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PRINTED FORK SHAPED DUAL BAND MONOPOLE ANTENNA FOR BLUETOOTH AND UWB APPLICATIONS WITH 5.5 GHZ WLAN BAND NOTCHED CHARACTERISTICS

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Abstract—In this article, a compact microstrip-fed printed dual band antenna for Bluetooth (2.4–2.484 GHz) and UWB (3.1–10.6 GHz) applications with WLAN (5.15–5.825 GHz) band-notched characteristics is proposed. It is demonstrated that dual band characteristics with desired bandwidth can be obtained by using a fork shaped radiating patch, whereas, band-notched characteristics can be obtained by etching two L-shaped slots and two symmetrical step slots on the rectangular ground plane. The proposed antenna is simulated, fabricated and tested. The structure is fabricated on a low cost FR4 substrate having dimensions of 50 mm (L_{sub}) $\times$ 24 mm (W_{sub}) $\times$ 1.6 (H) mm and fed by a 50 Ω microstrip line. The proposed antenna has $S_{11} \leq -10$ dB over 2.18–2.59 GHz, Bluetooth band, 3.098–5.15 GHz and 5.948–11.434 GHz, UWB band with WLAN band notch. The structure exhibits nearly omnidirectional radiation patterns, stable gain, and small group delay variation over the desired bands.

1. INTRODUCTION

Recently, the ability to incorporate more than one communication standard into a single system has become an increasing demand for a modern portable wireless communication device. Due to the limited space, it often requires an antenna to operate at several bands [1]. Ultra-wideband (UWB) technology is emerging as a solution for IEEE 802.15.3a (TG3a) standard [2]. The purpose of this standard is to provide a specification for a low cost, low

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complexity, low power, and high data-rate wireless connectivity among devices within personal operating space. UWB technology has received an impetus and attracted academia and industrial attention in the wireless world ever since Federal Communication Commission released a 10 dB bandwidth of 7.5 GHz (3.1–10.6 GHz) with an effective isotropic radiated power (EIRP) spectral density of -41.3 dBm/MHz for communication applications [3]. The release of an extremely wide spectrum of 3.1–10.6 GHz for commercial applications has generated a lot of interest in the research and development of UWB technology for short range wireless communications, imaging radar, remote sensing, and localization applications. Various planar monopole antennas with ultra-wideband characteristic have been reported [4–14]. Beside UWB, Bluetooth applications also have the advantage of license free operation in the industrial, scientific and medical (ISM) band covering 2.4–2.484 GHz (IEEE 802.11b and IEEE 802.11g). However, wireless local-area network (WLAN) applications operating in 5.15–5.825 GHz (IEEE802.11a and HIPERLAN/2) interfere with UWB systems. Dual band [15, 16] and UWB with band notch characteristics planar monopole antenna [17, 18] have been reported.

In order to integrate 2.4–2.48 GHz band for Bluetooth, 3.1–5.15 GHz (low band) and 5.825–10.6 GHz (high band) for UWB applications in one device, it is essential to develop a dual band antenna with WLAN band notched characteristics. Based on this requirement, wideband antennas with band-notched characteristic have been reported [19, 20].

In this paper, a simple, easy to fabricate, compact, microstrip-fed printed dual band antenna for Bluetooth and UWB applications with WLAN band notched characteristics is proposed. The proposed antenna is composed of a fork shaped radiating element fed by a 50 Ω microstrip line and a rectangular shaped ground plane. A pair of L-shaped slots and a pair of symmetrical step slots are etched on the ground plane to obtain the 5.15–5.825 GHz band-notched characteristic. The proposed antenna is simulated, designed, and tested. Parametric studies are carried out using method of moments based IE3D electromagnetic software [21]. Details of antenna design, simulated and experimental results such as dual band with band-notched characteristic, radiation pattern, antenna gain and group delay are described in the subsequent sections.

2. ANTENNA DESIGN

Figure 1 shows the evolution of the proposed printed dual band monopole antenna. The structure is evolved from the circular

