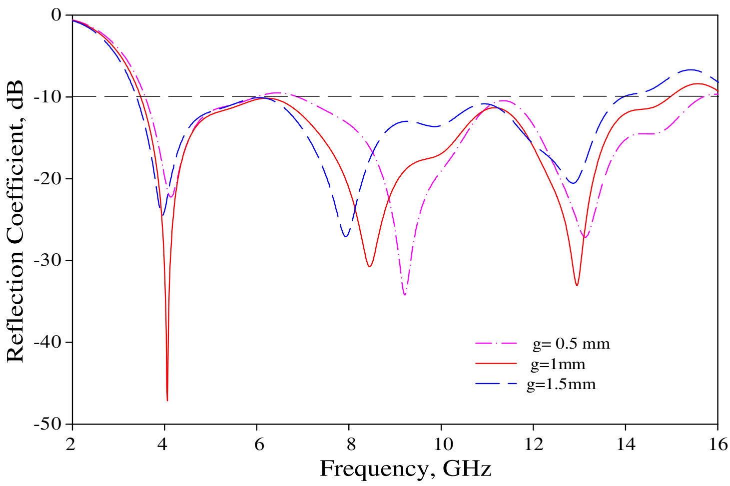


Figure 5. Variation of reflection coefficient of the antenna for different g.

but some discrepancies were noticed at higher frequencies especially in the E-plane which may be due to the destructive interference. The measured antenna gain is presented in Figure 10. It can be seen that the antenna gain is reasonable with a peak gain of 3.9 dBi and with the lowest at the center frequency of notched band.

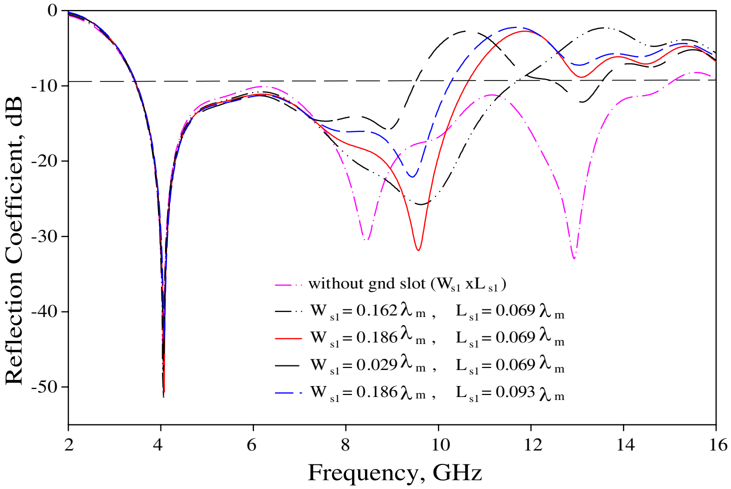


Figure 6. Variation of reflection coefficient of the antenna for different slot length and width.

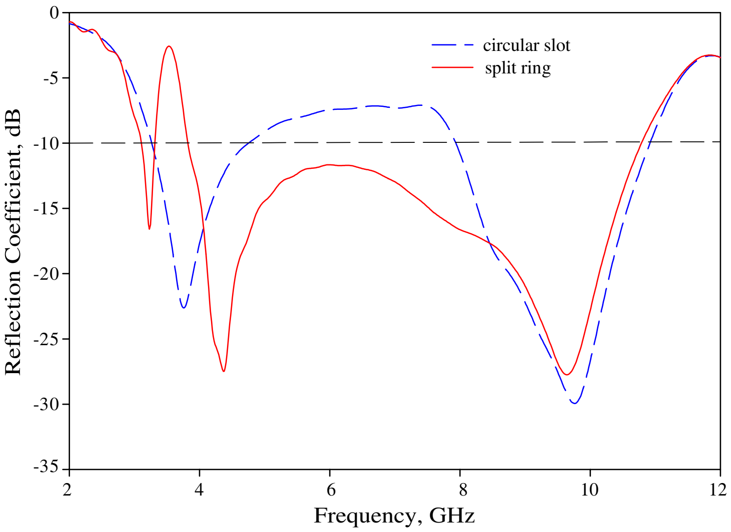


Figure 7. Comparison of circular ring slot and split ring slot.

