Progress In Electromagnetics Research M, Vol. 105, 109–118, 2021

Frequency and Time Domain Analysis of Triple Band Notched UWB Antenna with Integrated Bluetooth Band

Brij K. Bharti*, Abhay K. Singh, Raksh P. S. Gangwar, and Reeta Verma

Abstract—This paper presents the time and frequency domain analysis of a compact tri-band notched UWB (ultra-wideband) antenna with integrated Bluetooth frequency for wireless applications. Modifications in radiating element and DGS techniques are used to achieve high impedance bandwidth. The antenna operates at UWB frequency band 3.1–10.6 GHz as well as Bluetooth frequency 2.4 GHz. The band notch characteristics are at Wi-MAX (3.3–3.7 GHz), WLAN (5–6 GHz), and X-Band Satellite communication (7.1–7.76 GHz). These notches are obtained by etching different slots in the ground plane and radiating elements. Gain, group delay, pulse transmission, and radiation patterns of the proposed antenna are also investigated. A prototype of the antenna is fabricated, and the reflection coefficient is measured. A comparison has been made between the proposed antenna and previously published UWB antennas.

1. INTRODUCTION

The ultra-wideband (UWB) frequency spectrum 3.1–10.6 GHz is authorized by the Federal Communication Commission (FCC), USA for the use of unlicensed commercial applications [1]. For many wireless applications, such as ground-penetrating radars and short-range wireless local area networks, very low spectral power density, high precision ranging, low cost, and high data rate are needed. UWB antennas are a key component of UWB systems and have recently been extensively investigated by various researchers. Over the recent years, various studies have proposed monopole antennas for UWB applications. Since there are various narrowband technologies in the UWB range, including Worldwide Interoperability for Microwave Access (Wi-MAX, 3.3–3.7 GHz), Wireless Local Area Network (WLAN, 5.15–5.35 GHz and 5.725–5.825 GHz), and X-band (7.2–7.8 GHz) satellite communication systems (XSCS), these bands can interfere with UWB systems. Hence, it is required to design a UWB antenna with band-reject characteristics [1–4].

Planar UWB antennas with a single band-notched function have been developed in previous researches. A pair of T-shaped stubs was used inside an elliptical slot cut in the patch [5]. Simple π-shape or V-shape slots were introduced in its radiating patch [6]. Double band-notched antennas were designed by etching a single tri-arm resonator below the patch [7]. A V-shaped and a split ring-shaped slit were implemented [8]. In most of the research, band notching was achieved by inserting various types of slots on the radiating patch or associated ground plane and adding parasitic elements near the printed antennas. A slot-type Split Ring Resonator (SRR) is used effectively for notching [9], a slot resonator integrated within the radiator [10], by making U-shape parasitic element in the design [11]. In the past few years, researchers have also developed tri-band notched antennas with a tri-band notched characteristic based on an electric ring resonator (ERR) [12], a monopole antenna using defected ground structure (DGS) and semi arc-shaped slot [13], a half-wavelength hook-shaped slot on the ground and

Received 2 September 2021, Accepted 17 October 2021, Scheduled 20 October 2021

* Corresponding author: Brij Kumar Bharti (brijbhartibb@gmail.com).
The authors are with the Electronics and Communication Engineering Department, College of Technology, G. B. Pant University of Ag. & Tech., Pantnagar 263145, India.

adding quarter-wavelength rectangle-shaped strips in the patch [14], by coupling the triple-mode stepped impedance resonator (SIR) to 50 Ω microstrip feed-lines, and one more research gets the triple notches by using an SIR [15, 16].

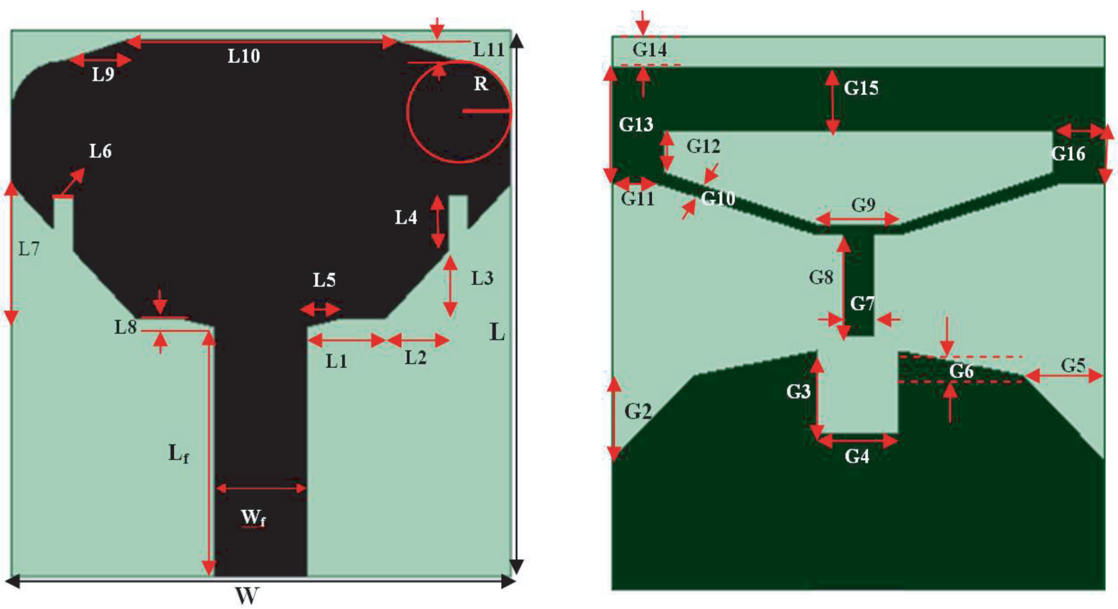
Bluetooth technology operates in the frequency band of 2.4–2.485 GHz. Due to its low power consumption and low cost, it is very popular. Bluetooth technology maintains the connection between computers, mobile phones, headphones, and other portable handheld devices. The use of an integrated antenna for Bluetooth and UWB applications without altering the performance makes the system design more miniaturized [10, 17]. However, the reported antennas are not physically compact.

