A CPW-Fed Diamond Shaped UWB Monopole Antenna with Dual Band-Notched Characteristic

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Abstract. A CPW-fed diamond-shaped UWB monopole antenna with dual band-notched characteristics at WiMAX (3.3-3.7 GHz) and WLAN (5.15-5.825 GHz) band is proposed. The proposed antenna consists of a CPW-fed diamond shaped monopole radiator, two vertically extended ground planes around the radiator, rotated C-shaped and inverted L-shaped slits. The antenna is fabricated on 1.6 mm thick FR4 material with an overall size of 25 × 23 mm^2 and offers an ultra-wide bandwidth from 2.49-12.8 GHz with dual band-notched characteristics at the WiMAX (3.1-3.8 GHz) and WLAN (4.9-5.8 GHz) bands without affecting the radiation performance of the antenna. Dual band-notched characteristics at 3.1-3.8 GHz (WiMAX) and 4.9-5.8 GHz (WLAN) are achieved due to inserting an inverted L-shaped slit on the ground plane and a rotated C-shaped slit on the radiating monopole, respectively. Thus, the antenna is suitable to be integrated into the portable devices without EMI interference at WiMAX and WLAN bands.

Keywords: UWB microstrip antenna, diamond shape, monopole antenna.

1. Introduction

Federal Communications Commission (FCC) [1] allocated frequency spectrum from 3.1 GHz to 10.6 GHz for ultra- wideband (UWB) applications in Feb 2002. Since then the UWB technology has to turn out to be the main center of research in wireless communication. UWB antenna is an integral part of any wireless communication system. Since 2002, many antenna designs have been proposed in the literature [2]–[8]. However, many narrowband services used by wireless communication system operates within the UWB band, i.e. the wireless local area network (WLAN) service from (5.15 to 5.825 GHz) and world interoperability for microwave access (WiMAX) service from (3.3 to 3.7 GHz), etc. These narrowband services may cause severe electromagnetic interference with UWB wireless systems. Thus, it is desirable to reject these serious electromagnetic interferences (EMI) for real UWB wireless services. To reject such electromagnetic interferences, the UWB antennas can be loaded with filter structures which may add extra circuitry and cost to the system. The loading of the filter to the antenna can be avoided by designing a UWB antenna with band-notched characteristics without adding additional circuit and cost. There are several methods to achieve band-notched characteristics in UWB antenna [9]–[11] out of which the most common approach is to cut different shapes and sizes of slots on the radiating element or its ground plane, such as L-shaped slot [12], U-shaped slot [13], T-shaped slot [14]. The addition of a split-ring resonator [15] and a loading of multi-resonator in the antenna structure [16] can also be used to achieve band-notched characteristics. In [17], a circle-like slot, a trident-shaped feed line, and two nested C-shaped stubs are used to obtain two frequency band-notched characteristics at WLAN and WiMAX, respectively. However, by using different techniques the above-reported designs achieve band-notched characteristics at various frequencies, but still there is a possibility to explore new UWB antenna designs with dual band notch characteristics at WLAN and WiMAX bands.

In this paper, a CPW-fed diamond-shaped monopole UWB antenna with dual band-notched characteristics at WLAN and WiMAX bands is proposed. It consists of a CPW-fed diamond-shaped monopole radiator, two vertically extended ground planes around the radiator, rotated C-shaped and inverted L-shaped slits. A diamond-shaped monopole antenna with CPW-feed line is used to obtain ultra-wide bandwidth. A frequency band-notched at 3.1-3.8 GHz (WiMAX) is achieved by etching an inverted L-shaped slit on the ground plane while a band-notched at 5.15 to 5.825 GHz (WLAN) is obtained by inserting a rotated C-shaped slit on the radiator. The proposed structure is illustrated in Figure 1. The prototype of an antenna with an overall size of 25 mm × 23 mm is fabricated and printed on a commercially available 1.6 mm thick FR-4 substrate with relative permittivity of 4.4 and a loss tangent of 0.024.

