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Compact Integrated Bluetooth UWB Antenna with Quadruple Bandnotched Characteristics

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ABSTRACT

In this paper, a compact printed dual band antenna for Bluetooth and UWB applications with Wi-MAX (3.3-3.7GHz), C-band satellite downlink (3.7GHz-4.2GHz), WLAN (5.15-5.825GHz) and DSRC (5.50-5.925GHz) band notched characteristics is proposed and investigated. By etching two half wavelength L-shaped slots in the radiating patch and an inverted U-shaped slot in the microstrip feed line the quadruple band notched characteristics are obtained. Further, by embedding quarter wavelength parasitic strip at the two edges of U-shaped radiating patch the dual band characteristic with desired bandwidth is obtained. The proposed antenna is designed and fabricated on a FR4 substrate with dimensions of 24 × 35mm^{2}that operates over a 2.4 to 11GHz with S11 ≤ -10dB except over notch bands of 3.3-3.7GHz, 3.7-4.2GHz, 5.15 to 5.625 GHz and 5.625-6 GHz. Directional pattern in E-plane and nearly omnidirectional pattern in H-plane are observed over a UWB band except at desired band-notched frequencies. Less variations in group delay and pulse deformation shows good time domain characteristics. In addition, the structure exhibits stable gain over the desired band.

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1. INTRODUCTION

Since 2002, after the declaration of unlicensed free frequency band of 7.5GHz (3.1GHz ~10.6GHz) for ultrawideband (UWB) communication by Federal Communication Commission (FCC) [1], the UWB antenna became more popular. UWB antennas are most widely used in UWB systems because of its attractive features such as light weight, small size, low profile, low cost and higher data rate. Various applications of UWB antenna such as imaging, remote sensing, location tracking, sensor networks and medical attracted industry people and researchers towards design of UWB antenna. Numerous designs of UWB antenna have been reported in [2]-[5].However the existing narrowband wireless communication system such as 3.3 to 3.7 GHz (Wi-MAX), 3.7-4.2 GHz (C-band satellite), 5.15 to 5.825 GHz (WLAN) ,7.25-7.75 GHz (X-band satellite communication system) and 8.025-8.4GHz (ITU-band) causes potential interferences to the UWB systems operating over 3.1-10.6GHz. UWB antenna is the most important element of UWB system and should provide a band notched characteristics to avoid the potential interferences of the forementioned band.

Interferences of these narrow band systems with UWB system can be eliminated with the use of filters which leads to increased size, cost and complexity of UWB system. Design of the UWB antenna with band notched characteristics is the effective and simple method to avoid the interference. Two major limitations of UWB antenna with multiple band notch functions are mutual coupling of multiband rejection element and space restrictions in the compact UWB antenna [6]. Several different techniques have been proposed and reported in literature to band notch single and multiple frequency bands [7]-[12]. In [7] crescent slot, U-slot [8] and compact coplanar waveguide (CPW) resonant cell (CCRC) [9] are used to realize single band-notched function. In [10] two nested c-shaped stubs gives dual notched band, interdigital capacitance loading loop resonator (IDCLLR) generates dual notched bands [CLL] in [11]. In [13] composite resonator with multiple resonant characteristics is used for obtaining triple band notched characteristics. Bluetooth Special Interest Group (SIG) in 2006 selected Wi-Media Alliance multiband orthogonal frequency division multiplexing (MB-OFDM) version of UWB, which could be integrated with Bluetooth wireless technology [14].This license free frequency band is integrated with the another license free UWB frequency band to facilitate the advantages of both Bluetooth and UWB frequency band for different applications in limited available space. Dual band antenna operating in Bluetooth and UWB proposed by [15]-[16] but without band notch characteristics. The UWB antenna with integrated Bluetooth and band-notched characteristics is investigated in [17]. L-shaped stubs of quarter wavelength placed in the ground plane near feed line and besides the radiating patch to create a resonance at Bluetooth and dual band notching respectively in [18].