In this paper, a microstrip-based triple band-notched characteristics UWB antenna with an integrated Bluetooth band is proposed. Modification in the radiating patch and DGS are responsible for ultra-wide bandwidth. A modified patch loaded with a primary U-shaped slot with two secondary U-shaped slots at both ends of the primary U-shaped slot is responsible for notching (Wi-MAX) and integrating Bluetooth frequency. The second notch (WLAN) is created by making two symmetric U-shape slots in the ground plane. Two symmetric slots have been used to improve notching characteristics at the desired frequency. The length of the slot is approximately $\lambda_g/2$ where, and λ_g is the wavelength corresponding to the notch band central frequency "f_{notch}". For getting a third notch band (XSCS), two symmetric U-shaped slots are created on the ground plane. The antenna does not radiate for these notched bands because the currents on both sides of the slots are 180° out of phase. Hence, destructive interference takes place. The −10 dB impedance bandwidth of the proposed antenna is sufficient to cover the entire ultra-wide frequency band with notched bands for Wi-MAX, WLAN, and XSCS with an integrated Bluetooth band.

2. ANTENNA DESIGN AND GEOMETRY

Figure 1 depicts the geometry of the proposed UWB antenna without notching slots. The antenna is fed by microstrip line and printed on a low-cost FR-4 epoxy substrate having height 1.6 mm, dielectric constant 4.4, loss tangent 0.02, and dimension $24 \times 26.5\,\text{mm}^2$. The proposed antenna is designed and simulated using High Frequency Structure Simulator (HFSS) v15. To feed the antenna, lumped port is used. The final values of parameters are shown in Table 1.

Figure 2 depicts the simulated results of the proposed antenna. Fig. 2(a) shows that the reflection coefficient (S_{11}) is below −10 dB for the entire UWB range 3.1–10.6 GHz, and Fig. 2(b) shows that the peak gain of the proposed antenna is around 4.7 dBi for the UWB range.

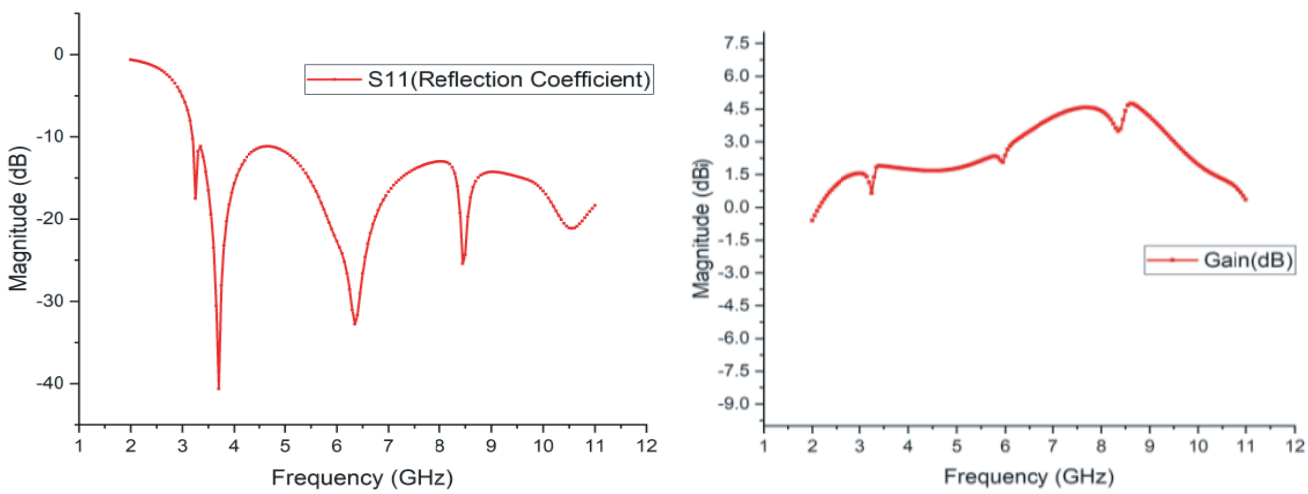


(a) (b)

Figure 1. (a) Radiating patch and (b) ground plane.