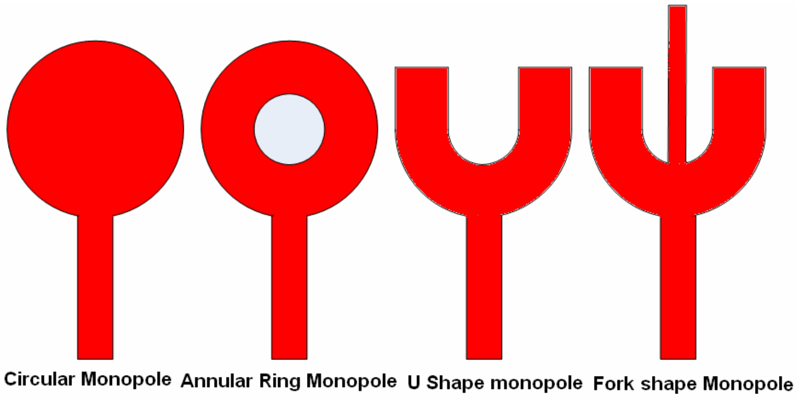
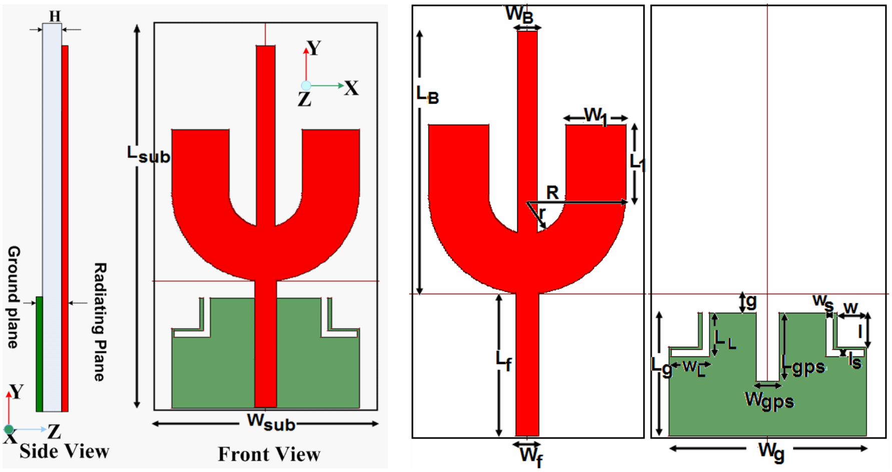


Figure 1. Evolution of the proposed dual band antenna.



(a) Whole structure (b) Top view (c) Bottom view

Figure 2. Geometry of proposed fork shaped dual band antenna with WLAN band notch.

monopole radiator to fork shaped radiator.

The geometry of the proposed printed dual band antenna with band notched characteristics is illustrated in Figure 2. The antenna is fabricated on a 50 mm × 24 mm FR4 substrate with a relative dielectric constant (ε_r) of 4.4, loss tangent ($\tan\delta$) of 0.02 and a substrate thickness of 1.6 mm. Antenna structure is a variation of circular monopole antenna. The radius (R) of circular monopole in centimeter (cm) is obtained by applying the following equation,

$$f_L = \frac{7.2}{2.25R + g}\,\text{GHz} \tag{1}$$

where 'g' is the gap between radiating patch and ground plane in cm, f_L is the lowest resonant frequency in GHz [9]. Further, antenna design is based on the fact that the current is mainly concentrated along the periphery of the circular monopole antenna. Therefore, central portion of the circular monopole can be removed with negligible effect on impedance bandwidth or radiation characteristics resulting in an annular ring monopole antenna [8]. Thereafter, a semi-annular ring is designed and a rectangular strip is placed on both sides at the top of semi-annular ring monopole resulting in a U-shaped monopole antenna. The structure is optimized such that $S_{11} \leq -10\,\text{dB}$ over the UWB frequency range.

To achieve the desired dual-band characteristics for Bluetooth and UWB operations, a rectangular monopole is placed in the central portion of U-shaped monopole antenna to resonate over Bluetooth band leading to tuning fork shaped dual band monopole antenna. The antenna provides a dual-band operation due to two different resonating elements. The central longer element resonates over Bluetooth band while the U-shape element resonates over UWB band. The length (L_B) of the rectangular monopole is about a quarter-wave long at the central Bluetooth band frequency (f_B) in Hz.

$$L_B \approx \frac{c}{4f_B}\,\text{cm} \quad \text{for} \quad W_B < 0.02\lambda_B \tag{2}$$

where, W_B is the width of rectangular monopole in cm and λ_B is the wavelength corresponding to the central Bluetooth band frequency in cm.

To achieve the desired WLAN band notched characteristics, a pair of L-shaped slots, symmetrical step slots on the both edge of ground plane and a rectangular slot in the center of the ground plane are etched on the rectangular ground plane. The dimensions of quarter-wave resonating (L-shaped) slot at central band-notched frequency can be postulated as

$$f_{notch} = \frac{c}{4(L + 2\Delta l)\sqrt{\varepsilon_{eff}}}\,\text{GHz} \tag{3}$$

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(\sqrt{1 + \frac{12H}{w_g}}\right)^{-1} \tag{4}$$

$$\Delta l = \frac{0.412H(\varepsilon_{eff} + 0.3)\left(\frac{w_g}{H} + 0.262\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w_g}{H} + 0.813\right)}\,\text{cm} \tag{5}$$

Table 1. Optimum dimensions of the proposed antenna (all dimensions are in mm).