2. Antenna design and parametric study

2.1. Full-band UWB diamond-shaped monopole antenna

In general, the conventional microstrip antenna is a narrowband antenna because it has only one resonance. The narrowband width performance of the microstrip antenna limits its operability as a UWB antenna. However, the overlapping of resonance of two or more resonant parts available with each one operating at its resonance may lead to multiband or broadband performance. Thus, the microstrip antennas need to be modified to support the multi-resonance. There are many methods to generate multiple resonances. In the proposed design, a diamond shaped monopole radiator and two grounds etched on the same plane of the monopole

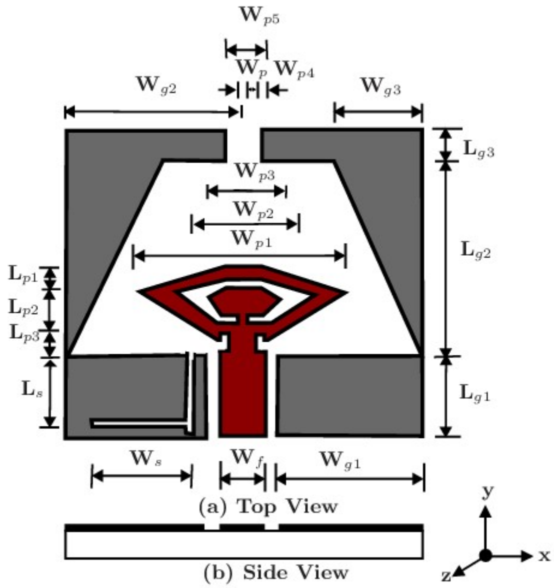

Fig. 1. Schematic configuration of the proposed dual band-notched diamond shaped UWB monopole antenna

are used to obtain an ultra-wide bandwidth. In the proposed design, a diamond shaped monopole radiator and two grounds etched on the same plane of the monopole are used to obtain an ultra-wide bandwidth. The overall size of the antenna is 25 mm × 23 mm × 1.6 mm ≈ λ/4 corresponding to 3 GHz resonance frequency. The basis of the monopole radiator is a rectangular patch, which has the dimensions of length L_{p1}, L_{p2} and width W_{p1} and finally the structure is modified to form a diamond shape. The ground planes are embedded from the patch's left and right sides on the same plane of the monopole radiator to provide the CPW-fed. Each of the embedded grounds consists of a vertical section of an inverted triangular shape with W_{g3} and L_{g2}, a base and altitude lengths, respectively, and two horizontal sections at upper ($L_{g3}\times W_{g3}$) and bottom ($L_{g1}\times W_{g1}$) faces. The width of the CPW feed line is fixed at 3.0 mm to achieve 50Ω-characteristic impedance. The horizontal feed section (x-axis) is separated from the ground by a gap of 0.5 mm (see Figure 1). The detailed dimensions of the proposed antenna, obtained after optimization using an Ansoft HFSS [18], are listed in Table 1. The proposed diamond shaped UWB monopole antenna with an overall size of 25 mm × 23 mm × 1.6 mm has an operating bandwidth of 2.71-12.61 GHz (9.9 GHz).

2.2. Single band-notched diamond shaped UWB antenna

A band-notched characteristic from 5.1 to 5.8 GHz is required in the UWB system to reject the interferences from the WLAN system. Figure 2(a) shows the fabricated prototype of proposed single band-notched diamond shaped UWB antenna. The single band-notched characteristic is obtained by cutting a + 90^{o} rotated C-shaped slit on the diamond shaped radiator. The total length of this rotated C-shaped slit is approximately equal to λ/2 at the centre frequency of the rejected band. Thus, the C-shaped slit will act as a half-wavelength resonator. The current densities at different frequency are plotted in Fig. 2(b)-(d) to understand the operation of a single band-notched UWB antenna. It is clearly seen in the Figure 2(c), at the notch frequency, the surface currents are concentrated around the C-shaped slit. Therefore, the single band-notched antenna does not radiate efficiently in rejected band frequencies, it verify the notched operation.

It is also evident from the Figure 2 (b) and (d), at the frequencies outside the band-notched, the surface currents are uniformly distributed over entire antenna which confirms the normal UWB operation.

Figure 3 shows the effect of W_P on the simulated return loss of the antenna. By adjusting the width W_P the total length of C-slit changes. As illustrated in Figure3, the position of the center frequency and bandwidth of the rejected band is controllable by varying W_P from 0.2 to 2 mm, the optimized value of W_P is 0.2mm. Figure 4 shows the effect of the outer width W_{P2} of a C-shaped slit on the return loss of the single band-notched antenna. It is seen from the Figure4. as the outer width of the C-shaped slit is varied from 8.5 to 11.5 mm, the band-notched is shifted towards lower frequencies. Thus, the optimum value of the outer length W_{P2} of a C-shaped slit is chosen 10.5 mm. The effect of the inner width W_{P3} of a C-shaped slit on the return loss of the single band- notched antenna is illustrated in Figure 5. It is observed that the center frequency of the notch band decreases with the increase of W_{P3}. The optimum value for W_{P3} is taken to be 6.5 mm. Thus, from these results, we can conclude that the notch frequency is controllable by changing the parameters of the C-shaped slit.