Table 1. Optimized parameters and their dimensions.

Parameters	L	W	Wf	Lf	R	$L1$	$L2$	$L3$
Dimensions (mm)	26.5	24	4.5	12	2.5	2.2	3	3.75
Parameters	$L4$	$L5$	$L6$	$L7$	$L8$	$L9$	$L10$	$L11$
Dimensions (mm)	2.75	1.55	1	6.5	1.05	3	13	1
Parameters	$G1$	$G2$	$G3$	$G4$	$G5$	$G6$	$G7$	$G8$
Dimensions (mm)	6.25	4.03	4	4	3.97	1.1	1.5	4.8
Parameters	$G9$	$G10$	$G11$	$G12$	$G13$	$G14$	$G15$	$G16$
Dimensions (mm)	4	0.5	2	2	5.5	1.5	3	2.5



(a) (b)

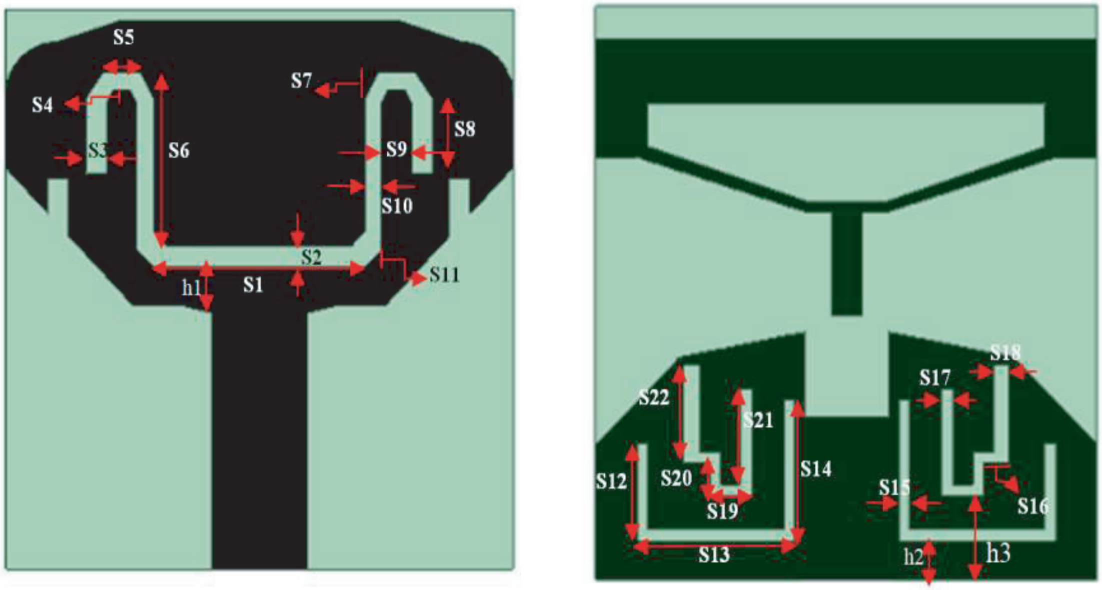
Figure 2. (a) Reflection coefficient and (b) gain plot of the proposed antenna.

The final design of the proposed UWB antenna with triple band-notched characteristics and integrated Bluetooth band is presented in Fig. 3. To achieve the band-notched characteristics, various slots on the patch and ground plane have been etched. For the initial choice of the resonator placed on the radiating patch and ground plane, the design equation is used at a desired notched band center frequency. "f_{notch}" is calculated using the following equation and further optimized in order to achieve better notch characteristics [13].