R	r	g	L_g	W_g	L_1	W_1	W_f
10.2	4	2	12.7	20.4	6.2	6.2	2.4
L_{gps}	w_s	l_s	w	l	L_B	W_B	-
7	0.75	0.75	3.5	3.5	27	2	-

where $L(= w_L + L_L)$ is the total length of the L-shaped slot and H is the substrate height in cm, ε_{eff} and ε_r are the effective and relative dielectric constant respectively and $c = 3 \times 10^{10}$ cm/s.

The mean electrical length of L-shaped slot at central notched frequency 5.5 GHz should be $\lambda_{eff}/4$ or 7.5 mm. The physical length of slot is calculated from Equations (3)–(5). $\varepsilon_{eff} = 3.3$, $\Delta l = 0.18$ mm and $L = 7.14$ mm. Simulated central band notch frequency is obtained at 5.5 GHz with mean slot length equal to $L = w_L + L_L = 7.75$ mm which is close to calculated value.

The dimensions of the proposed structure are optimized to cover 2.4–2.48 GHz band for Bluetooth, 3.1–5.15 GHz (low band) and 5.825–10.6 GHz (high band) for UWB applications and tabulated in Table 1.

3. PARAMETRIC STUDY OF PROPOSED ANTENNA

The performance of fork shaped dual band antenna with WLAN band notched characteristic depends on number of parameters, such as gap (g) between radiating patch and ground plane, width (w_s) and length (l_s) of the L-shaped slot in ground plane, width (w) and length (l) of the symmetrical step slot in ground plane, width (w_{gps}) and length (l_{gps}) of the central slot in ground plane, width (W_B) and length (L_B) of central rectangular monopole, width (W) and length (L) of rectangular strip over semicircular annular ring and inner (r) and outer radius (R) of semi-annular ring. Beside these, antenna performance also depends on ground plane size and shape. The parameters which have significant effects on dual band with WLAN band notched characteristic are discussed and their parametric studies are reported in this section.

The gap 'g' between the radiating patch and the ground plane affects the impedance bandwidth as it acts as a matching network. The impedance bandwidth of the proposed antenna at different gap 'g' is shown in Figure 3. The optimum impedance bandwidth is obtained at $g = 2.0$ mm. At $g = 2.0$ mm, the capacitance that results from the spacing between edge of ground plane and radiating patch reasonably balances the inductance of the antenna.

The rectangular monopole antenna (RMA) at the center of U-shaped radiation element resonates over Bluetooth band. The length 'L_B' of RMA determines the central resonating frequency while the width 'W_B' of the RMA affects impedance bandwidth of this band. Central resonating frequency increases with decrease in L_B. Impedance bandwidth increases with increase in W_B. The length of RMA is calculated using Equation (2). However, length of RMA is less than the calculated length due to dielectric substrate, fringing effect and mutual

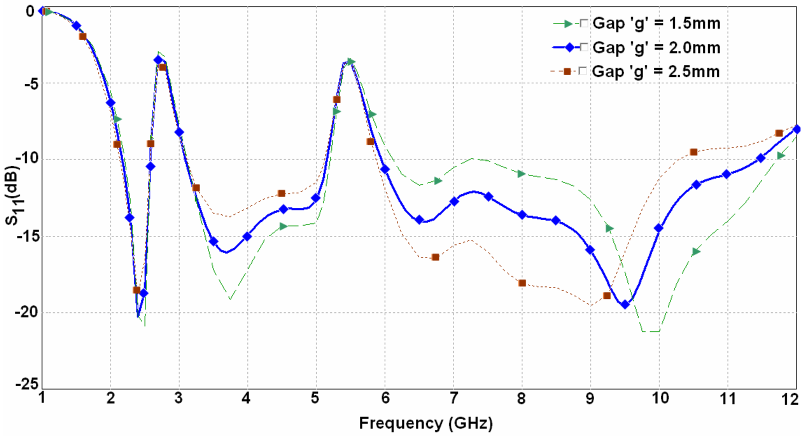


Figure 3. S_{11} vs. frequency for different gap 'g'.