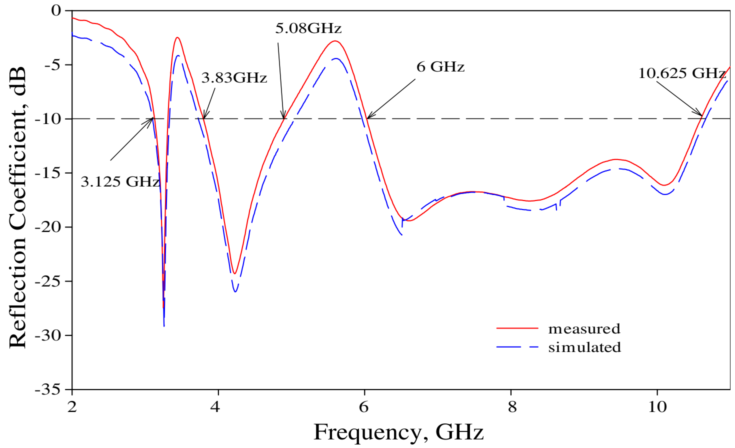


Figure 8. Simulated and measured reflection coefficient of the antenna.

Table 1. Fidelity factor.

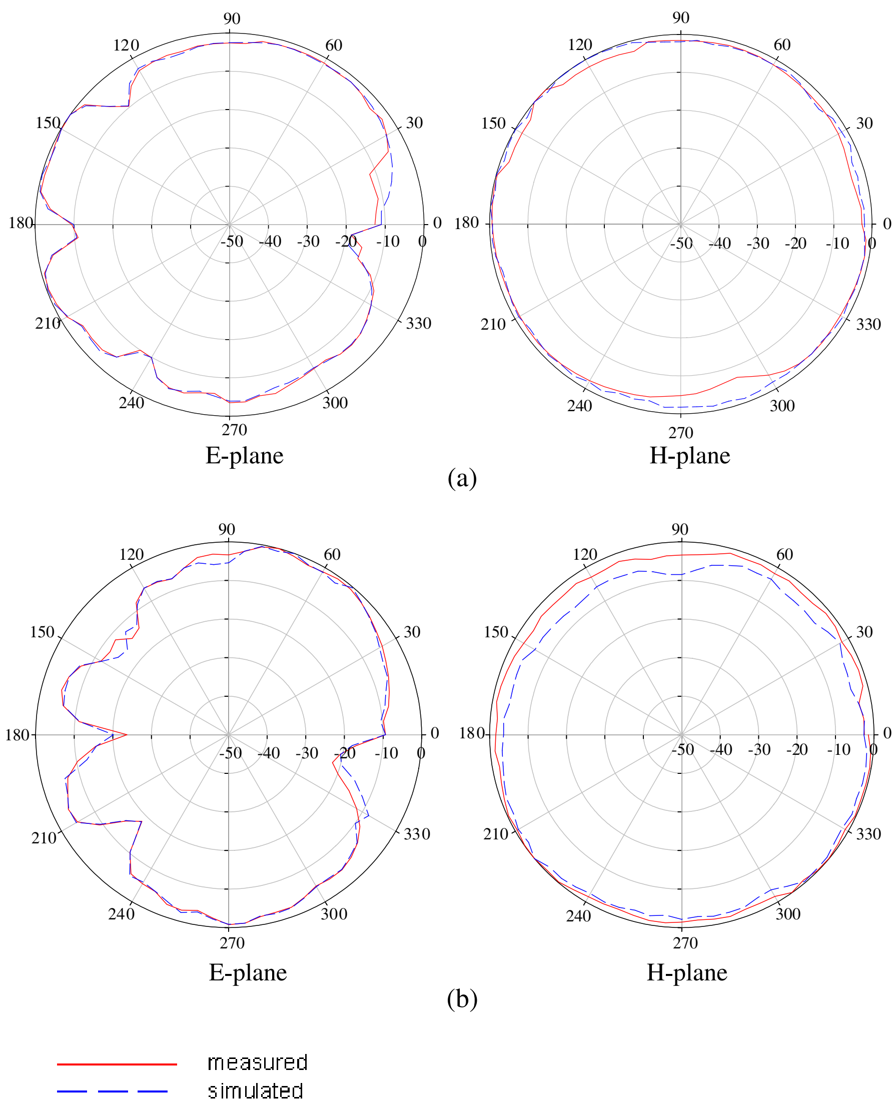
Probe position (θ)		**0°**	**30°**	**45°**	**60°**	**90°**
Rayleigh	E-Plane	0.9119	0.91609	0.91027	0.89106	0.86472
	H-Plane	0.9119	0.85816	0.80446	0.7083	0.69858
Gaussian	E-Plane	0.94107	0.94797	0.9286	0.92252	0.89557
	H-Plane	0.94201	0.88559	0.81647	0.7165	0.70432