Table 1: Optimized dimensions of the proposed antenna

Parameters	L_{p1}	L_{p2}	L_{p3}	L_{g1}	L_{g2}	L_{g3}
Units(mm)	1.5	4	1.3	7.5	15.5	2
Parameters	W_p	W_{p1}	W_{p2}	W_{p3}	W_{p4}	W_{p5}
Units(mm)	0.2	13	10.5	6.5	0.75	2
Parameters	W_f	W_{g1}	W_{g2}	W_{g3}	L_s	W_S
Units(mm)	3	9.5	11.5	5.25	7	7

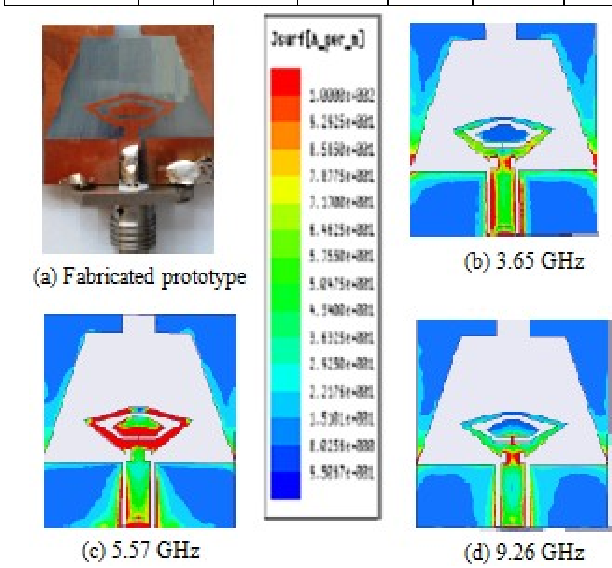

Fig. 2. Single band-notched diamond shaped monopole UWB antenna (a) Fabricated photograph (b) Current distribution at 3.65 GHz, (c) Current distribution at 5.57 GHz (d) Current distribution at 9.26 GHz

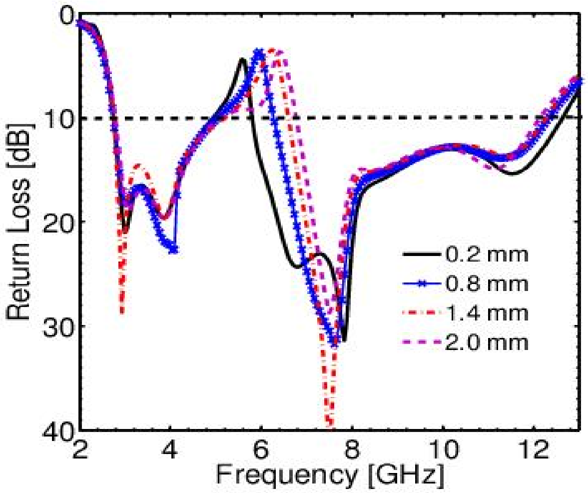

Fig. 3. Effect of W_p of the C-shaped slit on the simulated return loss of single band-notched UWB antenna; other parameters are the same as listed in Table 1.

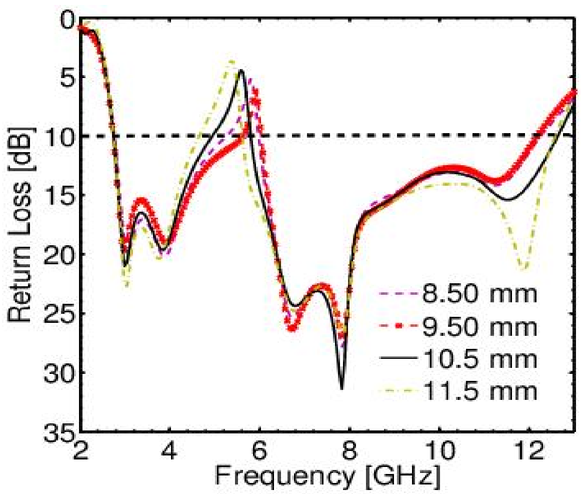

Fig. 4. Effect of the outer width W_{P2} of the C-shaped slit on the simulated return loss of the single band-notch UWB antenna; other parameters are the same as listed in Table 1