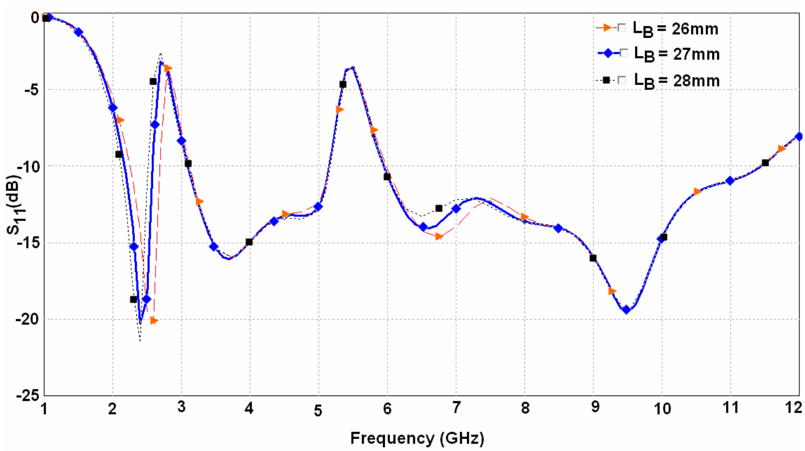


Figure 4. S_{11} vs. frequency for different 'L_B'.

coupling between two radiating elements resonating over Bluetooth and UWB band. The simulated return loss for different strip length 'L_B' is shown in Figure 4.

The central WLAN band rejection frequency can be tuned by changing the dimensions of w_s and l_s. It also affects the frequency rejection bandwidth. The central band rejection frequency increases and rejection bandwidth decreases with decrease in the dimensions of w_s and l_s. These two parameters can be tuned separately to fine tune the notched band. The simulated return loss for different w_s and l_s

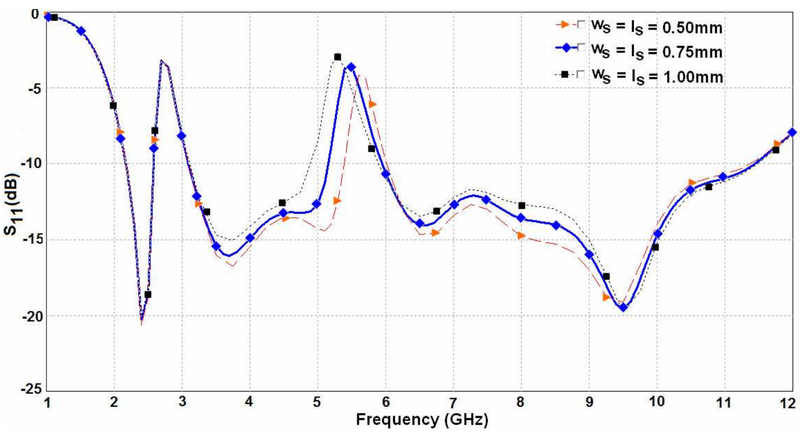


Figure 5. Simulated S_{11} vs. frequency for different L-shaped slot width w_s and length l_s.

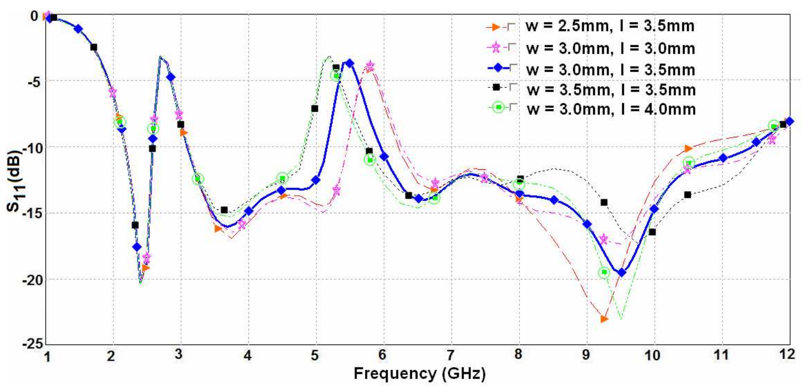
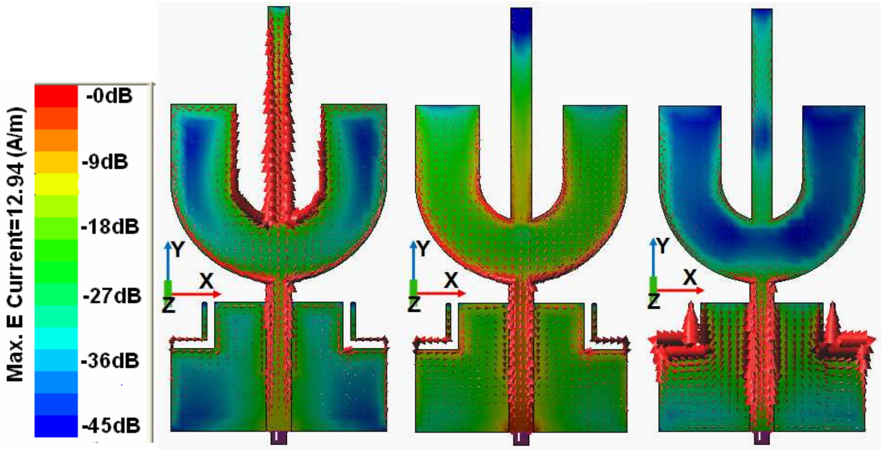