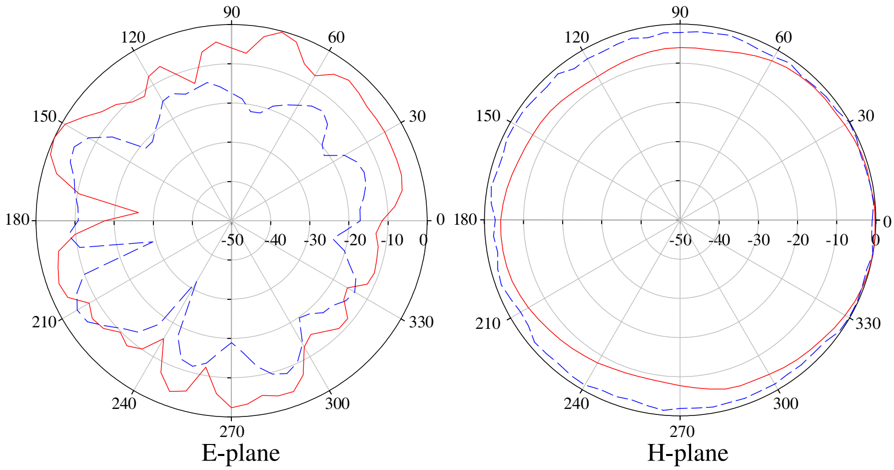
4. TIME DOMAIN ANALYSIS

UWB communication is based on the exchange of very fast time-domain pulses between a transmitter and receiver. Apart from the classical antenna characteristics in the frequency domain such as bandwidth, radiation pattern and gain, unambiguous depiction of time domain performance of the antenna are crucial. Group delay, antenna transient response and fidelity factor are significant time domain characteristics of the UWB antenna. It is imperative to know the input signal while designing, since the antenna element acts as band pass filter in transmitting the energy within the operating band. For this reason the input pulses are selected such that their corresponding power spectra and 10 dB bandwidth fully occupy the desired 7.5 GHz ultra wideband required by FCC. In this study, transmitting antenna is excited with two types of input sources, one is the first order Rayleigh pulse and the other fourth derivative Gaussian pulse as shown in

Figure 11 whose radiated PSD falls within the FCC indoor and outdoor masks.

Group delay quantitatively evaluates the non-dispersive behavior of the antenna, which is defined as the derivative of far-field phase response with respect to frequency. If group delay variation exceeds 1 ns, phases are no longer linear in the far field region and a pulse distortion is caused which can be a serious problem in UWB communication. The group delay performance of the antenna is





(c)

Figure 9. Radiation pattern of the antenna at (a) 4.5 GHz, (b) 6.5 GHz, (c) 8.5 GHz.

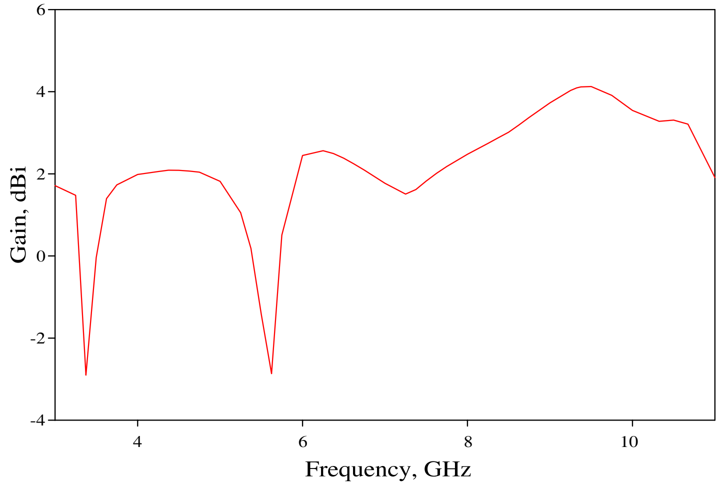


Figure 10. Measured gain of the proposed antenna.

illustrated in Figure 12. It can be clearly observed that the group delay of the antenna is stable with less than 1 ns variation throughout the band except for the notch band satisfying the requirement of linear phase response.