In this paper a simple, compact, microstrip feed printed dual band antenna for Bluetooth and UWB applications with Wi-Max & C-band satellite down link and WLAN & DSRC (dedicated short range communication) quadruple band notched characteristics is proposed. The proposed antenna consists of a U-shaped radiating element feed by a 50Ω microstrip line with modified ground plane. A pair of L-shaped slots in the radiating patch and inverted U-shaped slot in feed line is etched to obtain the 3.3-4.2GHz and 5.15-6GHz band notched characteristics respectively. Two parasitic elements at the edge of the U-shaped radiator are used to resonate at 2.45GHz frequency. The proposed antenna is designed, simulated, fabricated and tested. Simulation is carried out using method of moments based electromagnetic simulation software CAD FEKO (6.2 suite).

2. ANTENNA DESIGN

The geometry of the proposed dual band UWB antenna with band notched characteristics is illustrated in Figure 1. The proposed antenna is designed on a FR4 dielectric substrate with dielectric constant (ε_r) =4.4, loss tangent (tanδ) = 0.02 with thickness of 1.6mm.U-shaped radiating patch is feed by a printed microstrip line on the top side of the substrate and printed modified ground plane with a size of $W_{sub}\times L_{gnd}$ (24 × 10 mm^2) on the bottom side of the substrate. To obtain the 50Ω characteristics impedance, width (w_f) and length (l_f) of microstrip fed line is fixed at 3mm and 11mm respectively. The total dimension of the proposed antenna is 24 × 35mm^2.

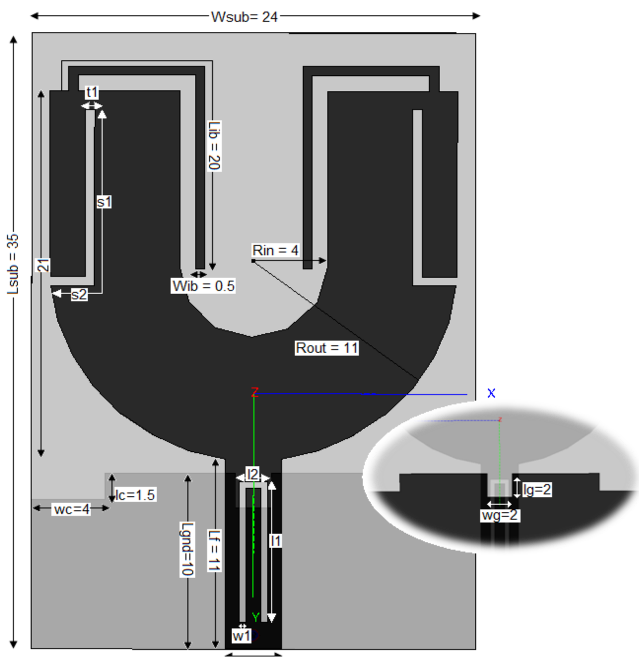


Figure 1. Geometry of Proposed antenna

Table 1. Optimum Dimensions of Proposed Antenna (All Dimensions are in mm)

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
Wsub	24	Lsub	35	Lf	11	Wf	3	Rin	4
Rout	11	wc	4	lc	1.5	Lgnd	10	wg	2
lg	2	Lib	20	Wib	0.5	s1	10	s2	1.5
w1	0.35	l1	8	l2	1.2	t1	0.5		

The structure is evolved from the semicircular monopole antenna to U-shaped radiator and the proposed one. The lower band edge frequency ‘f_l’ of UWB has been determined using formulas [4] as given in Equation (1).

$$f_l = \frac{7.2}{\{(L+R_{out}+L_f)*k\}} \quad (1)$$

Where, L = effective length of the circular monopole, k = 1.15 is taken empirically for a dielectric substrate with ε_r= 4.4 and dielectric thickness of 1.6mm, R_{out}=11mm.