Figure 6. Simulated S_{11} vs. frequency for different symmetrical step slot width w and length l.

are shown in Figure 5. Step slots in the ground plane also affect the central notched frequency and notched bandwidth. The return loss for different w and l are shown in Figure 6. Besides tuning notched band w_s, l_s, w and l also affect impedance matching and therefore these parameters are also optimized to achieve the desired UWB response with WLAN band notch characteristics. The symmetrical step slot 3 mm × 3.5 mm on the both edge of ground plane not only enhances impedance bandwidth but also improve omnidirectional radiation pattern characteristics for UWB applications. The proposed antenna provides $S_{11} \cong -3$ dB in the 5.15–5.948 GHz notch band. It can be improved but at the cost of increase in notch bandwidth. S_{11} can be improved by using substrate with low dielectric constant.

The surface current distributions in stop band and pass band at 2.45, 3.5, and 5.5 GHz frequencies are shown in Figure 7. In monopole antennas, both monopole radiator and ground plane contribute to radiating fields. The current distributions in pass band at 2.45, and 3.5 GHz shows that the surface current from transmission line couples to radiating patch with little surface current around the L-shaped slot as shown in Figures 7(a), and (b). Figure 7(a) shows that the central arm resonates at 2.45 GHz, however, current is also induced in U-shaped monopole, but the surface current forms a loop around the periphery of U-shaped monopole and therefore, radiations are primarily from central rectangular arm. There is small J_x current



(a) 2.45 GHz (b) 3.5 GHz (c) 5.5 GHz

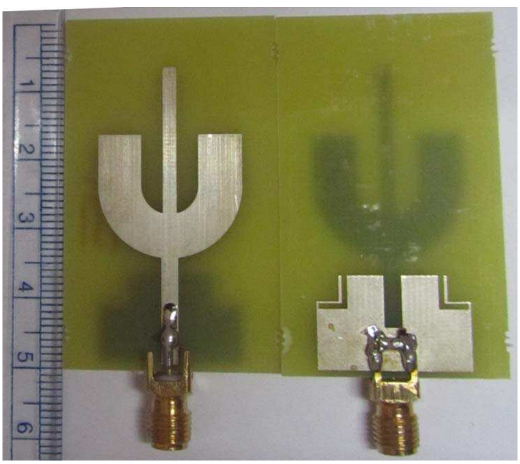
Figure 7. Surface current distributions of proposed antenna at 2.45, 3.5, and 5.5 GHz.

component induced at the edge of ground plane near the radiating patch at 2.45 GHz. The current distribution at 3.5 GHz in Figure 7(b) shows that the surface current flows in vertical direction in U-shaped monopole and there is little current in the central arm. There is small J_x current component induced at the edge of ground plane near the radiating patch. Therefore, radiation patterns are nearly omnidirectional with negligible cross polar component.

However in stop band at 5.5 GHz the surface current is concentrated around the L-shaped slots as shown in Figure 7(c) which act as resonator. There is little current in the radiating patch and therefore it does not radiate. Also at 5.5 GHz, the ground plane has considerable surface current which causes the antenna to be non-responsive at this frequency. Further destructive interference between radiating patch and ground plane excited surface currents results in decrease in antenna efficiency and gain in stop band.

4. FABRICATION AND MEASURED RESULTS

The antenna structure is fabricated on a printed circuit board (PCB) using Photolithography technique and tested. The fabricated antenna is shown in Figure 8. The measured return loss using Agilent 8722ET VNA and simulated return loss of the proposed structure are shown in Figure 9. The measured results reasonably agree with simulated results. The proposed antenna rejects the WLAN band and still



(a) Top view (b) Bottom view

Figure 8. Photograph of the proposed dual band antenna with WLAN band notch.