$$f_{notch}=\frac{C}{2L_{slot}\sqrt{\varepsilon_{eff}}}$$

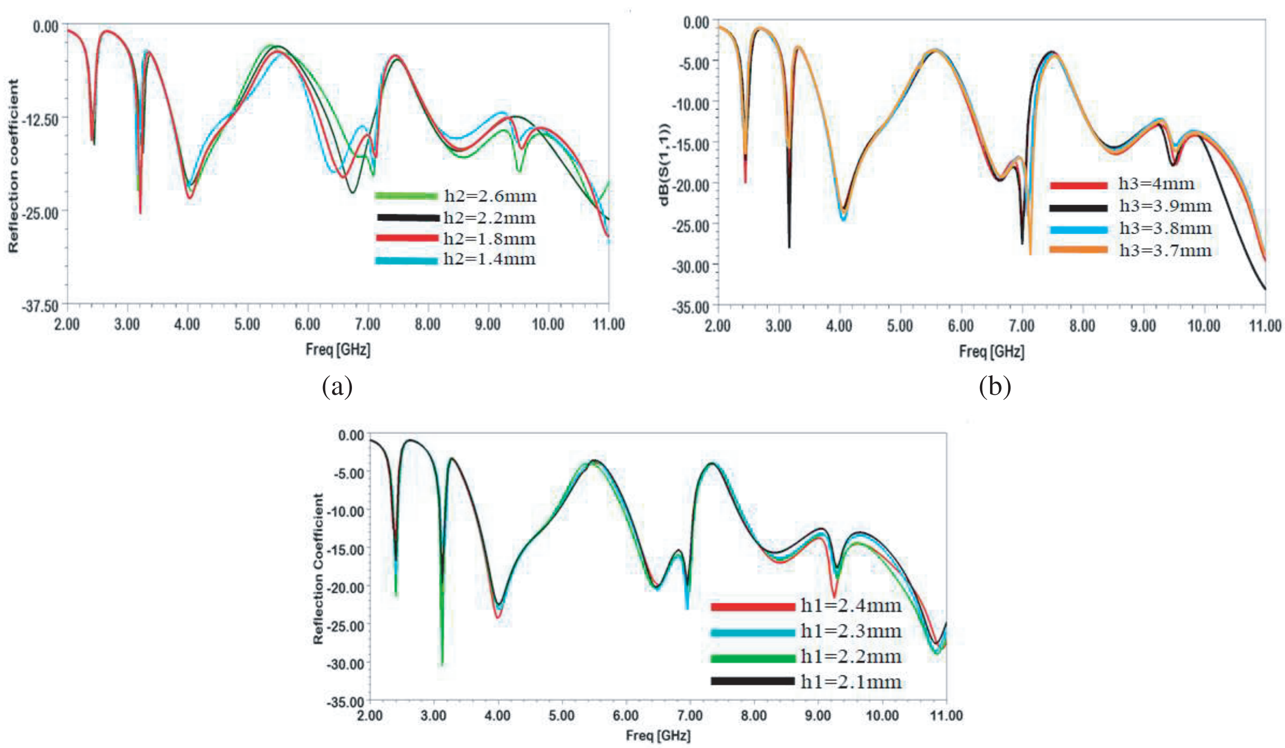
where "ε_{eff}" is the effective permittivity, L_{slot} the total length of the slot, and $C = 3 \times 10^8$ m/sec.

Final optimized values of all the parameters used in the UWB band-notched antenna with integrated Bluetooth band are shown in Table 2. As a result, the antenna radiates effectively to generate a wide operating band ranging from 2.38 to 2.46 GHz and 3.1 to 11 GHz except for the notch bands 3.3–3.7 GHz, 5–6 GHz, and 7.1–7.76 GHz as shown in Fig. 4. It is seen from Fig. 3 that without the insertion of slots, the passband of the proposed antenna rages from 3.1 to more than 11 GHz while the insertion of slot introduces three notch bands and integrate Bluetooth band also within the passband. A fabricated prototype of the proposed antenna is shown in Fig. 5.



(a) (b)

Figure 3. (a) Slot in the radiating patch and (b) slots in the ground plane of the final UWB antenna.



(a) (b) (c)

Figure 4. (a) Simulated return losses for different values of $h2$, (b) Simulated return losses for different values of $h3$ and (c) Simulated return losses for different values of $h1$.

Table 2. Optimized parameters and their dimensions.

Parameters	$S1$	$S2$	$S3$	$S4$	$S5$	$S6$	$S7$	$S8$
Dimensions (mm)	10	1	1	0.6	1.8	8.17	1.2	3.6
Parameters	$S9$	$S10$	$S11$	$S12$	$S13$	$S13$	$S14$	$S15 = S17$
Dimensions (mm)	1.4	0.8	0.77	4.5	7.5	7.5	6	0.5
Parameters	$S16$	$S18$	$S19$	$S20$	$S21$	$h1$	$h2$	$h3$
Dimensions (mm)	1.25	0.75	2	1.6	4.4	2.2	1.8	3.9

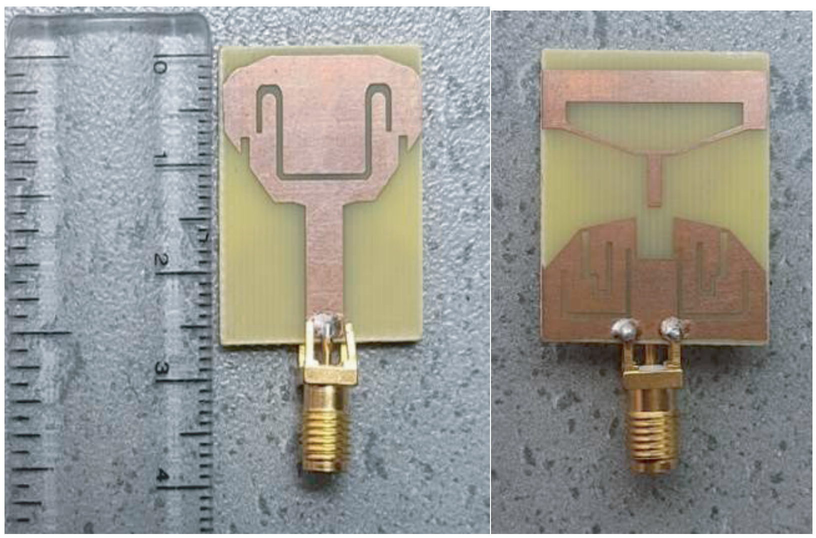


Figure 5. Fabricated prototype of proposed UWB antenna.