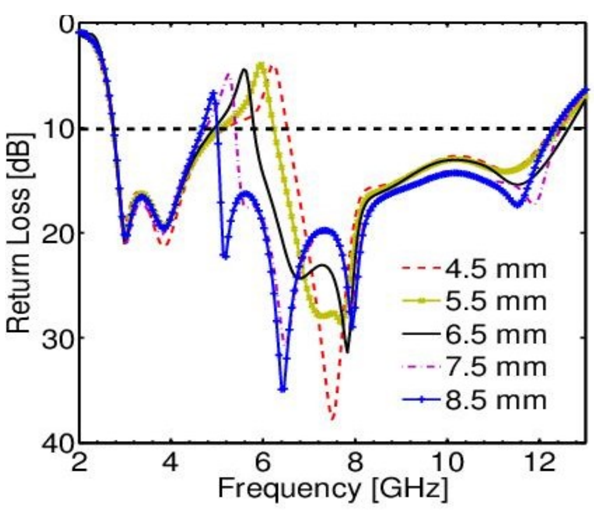

Fig. 5. Effect of the inner width W_{p3} of the C-shaped slot on the simulated return loss of the single band-notch UWB antenna; other parameters are the same as listed in Table 1

2.3. Dual band-notched diamond shaped UWB antenna

After designing the single band-notch at WLAN band, the next aim is focused on the design of another band-notch at WiMAX band. This potential interference can be rejected by cutting inverted L-shaped slit i.e. mirror image along X-axis on the ground plane as shown in the Figure 6(a). By appropriately adjusting the lengths and widths of the inverted L-shaped slit, it is possible to control the bandwidth and amplitude of the rejected band. This L-shaped slit acts as a quarter-guided-wavelength resonator, the center band notched frequency f_1 for the stop bands at WiMAX band may be empirically approximated by [19].

$$f_1 = \frac{c}{4(L_s + W_s)\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

where, L_S and W_S are the total length and width of the inverted L-shaped slit, ε_r is the effective dielectric constant, and c is the speed of the light in free space. Since the center band notched frequency is expected about 3.65 GHz, the calculated length of inverted L-slit is 14.0 mm. Again, the current densities at different frequencies to understand the dual band-notched function are plotted in Figure 6(b)-(d). It is clearly seen in the Figure 6(b) and (c), at the notch frequencies, the surface currents are concentrated around the rotated C-shaped slit and inverted L-shaped slit, respectively. Therefore, the dual band-notched antenna does not radiate efficiently in rejected band frequencies; it verifies the dual band-notched operation at WLAN and WiMAX bands. It is also evident from the Figure 6(d), at the frequency outside the band-notched; the surface currents are uniformly distributed over entire antenna which confirms the normal UWB operation. Further, the effect of the length and width of the L-shaped slit is also studied for the band-notch operation at WiMAX.

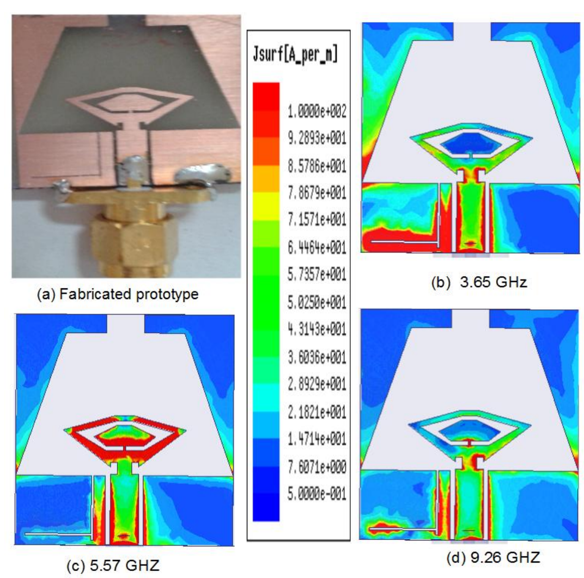

Fig. 6. Dual band-notched Diamond Shaped Monopole UWB antenna (a) Fabricated photograph (b) Current distribution at 3.65 GHz, (c) Current distribution at 5.57 GHz (d) Current distribution at 9.26 GHz.