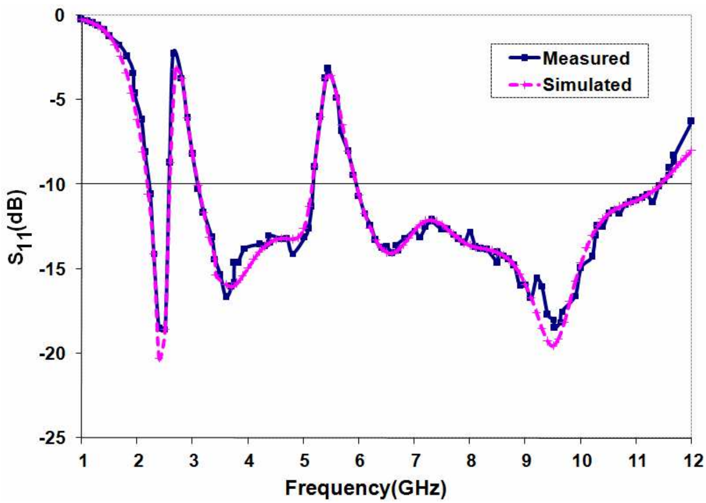
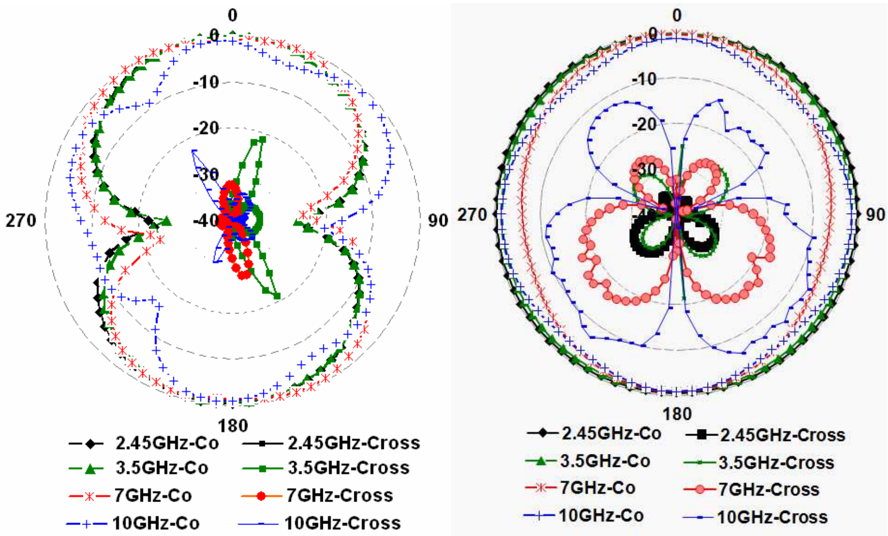


Figure 9. Measured and simulated S_{11} of the proposed antenna.

performs good impedance matching over the UWB and Bluetooth band.

Radiation patterns and gain are measured using standard horn antennas. The normalized measured radiation patterns at 2.45, 3.5, 7, and 10 GHz in the E- and H-planes are shown in Figure 10 while measured gain of proposed antenna structure is shown in Figure 11. The antenna exhibits a stable omnidirectional radiation over both Bluetooth and UWB bands. It is observed that in H-plane, the cross polarization increases with increase in frequency. The cross polarization is due to the excitation of higher order modes, J_x current at the edge of ground plane [10, 11, 13] and discontinuity at substrate-air and metallic patch-substrate interface, resulting in surface waves [11]. At higher frequency, the radiation patterns also deteriorate because the equivalent radiating area changes with frequency over UWB. Unequal phase distribution and significant magnitude of higher order mode at higher frequencies also play a part in the deterioration of radiation pattern at higher frequencies. Omnidirectional characteristics and radiation bandwidth can be improved if ground plane length is approximately of the same size as that of radiating structure width [11]. Omnidirectional characteristics and radiation bandwidth can further be improved by using thin substrate or substrate with low dielectric constant [12].

In the proposed antenna structure, different modes correspond to resonant frequencies which occur at 3.8, 6.6 and 9.5 GHz as



(a) *E* plane (b) *H* plane

Figure 10. Measured radiation patterns of proposed antenna at 2.45, 3.5, 7 and 10 GHz.

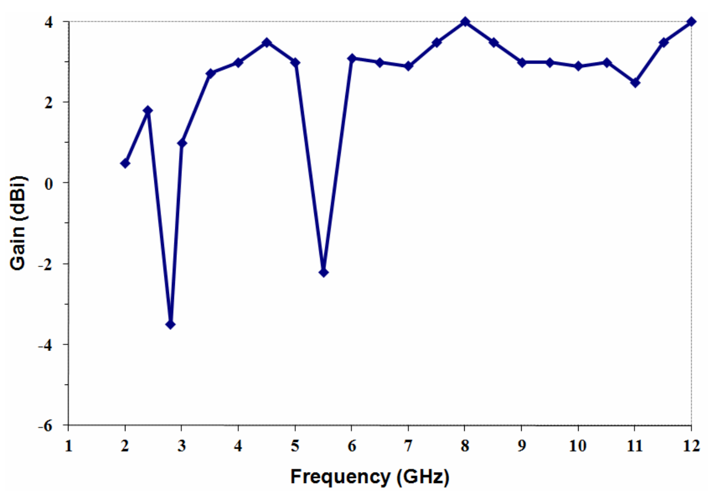


Figure 11. Measured gain of the proposed antenna at different frequencies.

shown in Figure 9. Dominant mode occurs at 3.8 GHz. Radiation pattern degrades after 6.6 GHz. The proposed antenna has nearly omnidirectional radiation characteristic in H plane and figure of eight radiation pattern in the E plane over both Bluetooth and UWB band.