3. EFFECT OF GEOMETRICAL PARAMETERS OF SLOTS ON NOTCHING

In order to understand UWB antenna characteristics and to know the effects of some geometrical parameters on notch bands, a parametric study has been carried out. To perform all the designing and optimization processes of commercially available full-wave electromagnetic simulators, HFSSv15 is used. Since the U-shaped slots in the ground and the radiating patch are the main factors in achieving triple-band notched characteristics, three parameters $h1$, $h2$, and $h3$ are selected to study their effects on band-notch characteristics and so on impedance bandwidth. Fig. 4(a) shows the simulated results with the effect of $h2$, which is more susceptible to 5–6 GHz notch band. It can be observed that $h2$ determines the center frequency of the notched 5–6 GHz band. As the values of $h1$ increase, the notched bands center frequency gradually moves towards the higher frequency band, and the bandwidth of the notched band increases. From Fig. 4(b) it can be seen that the center frequency of the notched band 7.1–7.76 GHz is accordingly affected by the value of $h3$. It can be seen by Fig. 4(b) that $h3$ does not affect other notches. In conclusion, we can say that adding N number of different slots of length $\lambda_g/2$ could add N number of notch bands to the system. To achieve sharper notched bands, one can make a pair of symmetrical slots either in the ground or in the radiating patch.

As $h3$ increases from 3.8 mm to 4.1 mm, the center frequency of the notched band shifts to lower frequencies, and the bandwidth of the notched band increases. Fig. 4(c) depicts the simulated return loss plot for different values of $h1$. It is noticed that $h1$, the distance between slots on the patch from the upper end of the feed line, is the most affected by the band notch (3.26–3.66 GHz) characteristics and the Bluetooth band. It can be said from return loss curves that with increasing $h1$, the bandwidths of the notch band increase, and the center frequency of the notch band shifts towards lower frequencies.

4. RESULTS & PERFORMANCE ANALYSIS

4.1. Frequency Domain Analysis

The performance analysis of the proposed UWB antenna was done by using full-wave electromagnetic simulator HFSS, which is based on the finite element method (FEM). Fig. 6(a) illustrates the simulated and measured return loss curves of the proposed antenna. The results indicate that the -10 dB impedance bandwidth of the proposed antenna is in the frequency range from 3.1 to 10.6 GHz, which covers the bandwidth of the FCC definition for UWB indoor in the frequency range from 3.1 to 10.6 GHz, which covers the FCC definition bandwidth for UWB indoor communication systems. It can be seen that the proposed antenna exhibits notched bands at 3.26–3.66 GHz, 5–6 GHz, and 7.1–7.76 GHz. Fig. 6(b) presents the simulated gain (dBi) of the proposed antenna. It can be seen that the maximum gain is 3.78 dBi. The value of gain for the notch bands is sufficiently low to eliminate them. Due to the unavailability of a measurement facility for gain and radiation pattern, their simulation results are shown. Despite multiple slots used to create notches, the proposed antenna with triple-band notch characteristics can exhibit stable and omnidirectional radiation patterns. The simulated radiation patterns (E-plane and H-plane) for the proposed UWB antenna at different frequencies, i.e., 2.4, 4.52, 6.5, and 8.12 GHz, are shown in Fig. 7.

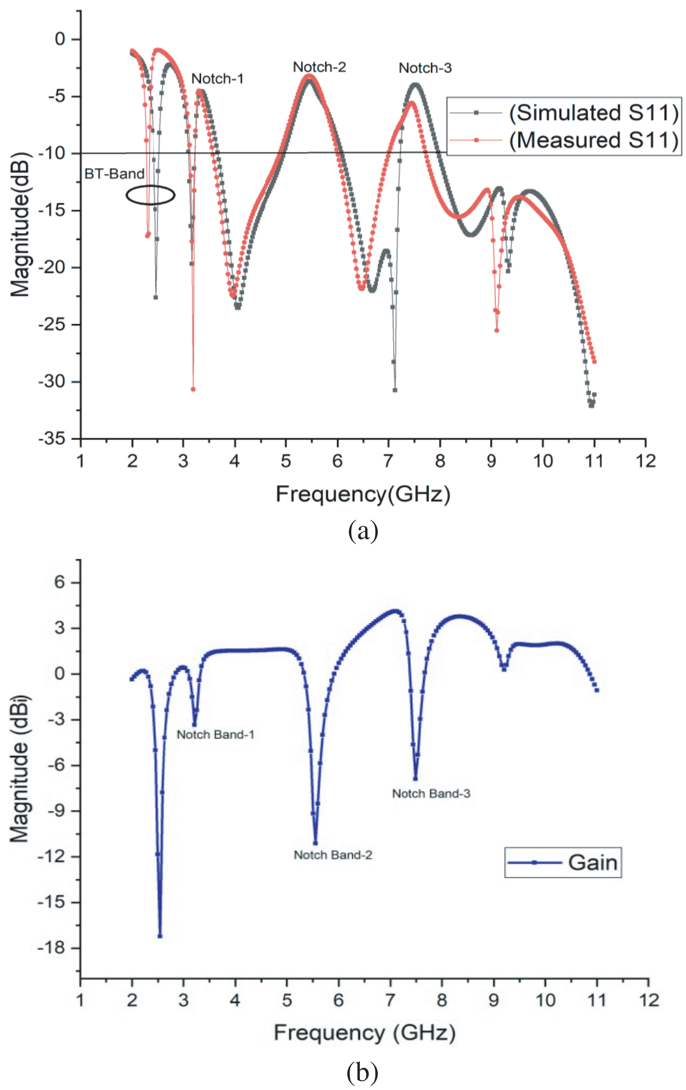


Figure 6. (a) Simulated return loss and (b) Simulated gain total plot of the proposed UWB antenna.