Figure 7 shows, the simulated return loss of antenna with the length L_s of L-shaped slit varied from 5 mm to 8 mm. It is observed that the change in slit length L_s causes the change in current path, in turn, additional stop band occurs. Further, as the length L_s increases, the band-notch frequency shifted towards lower frequency and magnitude of the band-notch also increases and band-notched at the WLAN remains unchanged. Therefore, it is decided on L_s= 7 mm as the optimum with the notch rejection about 3.65 GHz. Figure 8 shows the simulated return loss variation with width W_s of inverted L-shaped slit, from 1.0 to 9.0 mm. It can be seen that the band-notch frequency shifted towards lower frequency and magnitude of the band-notch also increases and band-notched at the WLAN remains unchanged. Therefore, it is decided on W_s= 7.0 mm as the optimum with the notch rejection about 3.65 GHz. From the results discussed above, it is concluded that the notch frequency is controllable by changing the dimensions of the inverted L-shaped slit.

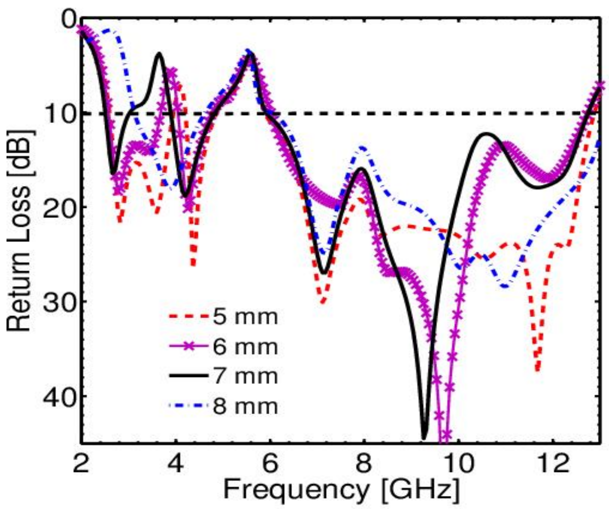

Fig. 7. Effect of the length L_s of the L-shaped slit on the simulated return loss of the dual band-notch UWB antenna; other parameters are the same as listed in Table 1

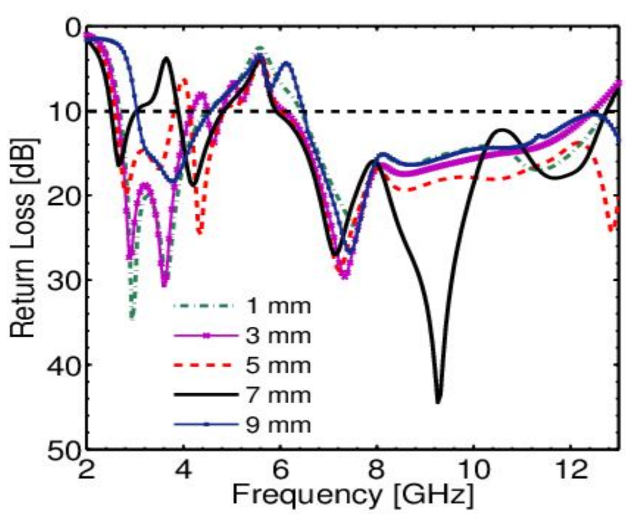

Fig. 8. Effect of the width W_s of the L-shaped slit on the simulated return loss of the dual band-notch UWB antenna; other parameters are the same as listed in Table 1

3. Experimental results and discussion

The performance parameters of the proposed antenna such as impedance bandwidth, return loss, gain, etc. are measured using Agilent N5230A vector network analyzer.

Figure 9 shows the measured and simulated return loss curves of the diamond shaped UWB antenna with single and dual band-notched characteristics. As shown in Figure 9, a good agreement between the simulated and measured results is observed. The designed antenna has an ultra- wideband performance of 10.31 GHz (from 2.49 to 12.8 GHz), with two band-notched at WiMAX from 3.1 to 3.8 GHz and WLAN from 4.9 to 5.8 GHz. The measured and simulated radiation patterns of UWB antenna with single and dual band-notch characteristics, in the E- (xy-) and the H- (yz-) planes at (a) 3.65 GHz (b) 5.57 GHz resonance frequencies, are shown in Figure 10, respectively. It is found that the antenna has nearly good omnidirectional radiation patterns at all sampling frequencies in the E-plane (xy-plane) and the H-plane (yz-plane). As seen from the Figs., at the band-notched frequencies (3.65 GHz and 5.57 GHz), the antenna shows the degradation in gain as shown in Figure 10(a) and (b). Figure 11 shows, the measured gain of diamond shaped UWB antenna, single band-notched diamond shaped UWB antenna and dual band-notch diamond shaped UWB antenna which varies from -3.85 dB to 3.67 dB. It is observed that the gain of the UWB antenna remains almost constant while the gain is suddenly dropped down at both band-notched which confirm the notched operation. The small difference between the measured and simulated results is due to the effect of SMA connector soldering and fabrication tolerance.