Antenna efficiency of the proposed antenna is measured using wheeler cap method and shown in Figure 12. There is a sharp decrease in gain and efficiency at WLAN notched band. Gain variation is < 3 dB over two bands. The proposed antenna provides more than 85% antenna efficiency and gain varies from 1–4 dB over 2.18–2.59 GHZ, for Bluetooth band, 3.098–5.15 GHz (low band) and 5.948–11.434 GHz

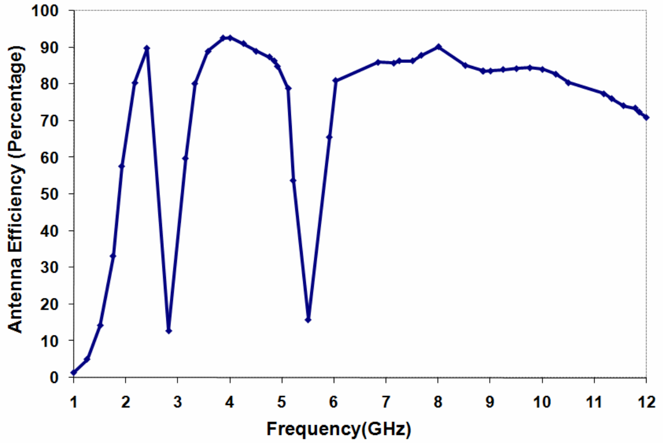


Figure 12. Antenna efficiency vs. frequency of proposed dual band antenna with WLAN band notch.

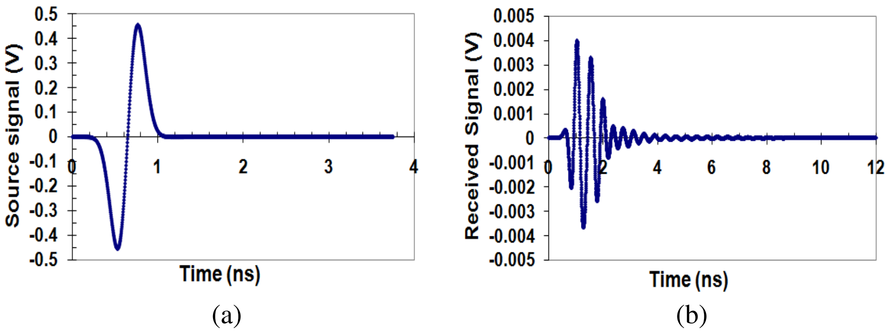


Figure 13. (a) Excited Gaussian source pulse and (b) the received pulse at the receiving antenna.

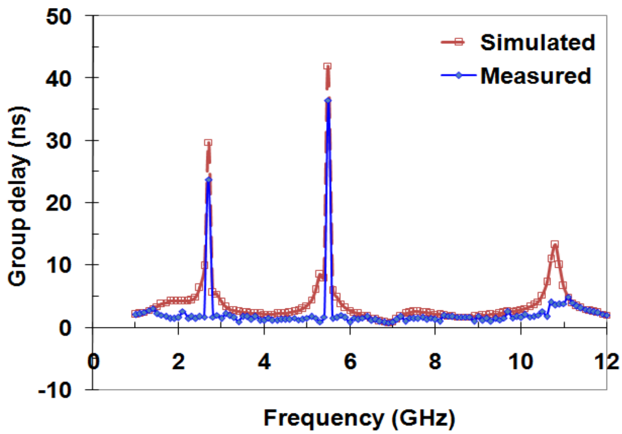


Figure 14. Measured group delay of the proposed antenna.

(high band) for UWB applications.

The time domain characteristics viz. group delay of the proposed antenna is measured between two identical antennas placed at 0.3 m in the face-to-face orientations, using Agilent E8364B PNA Network Analyzer. Figures 13(a) and (b) show excited Gaussian source pulse that is feed to excite the transmitting antenna and the received pulse at the receiving antenna respectively. As shown in Figure 14, the measured group delay is constant over the operating bands except over the notched band.

The fidelity factor is given by [18]

$$\rho = \max_{\tau} \left\{ \left| \frac{\int p(t)s(t-\tau)dt}{\sqrt{\int p^2(t)dt}\sqrt{\int s^2(t)dt}} \right| \right\} \tag{6}$$

where, τ is a delay which is varied to make the numerator in Equation (6) a maximum. It determines the correlation between the excited pulse signal $p(t)$ and radiated or received pulse signal $s(t)$. The fidelity factor is 0.7420 between excited and radiated pulse while it is 0.6652 between excited and received pulse, which is a slightly less than the fidelity factor between excited and radiated pulse. Therefore, the proposed antenna is capable of offering good pulse handling capability as demanded by modern Bluetooth and UWB communication systems.