Further, two rectangular slots are cut from the edges of the modified ground plane to enhance the impedance matching in UWB frequency band. To prevent the interferences of Wi-MAX & C-band satellite downlink frequency and WLAN& DSRC narrow band systems, a pair of L-shapedslot in the radiating patch and an inverted U-shaped slot is etched in the microstrip feed line are etched respectively. The lengths of the slot has been taken about half the guided wavelength:

$$L_{SLOT} = \frac{\lambda_g}{2} \quad (2)$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \quad (3)$$

Where, ε_{reff} = effective dielectric constant = $(\varepsilon_r + 1)/2$, λ_0 = free space wavelength = C_0/f_r, C_0= velocity of light signal and f_r= centre frequency of the notch band.

The total length of L-shaped pair, $Lslot_1= 2(s_1+s_2+t_1)$ = 24.6mm is etched in the radiating patch to generate a notch for first two consecutive bands centered at 3.7GHz (3.3-3.7GHz &3.7-4.2GHz) and second inverted U-slot $Lslot_2 =(2l_1+l_2+2t_2)$ = 16.52mm is etched in the microstrip feed line to generate a next consecutive notch bands centered at 5.5GHz (5.15-5.825GHz & 5.50 to 5.925GHz).The optimized dimensions of $slot_1$ and $slot_2$ are 24mm and 19.1mm respectively.

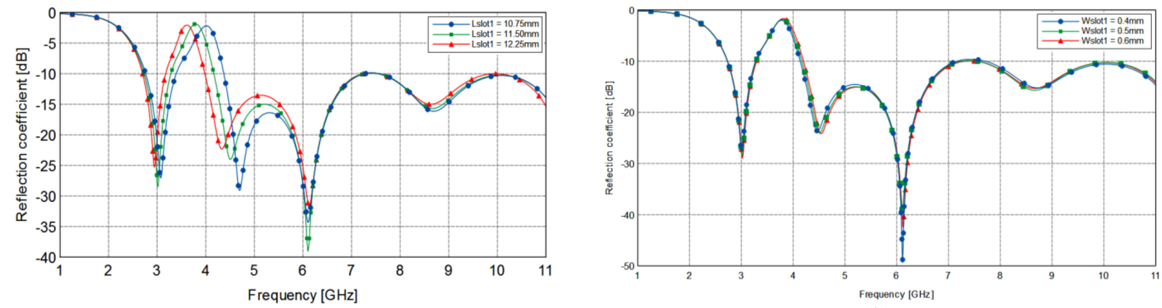
By positioning the two rectangular parasitic elements from upper edge to centre of U- patch, desired dual-band characteristics for Bluetooth and UWB operations have been achieved. Placing the rectangular parasitic elements to the centre portion of radiating U-shaped patch, makes the antenna compact and symmetric one. Two rectangular parasitic elements resonate over Bluetooth frequency band while U-shaped radiating element resonates over UWB band. The total length ‘L_{ib}’ of the two parasitic elements is about quarter wave long at centre Bluetooth frequency band ‘f_{ib}’.

$$L_{ib} = \frac{C_0}{4f_{ib}} \quad (4)$$

The optimized dimensions of Bluetooth parasitic strip are width ‘W_{ib}’ = 0.5mm and length ‘L_{ib}’= 20mm.

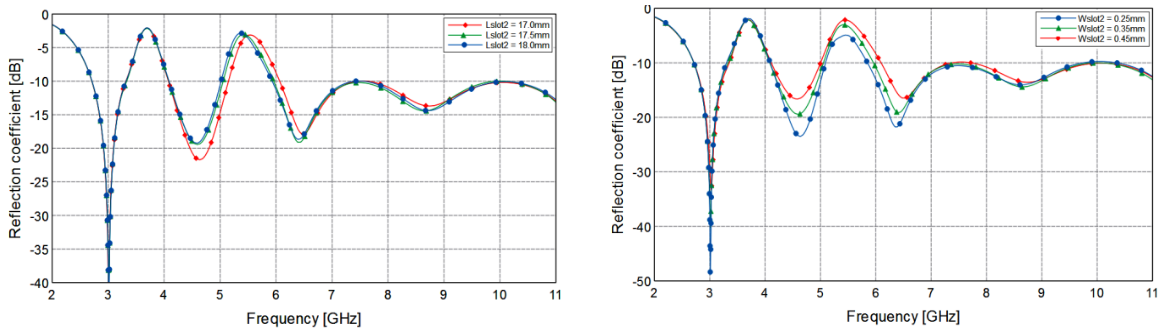
The performance of U-shaped dual band antenna with quadruple band notched characteristic depends on different parameters such as inner (R_{in}) and outer radius (R_{out}) of semi-annular ring, gap(‘g’) between the radiating patch and ground plane, length(l_c) and width(w_c) of corner cut slots in the modified ground plane, width (t_1)and length(s_1+s_2) of the L-shaped slots in the radiating patch, length(l_1+l_2) and width (w_1)of the inverted U-shaped slots in the microstrip feed line, length (L_{ib}) and width (W_{ib}) of the parasitic element operating at Bluetooth frequency band.