The group delay is an important parameter as the distortion of the transmitted pulses in the UWB communication is shown by it. The group delay shall be almost constant in the entire operating band for a good pulse transmission. Figure12 describes the simulated group delay of the proposed antenna. The variation of the group delay is less than 1 ns for the entire UWB band except at notch characteristics where it exceed 1 ns, which distorts the minimal phase linearity.

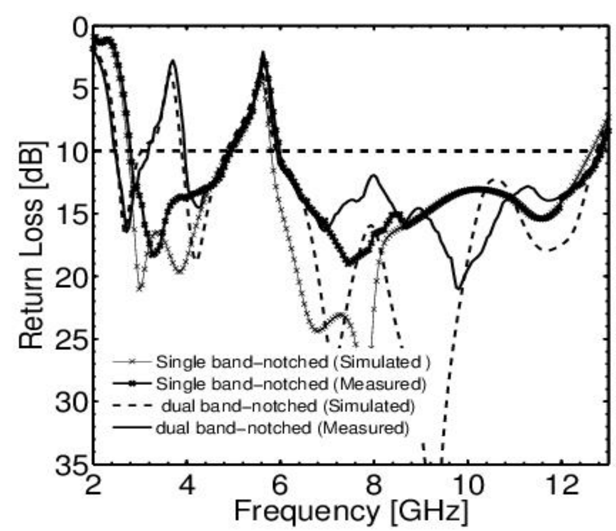

Fig. 9. Simulated and measured return loss of the CPW-Fed Compact diamond Shaped UWB Antenna with single and dual band-notched characteristics