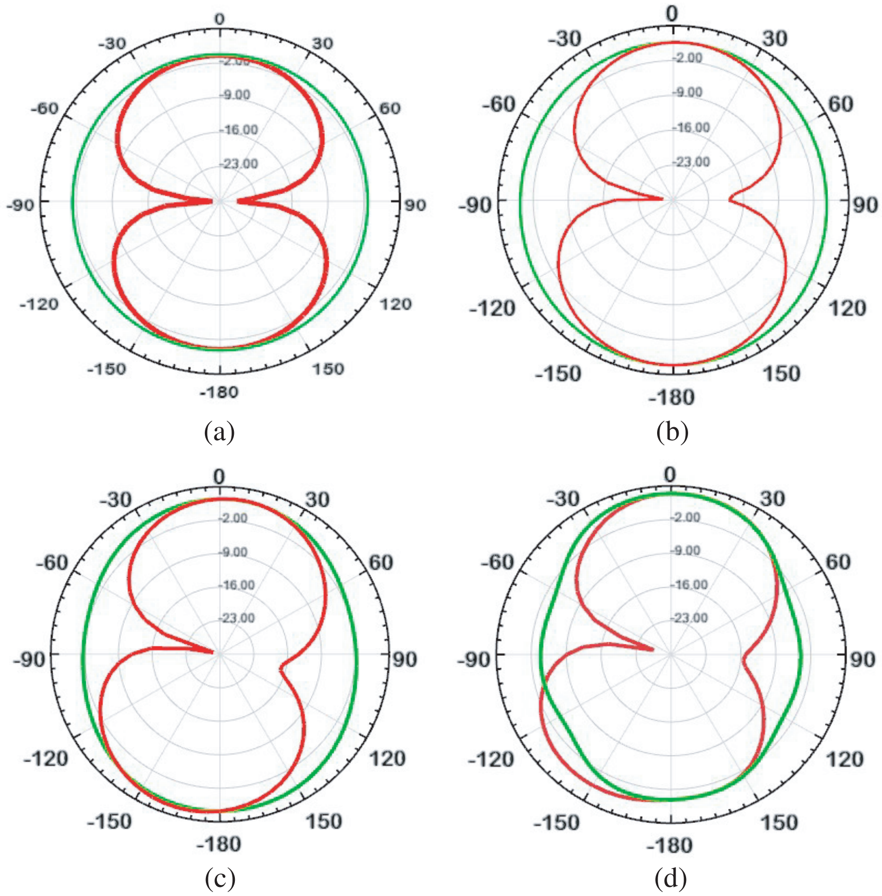


Figure 7. (a) E-plane & H plane at 2.4 GHz, (b) E-plane & H plane at 4.52 GHz, (c) E-plane & H-plane at 6.50 GHz and (d) E-plane & H plane at 8.12 GHz.

4.2. Time Domain Analysis

UWB systems directly transmit broadband signals or short duration pulses (psec) rather than continuous wave, and the time domain performances of the UWB antenna is very important. The antenna performance can be optimized to reduce undesired pulse distortions. The group delay is defined as the negative derivative of the phase response with respect to frequency and indicates the time delay of an impulse signal at different frequencies [17, 18]. The pulse input to the antenna system has an extremely large bandwidth, and hence, any variation in group delay across the passband of the transmitted pulse is likely to distort the pulse. Constant group delay is required for distortion-less transmission. To find the group delay, two antennas with the same radiation characteristics are placed 100 mm from each other in the face-to-face configuration in Fig. 8, and each antenna is in the far field of the other antenna. This far-field distance is calculated by using equation.

$$d = \frac{2D^2}{\lambda}$$

where D is the maximum dimension of the antenna, which is 35.75 mm (diagonal length) for the proposed antenna.

The simulation results of group delay and transmitted and received pulses are shown in Fig. 9. From Fig. 9(a), the group delay is almost constant for the passbands, whereas the group delay is disturbed for the reject bands. In Fig. 9(b), the black color plot is the transmitted signal which is transmitted by antenna 1, and the red one is the received signal of antenna 2. For the measurement of transmitted and