Insight of the antenna characteristics is given by conducting the parametric study of important parameters. Two L-shaped slot having length L_{slot1} = 23mm is etched in U-shaped radiating patch to create a notch band at centre frequency of 3.75GHz(3.3-4.2GHz).Effect of length and width variations of these slot is depicted in Figure 2(a) and (b) respectively. Figure 2(a) shows that with increase in the length of the slot, resonant frequency shifts to the left side of the notch band because increase in the slot length decreases the resonance frequency. While increase in the slot width increases bandwidth of notched band without affecting the UWB characteristics as illustrated in Figure 2(b).



(a) (b)

Figure 2. Simulated reflection coefficient of Wi-Max & C-band satellite downlink band–notched UWB antenna for (a) different slot length ‘L_{slot1}’ (b) different slot length ‘W_{slot1}’



(a) (b)

Figure 3. Simulated reflection coefficient of dual band–notched UWB antenna for (a) different slot length ‘L_{slot2}’ of inverted U- slot (b) different slot width ‘W_{slot2}’ of inverted U -slot

Similar investigations are observed by varying the length and width of the inverted U-slot in the feed line to generate a notch band centered at 5.5GHz (5.15-6GHz). From the above analysis we can conclude that, length and width of slots mainly controls the performance of notched-band antenna. Simulated return loss of inverted U-shaped slot in the feedline for length and width variations is depicted in Figure 3(a) and (b).

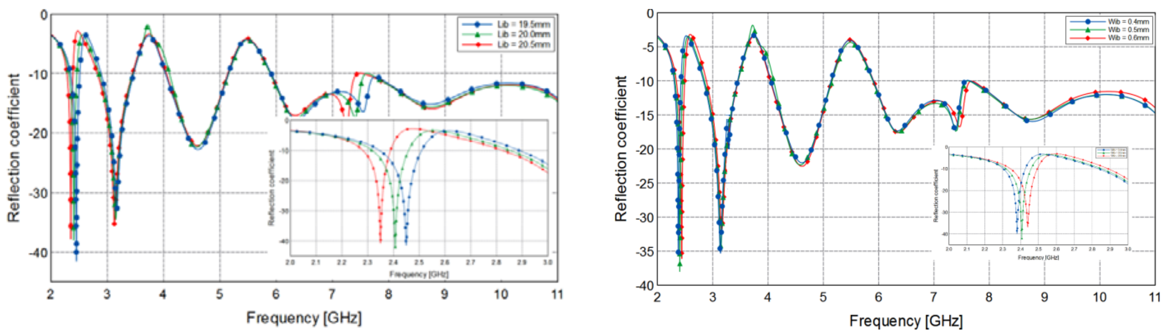
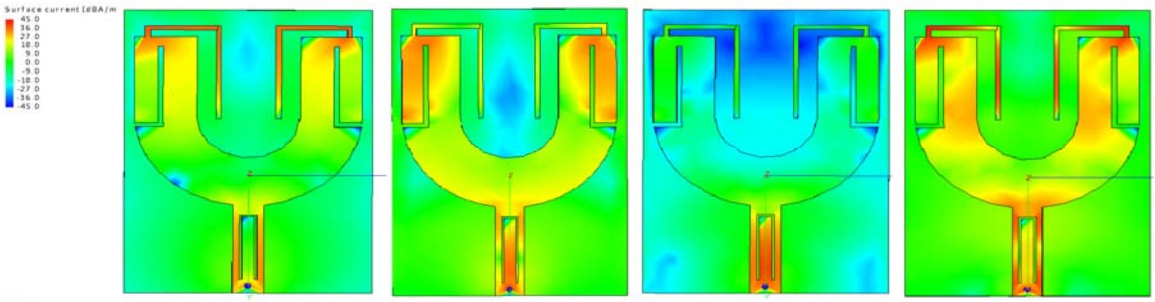