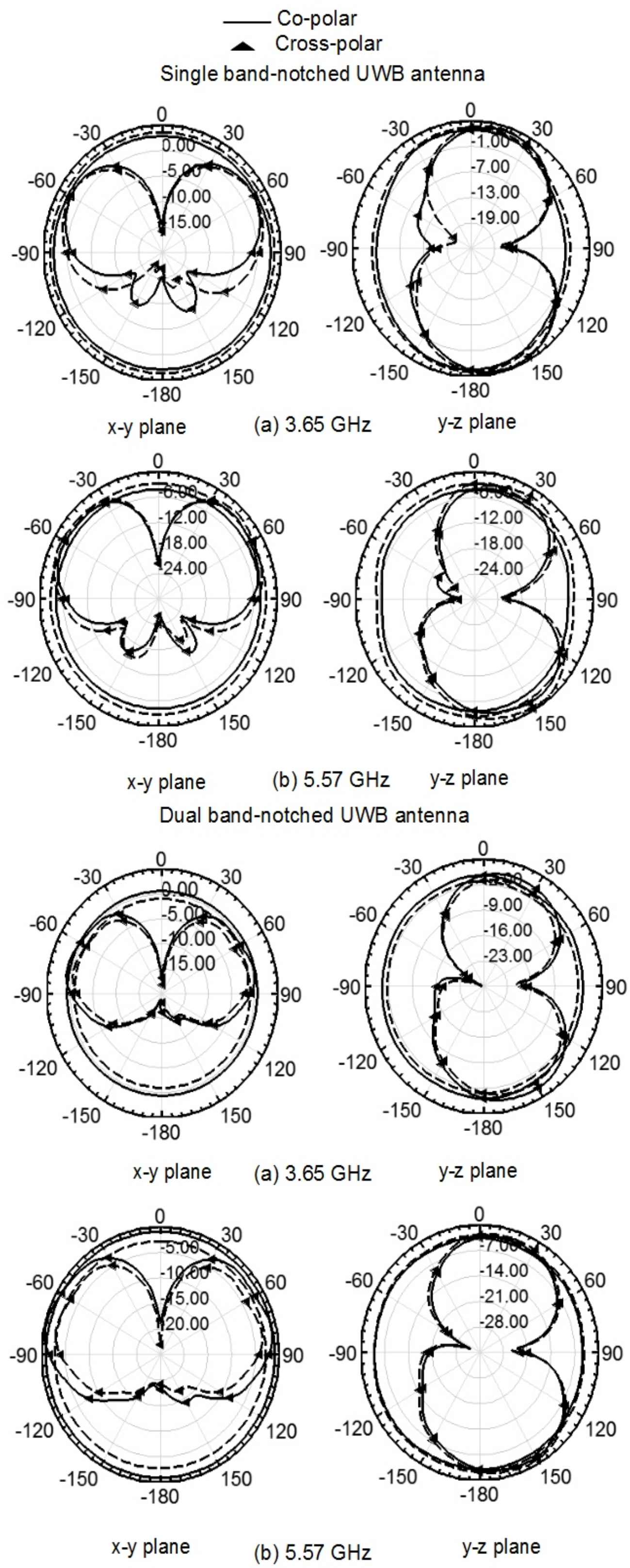

Fig. 10. Radiation pattern for various resonance frequency for the proposed UWB microstrip antenna with single and dual band-notched characteristics — Measured - - - Simulated at (a) 3.65 GHz (b) 5.57 GHz.

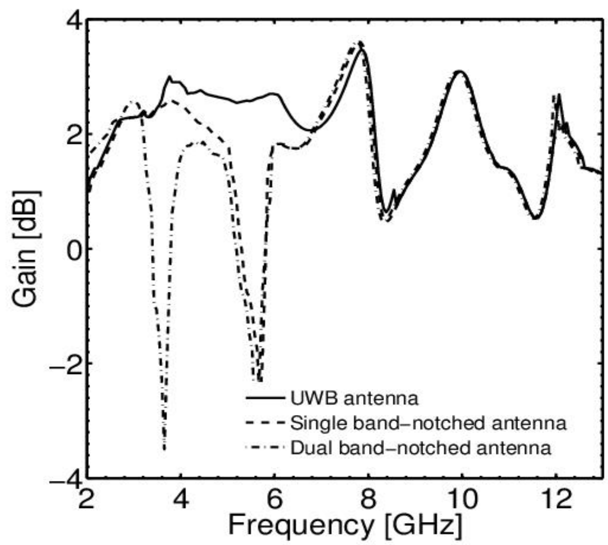

Fig. 11. Measured gain of the proposed diamond shaped UWB antenna, single band-notched diamond shape UWB antenna and dual band-notch diamond shape UWB antenna

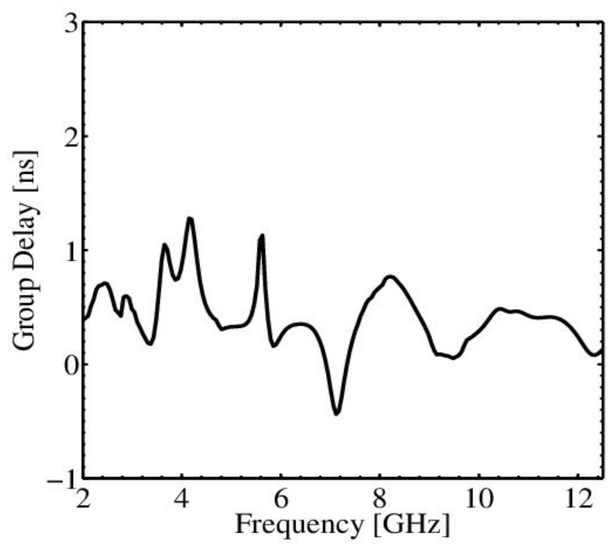

Fig. 12. Group delay of the proposed band-notch diamond shape UWB antenna

4. Conclusion

A CPW-fed diamond-shaped monopole UWB antenna with dual band-notched characteristics is successfully proposed, fabricated, and discussed. The dual band-notched are realized by etching rotated C-slit on the radiating structure and quarter-wavelength inverted L-shaped slit on ground plane. The effects of the width and length of the slits are also analysed to find the optimized configuration of the slits to get a good level of band rejection even at high frequencies. The fabricated antenna showed good agreement between measured and simulated results with a wide bandwidth from 2.49 to 12.8 GHz and two intended notched bands in a small size at WLAN and WiMAX bands. The antenna is thus suitable to be used in the portable devices without EMI interference at the WiMAX/WLAN bands.

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Biography of the authors

Richa Chandel was born in Dehradun, Uttarakhand, India,. She completed her B.Tech. in Electronics and Communication Engineering from Uttar Pradesh Technical University, Lucknow, India and M. Tech (Digital Signal Processing) from Uttarakhand Technical University, Dehradun, India in the year 2010 and 2013, respectively. Presently, she is working towards her doctorate from G B Pant Engineering College, Pauri Garhwal (INDIA). She has published many research papers in peer reviewed journals/conferences. Her primary research interest is designing and modeling of ultra-wideband microstrip antenna.