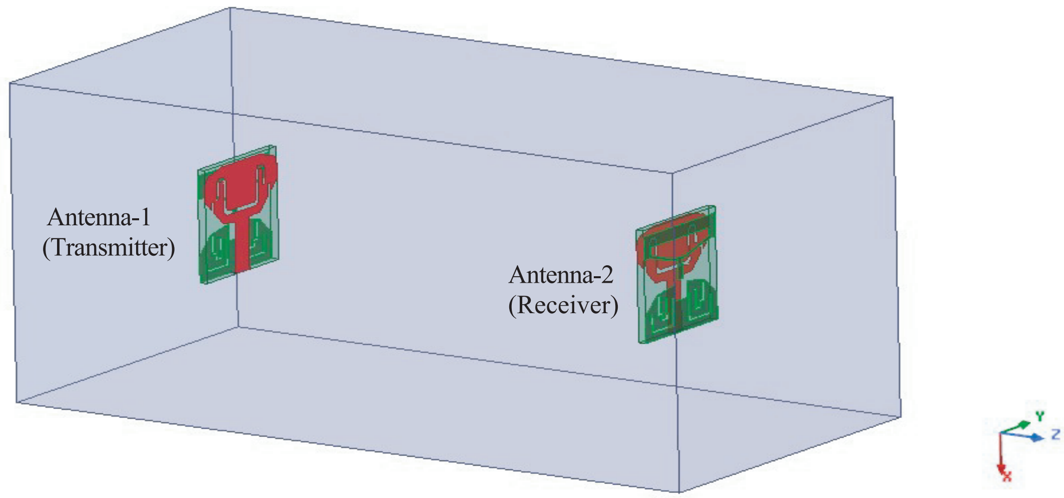


Figure 8. Face to face orientation of two same antennas.

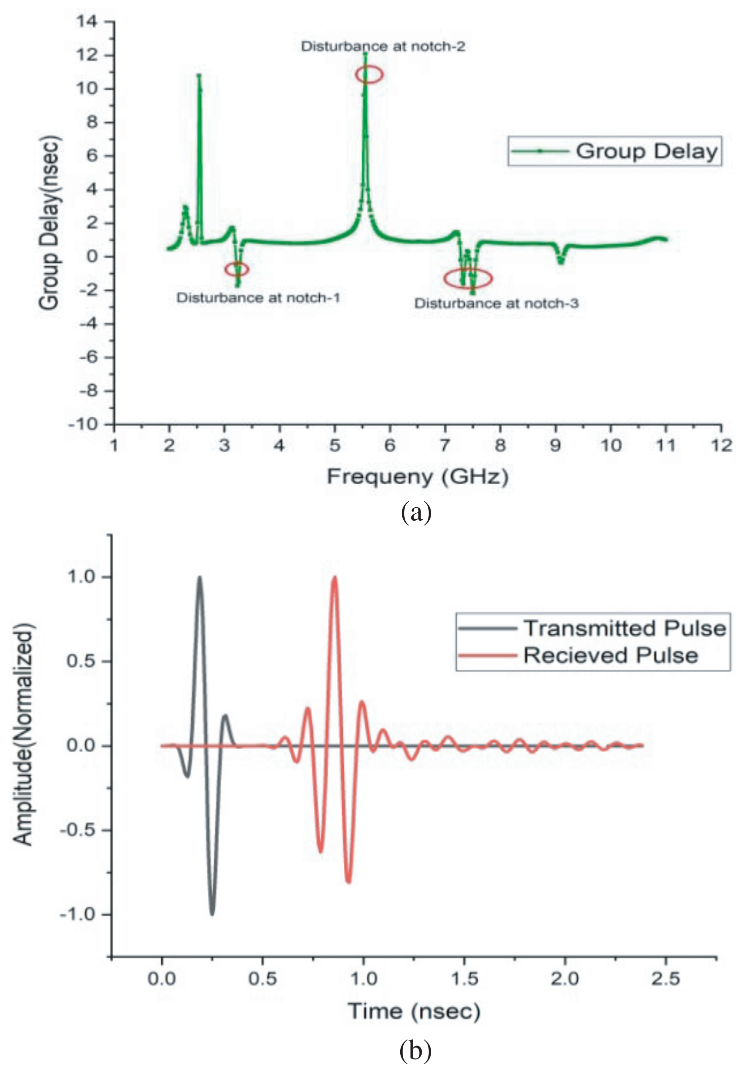


Figure 9. (a) Group delay. (b) Transmitted and received pulses of two antennas system in face-to-face orientation.

received pulses, a transient network solver is used in HFSS. A comparison of the parameters in terms of bandwidth, gain, size, and notched bands for the proposed antenna and earlier designed antennas is shown in Table 3.

Table 3. A comparison in terms of bandwidth, gain, size, substrate, and notch bands for the proposed antenna and earlier designed antennas.

Ref.	**Band-width (GHz)**	**Band notch frequencies (GHz)**			**Gain (dBi)**	**Substrate used**	**Size (mm^3)**
		f_1	f_2	f_3			
[12]	2.2–12	3.5	5.8	7.5	4.9	Rogers RO3003	$50 \times 50 \times 1.52$
[13]	3.1–11	3.6	5.5	7.5	3	FR-4	$42 \times 24 \times 1.6$
[14]	3–11	3.5	5.2	5.8	3	Rogers RO4003	$30 \times 30 \times 1.6$
[15]	2–11	5.2	6.8	8	3.7	Rogers 4350B	$38 \times 20 \times 0.0508$
[16]	2–11	4.1	5.9	8	3	Rogers 4350B	$38 \times 20 \times 0.0508$
This work	2.38–2.46, 3.1–11	3.5	5.5	7.5	3.78	FR-4	$26.5 \times 24 \times 1.6$

5. CONCLUSIONS

A compact microstrip-based planar triple band-notched UWB antenna with an integrated Bluetooth band is designed and analyzed. The antenna employs a slot in the radiating patch and 4 slots in the partial ground plane and has an overall dimension of 26.5 mm × 24 mm. The slots in the radiator and ground plane are used to realize the band-notched characteristics. It is observed from the simulated and measured results that the proposed antenna achieved good UWB performance, along with the Bluetooth band, and reduces the potential interference caused by Wi-MAX, WLAN, and X-band. Low profile characteristics, integrated Bluetooth band, satisfactory gain, and good time-domain performance make the proposed antenna suitable for personal wireless and UWB applications.