Figure 4. Simulated reflection coefficient of Integrated Bluetooth and band–notched UWB antenna for (a) different parasitic element length ‘L_{ib}’ (b) different parasitic element width ‘W_{ib}’

Two quarter wavelength parasitic strip resonating at centre Bluetooth frequency are embedded at the two edges of U-shaped radiating patch at minimum current position of UWB to ensure the minimum coupling between UWB and Bluetooth element. The length of two parasitic element is calculated using Equation (3).Total length of theBluetooth element L_{ib}= 20mm, which is less than the calculated length due to the dielectric substrate, fringing effect and mutual coupling between U-shaped patch and Bluetooth parasitic elements [19]. Simulated reflection coefficient for length and width variations of the Bluetooth parasitic element is shown in Figure 4. The length 'L_{ib}' of Bluetooth element decides the resonance frequency. Resonance frequency shifts to the lower side of the plot with increase in length as shown in Figure 4(a). Variations in 'W_{ib}' affects the bandwidth as well as resonance frequency. As 'W_{ib}' increases impedance bandwidth of Bluetooth band increases and resonance frequency of Bluetooth decreases as depicted in Figure 4(b).

3. RESULTS AND DISCUSSIONS

Surface current distributions are used to analyse the effect of Bluetooth parasitic strip, the L-shaped slots in the radiating patch and an inverted U-shaped slot in feed line. At 2.45GHz, maximum current concentration is observed along parasitic Bluetooth element showing that these elements are primarily responsible for producing resonance at 2.45 GHz, while U-shaped radiating patch appears to be non-radiating at this frequency. Intense current concentration around the L and Inverted U-shaped slots at 3.75GHz and 5.5GHz respectively shows the effect of band notching and independent control of individual notched band. Other than Bluetooth and notched frequency bands maximum current concentration is observed on the edges of patch showing UWB behaviour of antenna.



(a) (b) (c) (d)

Figure 5. Surface current distribution of integrated Bluetooth and band notched UWB antenna at (a) 2.45GHz (b) 3.5GHz (c) 5.5GHz (d) 7.5GHz