Anil Kumar Gautam was born in Noida, Uttar Pradesh, India. He received his B.E. degree in Electronics and Communication Engineering from Kumaon Engineering College, Almora, India and his Ph.D. degree in Electronic Engineering from Indian Institute of Technology, Banaras Hindu University, Varanasi, India, in 1999 and 2007, respectively. He joined the Department of Electronics and Communication Engineering, G B Pant Engineering College, Pauri Garhwal, India, in 2000, as an Assistant Professor and he has been an Associate Professor there since 2009. Dr. Gautam is an active member of Board of Study (BOS), Academic council, and many other academic committees of G B Pant Engineering College (GBPEC), Pauri. He is also a member of BOS of HNB Garhwal Central University, India and Uttarakhand Technical University, Dehradun, India. He is nominated as Nodal Officer, TSP, and SCSP Grants by Government of Uttarakhand and executed several projects under these grants. He has supervised 23 M. Tech. and one Ph.D. thesis and presently supervising nine Ph.D. thesis in the area of microstrip antenna. Dr. Gautam is the author/co-author of more than 90 research papers published in the refereed international journals and conferences such as IEEE, Microwave and Optical Technology Letters, Springer, etc. He is the author of 13 books in the field of Electronics Engineering, Digital Electronics, Antenna and Microwave Engineering. He is a member of IEEE (USA) and many other technical societies. He is also in reviewers panel of IEEE, Transaction on Antenna and Propagation, IEEE, Antenna and Wave Propagation Letters, IET Microwaves, Antennas & Propagation, Personal and wireless communication, Springer, International Journal of Electronics, International Journal of Microwave and Wireless Technologies, International Journal of Antenna and Propagation, etc. His main research interests are in design and modeling of active microstrip antenna, microstrip antennas with defected ground structure, ultra-wide bandwidth antennas, and reconfigurable antennas, reconfiguration antenna array, circular-polarized antenna, etc.

Binod Kumar Kanaujia is presently working as an Associate Professor in the Department of Electronics and Communication Engineering in Ambedkar Institute of Advanced Communication Technologies and Research (formerly Ambedkar Institute of Technology), Geeta Colony, Delhi. Dr. Kanaujia joined this Institute as an Assistant Professor in 2008 through selection by Union Public Service Commission, New Delhi, India and served on various key portfolios i.e. Head of Department, In-charge Central Library, Head of Office, etc. Before joining this institute, he served in the M.J.P. Rohilkhand University, Bareilly, India as a Reader in the Department of Electronics and Communication Engineering and also as Head of the Department. He has been an active member of Academic Council and Executive Council of the M.J.P. Rohilkhand University and played a vital role in academic reforms.

Prior, to his career in academics, he worked as an Executive Engineer in the R&D division of M/s UPTRON India Ltd. Dr. Kanaujia completed his B. Tech. in Electronics Engineering from KNIT Sultanpur, India in 1994. He did his M. Tech. and Ph.D. in 1998 and 2004, respectively, from the Department of Electronics Engineering, Indian Institute of Technology Banaras Hindu University, Varanasi, India. He has been awarded Junior Research Fellowship by UGC Delhi in the year 2001–2002 for his outstanding work in the electronics field. He has keen research interest in design and modeling of the microstrip antenna, dielectric resonator antenna, left-handed metamaterial microstrip antenna, shorted microstrip antenna, ultra-wideband antennas, and reconfigurable and circular-polarized antenna for wireless communication. He has supervised 45 M. Tech. and three Ph.D. research scholars in the field of microwave engineering. He is a reviewer for several journals of international repute i.e. IET Microwaves, Antennas and Propagation, IEEE Antennas and Wireless Propagation Letters, Wireless Personal Communications, Journal of Electromagnetic Wave and Application, Indian Journal of Radio and Space Physics, He has been credited to publish more than 105 research papers with more than 200 citations with h-index of 10 in peer-reviewed journals and conferences.IETE Technical Review, International Journal of Electronics, International Journal of Engineering Science, IEEE Transactions on Antennas and Propagation, AEU-International Journal of Electronics and Communication, International Journal of Microwave and Wireless Technologies, etc. He has successfully executed four research projects sponsored by several agencies of Government of India, i.e. DRDO, DST, AICTE, and ISRO. He is also a member of several academic and professional bodies, i.e. IEEE, Institution of Engineers (India), Indian Society for Technical Education and the Institute of Electronics and Telecommunication Engineers of India.