REFERENCES

1. Weng, Y. F., S. W. Cheung, and T. I. Yuk, "Design of multiple band-notch using meander lines for compact ultra-wide band antennas," *IET Microwaves, Antennas & Propagation*, Vol. 6, No. 8, 908–914, 2012.
2. Kumar, S., R. D. Gupta, and M. Parihar, "Multiple band notched filter using C-shaped and E-shaped resonator for UWB applications," *IEEE Microwave and Wireless Components Letters*, Vol. 26, No. 5, 340–342, 2016.
3. Ghosh, A., T. Mandal, and S. Das, "Design and analysis of triple notch ultrawideband antenna using single slotted electromagnetic bandgap inspired structure," *Journal of Electromagnetic Waves and Applications*, Vol. 33, No. 11, 1391–1405, 2019.
4. Abbas, S. M., Y. Ranga, A. K. Verma, and K. P. Esselle, "A simple ultra wideband printed monopole antenna with high band rejection and wide radiation patterns," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 9, 4816–4820, 2014.

5. Hong, C. Y., C. W. Ling, I. Y. Tarn, and S. J. Chung, "Design of a planar ultrawideband antenna with a new band-notch structure," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 12, 3391–3397, 2007.
6. Ahmadi, B. and R. Faraji-Dana, "A miniaturised monopole antenna for ultra-wide band applications with band-notch filter," *IET Microwaves, Antennas & Propagation*, Vol. 3, No. 8, 1224–1231, 2009.
7. Azim, R., M. T. Islam, and A. T. Mobashsher, "Dual band-notch UWB antenna with single tri-arm resonator," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 670–673, 2014.
8. Bong, H.-U., N. Hussain, S.-Y. Rhee, S.-K. Gil, and N. Kim, "Design of an UWB antenna with two slits for 5G/WLAN-notched bands," *Microw. Opt. Technol. Lett.*, 1–6, 2019.
9. Kim, J., C. S. Cho, and J. W. Lee, "5.2 GHz notched ultra-wideband antenna using slot-type SRR," *Electronics Letters*, Vol. 42, No. 6, 315–316, 2006.
10. Rahman, M., M. NagshvarianJahromi, S. S. Mirjavadi, and A. M. Hamouda, "Compact UWB band-notched antenna with integrated bluetooth for personal wireless communication and UWB applications," *Electronics*, Vol. 8, No. 2, 158, 2019.
11. Bahri, I. S., Z. Zakaria, N. A. Shairi, and N. Edward, "A novel UWB reconfigurable filtering antenna design with triple band-notched characteristics by using U-shaped coppers," *International Journal of Electrical, Electronics and Computer Systems (IJEECS)*, Vol. 14, No. 1, 267–275, 2019.
12. Vendik, I. B., A. Rusakov, K. Kanjanasit, J. Hong, and D. Filonov, "Ultrawideband (UWB) planar antenna with single-, dual-, and triple-band notched characteristic based on electric ring resonator," *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, 1597–1600, 2017.
13. Elhabchi, M., M. N. Srifi, and R. Touahni, "A tri-band-notched UWB planar monopole antenna using DGS and semi arc-shaped slot for WIMAX/WLAN/X-band rejection," *Progress In Electromagnetics Research Letters*, Vol. 70, 7–14, 2017.
14. Cui, L., H. Liu, C. Hao, and X. Sun, "A novel UWB antenna with triple band-notches for WiMAX and WLAN," *Progress In Electromagnetics Research Letters*, Vol. 82, 101–106, 2019.
15. Peng, H., Y. Luo, and Z.-X. Shi, "Triple band-notched UWB planar monopole antenna using triple-mode resonator," *Progress In Electromagnetics Research C*, Vol. 57, 117–125, 2015.
16. Pan, S., G. Luo, B. Ke, and K. Li, "A planar UWB antenna with triple-notched bands using triple-mode stepped impedance resonator," *Progress In Electromagnetics Research Letters*, Vol. 55, 45–52, 2015.
17. Yadav, S., A. K. Gautam, and B. K. Kanaujia, "Design of band-rejected UWB planar antenna with integrated Bluetooth band," *IET Microwaves, Antennas & Propagation*, Vol. 10, No. 14, 1528–1533, 2016.
18. Malik, J., A. Patnaik, and M. V. Kartikeyan, *Compact Antennas for High Data Rate Communication*, Springer, 2018.