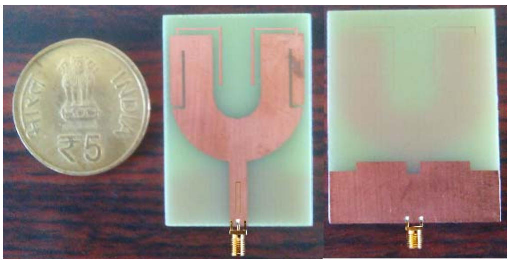


Figure 6. Fabricated prototypes of the proposed antenna

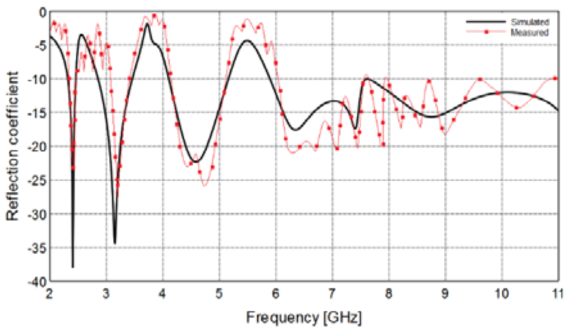


Figure 7. Simulated and measured S_{11} of the proposed antenna

The proposed integrated Bluetooth, band notched UWB antenna was successfully fabricated as shown in Figure 6. The impedance bandwidth was measured using an Agilent Field-fox N9916A vector network analyzer as depicted in Figure 7. Small discrepancy between simulated and measured results was observed. This discrepancy is due to the use of SMA connector and cable through which SMA connector of the antenna connected to VNA for measurement of reflection coefficient while during simulation using CAD FEKO antenna is excited by a wire port having 50Ω impedance for all frequencies. Measured results shows the proposed antenna integrates Bluetooth frequency band from 2.4-2.5GHz while rejects Wi-MAX& C-band satellite downlink (3.3GHz-4.2GHz) and WLAN & DSRC band (5-6 GHz), while providing the wide impedance bandwidth from 3.1GHz to 11GHz.Radiation patterns of antenna across E-plane and H-planes at

2.4 GHz, 4.5 GHz and 7GHz are illustrated in Figure 8(a) and (b).Directional pattern in E-plane and omni-directional pattern in H-plane are observed over a UWB frequency band except at the notched bands frequencies.

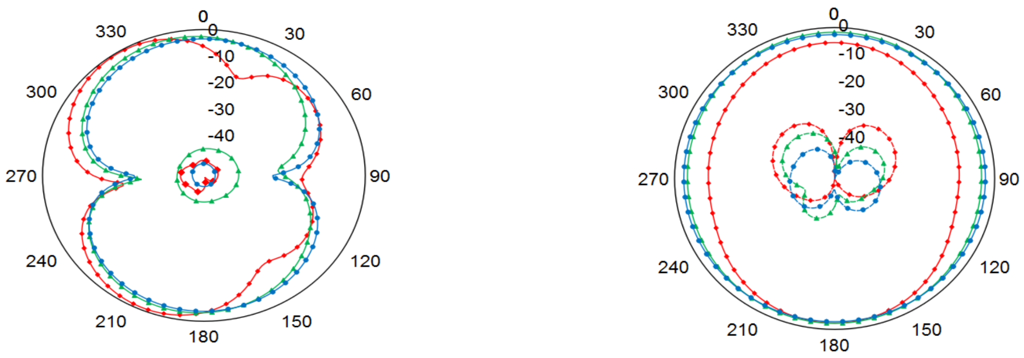


Figure 8. Radiation pattern of the proposed antenna for (a) E-plane and (b) H- plane at sampling frequencies 2.4 GHz, 4.5 GHz and 7 GHz

Average radiation efficiency across the UWB frequency band is about 75% and at notched band 10% drop in the efficiency from 3.3-4.2GHz and 5.15-6GHz clearly indicates the WiMax& C-band satellite downlink and WLAN & DSRC band rejection capability of the proposed antenna. A 10% drop in the efficiency is due to less radiation of antenna at aforementioned notched frequency bands. Similarly almost stable gain over UWB except notched bands is observed as shown in Figure 9.