Fidelity qualitatively describes how similar the received pulses are to the incident pulse. This factor is used to assess bit error rate performance and pulse distortion capability. Probe fidelity parameter involving auto correlation of the difference of time domain waveform with different source pulses such as Rayleigh pulse (pulse characteristic time of 45 ps) and fourth derivative Gaussian pulse (pulse characteristic time of 50 ps) are chosen as template functions. Fidelity between transmit and receive antenna is evaluated by performing the transceiver setup in CST by placing virtual probes at 20 cm away from antenna in XZ plane as illustrated in Figure 13. An ideal value of unity fidelity factor implies the two pulses are exactly same in shape. The fidelity factor better than 0.97 implies, the distortion introduced by the

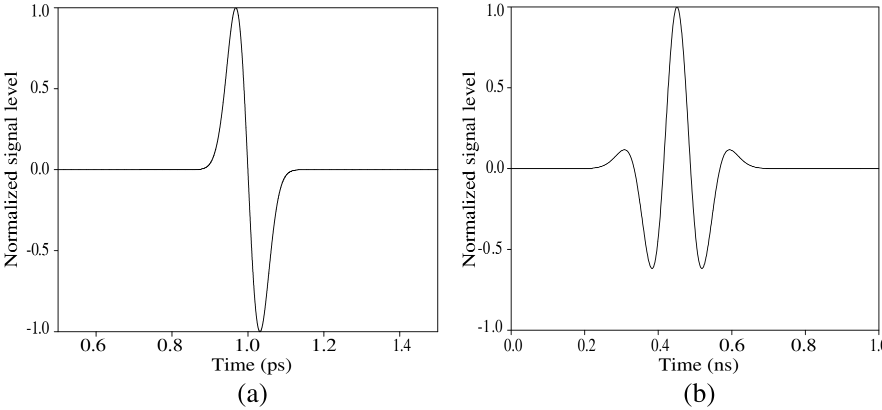


Figure 11. Normalized source pulse waveform (a) Rayleigh pulse, (b) fourth derivative Gaussian pulse.

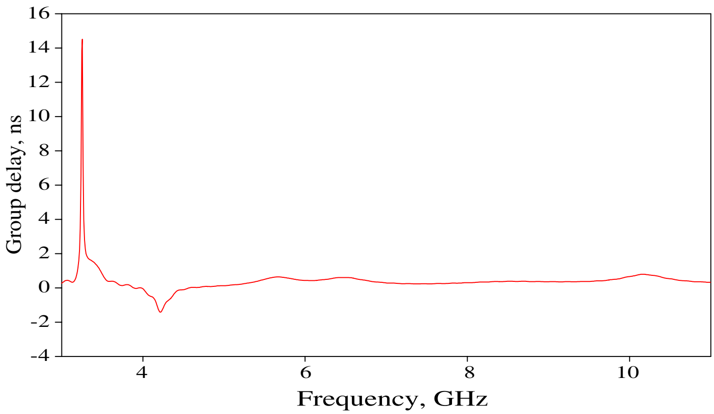


Figure 12. Group Delay of the antenna.

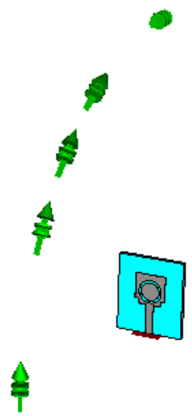


Figure 13. Probe location for fidelity in CST.

antenna is smaller. The fidelity factor between virtual probe signal and transmitted pulse presented in Table 1 demonstrates that the fidelity factor for Gaussian excitation is better than the Rayleigh excitation which may be due to the partial distribution of energy outside the working band for Rayleigh excitation.

5. CONCLUSION

A compact printed UWB antenna with dual band reject characteristics has been developed and analyzed. Radiation outside FCC recommended 3.1–10.6 GHz is achieved by etching rectangular slot in the ground plane. Dual band reject performance at 3.3–3.7 GHz and 5–6 GHz is obtained by etching split ring slot and S shaped slot. The measured gain of the fabricated antenna is nearly omnidirectional. Pulse distortion of the antenna is investigated for different source pulse excitation. The antenna exhibits good performance in both frequency domain and time domain and can be employed in UWB communication systems.

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