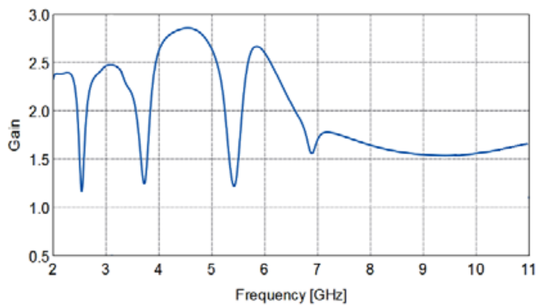


Figure 9. Simulated gain of the proposed antenna

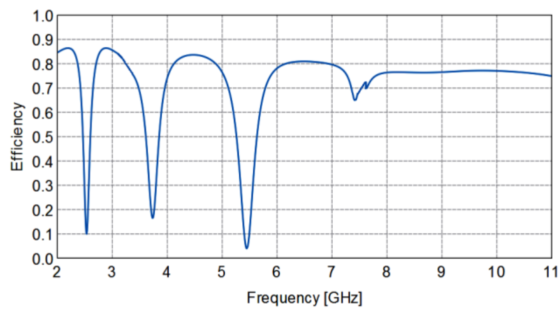


Figure 10. Efficiency of the proposed antenna

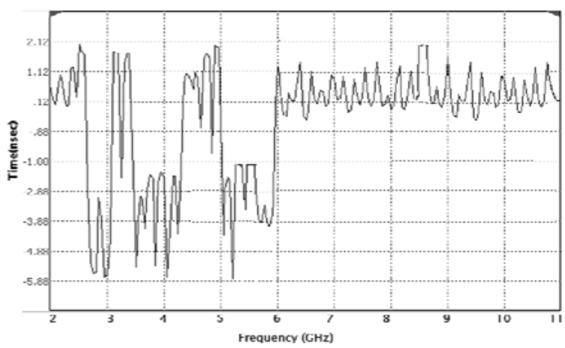


Figure 11. Measured group delay of the proposed antenna

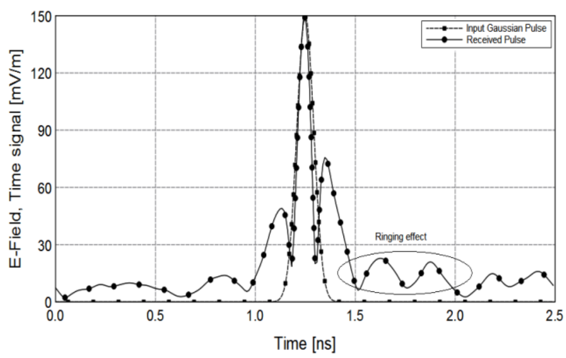


Figure 12. Time Domain Analysi

Time domain characteristics of UWB antenna is given in terms of pulse spreading and group delay performance. Good time domain performance is an important requirement of UWB antenna [20]-[21]. Time delay of impulse signal at different frequencies gives the group delay. Two identical antennas are placed 400mm apart from each other for measurement of group delay. Less variation in group delay is observed over UWB frequency band except notched frequency band. Group delay of proposed UWB antenna is depicted in Figure 11. Except notched frequency bands less variation in the group delay are observed over entire UWB band. Pulse spreading behavior of proposed antenna is obtained using time domain analysis of CAD FEKO [24]. Excited Gaussian pulse and received signal for Integrated Bluetooth and band notched UWB monopole antenna is shown in Figure 12. A small ringing in the received pulse is observed.

Table 1. Comparison between reported integrated Bluetooth and Band notch UWB antennas

Parameter	Ref.[14]	Ref.[22]	Ref.[18]	Ref[23]	Proposed Work
UWB operating frequency	3.1-10.6GHz	3.1-10.6GHz	3.1-11.434 GHz	3.04-10.8GHz	3.1-11GHz
Bluetooth frequency band	2.4-2.5GHz	2.4382.495GHz	2.18-2.59GHz	2.33-2.5GHz	2.4-2.5GHz
Number of notched bands	Two(CMMB 2.856GHz and WLAN 5.5GHz)	Single(WLAN 5.14GHz to 5.823GHz)	Single (WLAN 5.15-5.825GHz)	Dual(Wi-Max:3.3-4.1GHz),WLAN(5-5.9GHz)	Quad (WiMAX,C-band satellite downlink,WLAN,DSRC)
Dielectric constant	3.48	4.4	4.4	4.4	4.4
Thickness	0.832	1.59	1.6	1.6	1.6
Size(Lsub × Wsub) mm^2	39.75 × 31.5	52 × 32	50 × 24	41 × 30	35 × 24

4. CONCLUSION

A compact dual band antenna for Bluetooth and UWB applications with band notched characteristics has been presented. To achieve the integrated Bluetooth characteristics two parasitic elements are placed at two edges of the U-shaped radiating patch and two L-shaped slots and Inverted U-shaped slots are etched in radiating patch and the microstrip feed line respectively to obtained quadruple band notched characteristics. It has been observed that by simply adjusting the length and width of the parasitic element and the slots, resonant frequency and bandwidth of integrated Bluetooth and notched band can be controlled.

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