5. CONCLUSION

A simple, low cost and compact printed fork shaped dual band antenna for Bluetooth and UWB applications with WLAN band notched characteristic is proposed. This microstrip line fed antenna can be easily integrated. Dimensions of central arm govern the Bluetooth band while dimensions of U-shaped monopole govern the UWB band. Simply adjusting the total length of L-shaped slot in the ground plane, the desired band-notched frequency can be controlled to minimize the potential interferences between the UWB system and the WLAN system. The proposed antenna provides more than 80% antenna efficiency and gain varies from 1–4 dB over 2.18–2.59 GHz for Bluetooth, 3.098–5.15 GHz (low band) and 5.948–11.434 GHz (high band) for UWB applications with effective control over operating bands. The radiation patterns are nearly omnidirectional over the desired bands except in the WLAN notched band. Accordingly, the proposed antenna is a good candidate for integrated Bluetooth and UWB systems.

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REFERENCES

1. Zhao, Q., S.-X. Gong, W. Jiang, B. Yang, and J. Xie, "Compact wide-slot tri-band antenna for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 18, 9–18, 2010.
2. Kohno, R., M. McLaughlin, and M. Welborn, "DS-UWB physical layer sub-mission to 802.15 task group 3a," *IEEE Document 802.15–04-0493r4*, 2005.
3. Federal Communications Commission, "First order and report: Revision of part 15 of the Commission's rules regarding UWB transmission systems," Apr. 22, 2002.
4. Agrawall, N., G. Kumar, and K. Ray, "Wide-band planar monopole antennas," *IEEE Trans. Antennas Propag.*, Vol. 46, 294–295, 1998.
5. Gopikrishna, M., D. D. Krishna, A. R. Chandran, and C. K. Aanandan, "Square monopole antenna for ultra wide band

communication applications," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 11, 1525–1537, 2007.

6. Ching, W. L., W. H. Lo, R. H. Yan, and S. J. Chung, "Planar binomial curved monopole antennas for UWB communication," *IEEE Trans. Antennas Propag.*, Vol. 55, 2622–2624, 2007.
7. Yin, X.-C., C.-L. Ruan, C.-Y. Ding, and J.-H. Chu, "A planar U type monopole antenna for UWB applications," *Progress In Electromagnetics Research Letters*, Vol. 2, 1–10, 2008.
8. Evans, J. A. and M. J. Ammann, "Planar monopole design considerations based on TLM estimation of current density," *Microwave Opt. Technol. Lett.*, Vol. 36, 40–42, 2003.
9. Mishra, S. K., R. K. Gupta, and J. Mukherjee, "Parallel metal plated tuning fork shaped omnidirectional monopole antenna for UWB application," *Microwave Opt. Technol. Lett.*, Vol. 53, No. 3, 601–604, Mar. 2011.
10. Clerk, J., J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "Study of a printed circular disc monopole antenna for UWB systems," *IEEE Trans. Antennas Propag.*, Vol. 53, 3500–3504, 2005.
11. Wu, Q., R. Jin, J. Geng, and M. Ding, "Printed omni-directional UWB monopole antenna with very compact size," *IEEE Trans. Antennas Propag.*, Vol. 56, 896–899, 2008.
12. Mishra, S. K., R. K. Gupta, and J. Mukherjee, "Effect of substrate material on radiation characteristics of an UWB antenna," *Loughborough Antennas & Propagation Conference*, 157–160, U.K., 2010. [978-1-4244-7306-9/10©2010 IEEE].
13. Gopikrishna, M., D. D. Krishna, C. K. Anandan, P. Mohanan, and K. Vasudevan, "Design of a compact semi-elliptic monopole slot antenna for UWB systems," *IEEE Trans. Antennas Propag.*, Vol. 57, 1834–1837, 2009.
14. Chen, Y.-L., C.-L. Ruan, and L. Peng, "A novel ultra-wideband bow-tie slot antenna in wireless communication systems," *Progress In Electromagnetics Research Letters*, Vol. 1, 101–108, 2008.
15. Zaker, R., C. Ghobadi, and J. Nourinia, "A modified microstrip-FED two-step tapered monopole antenna for UWB and WLAN applications," *Progress In Electromagnetics Research*, Vol. 77, 137–148, 2007.
16. Yildirim, B. S., B. A. Cetiner, G. Roqueta, and L. Jofre, "Integrated Bluetooth and UWB antenna," *IEEE Trans. Antennas Propag. Letters*, Vol. 8, 149–152, 2009.
17. Peng, L., C.-L. Ruan, Y.-L. Chen, and G.-M. Zhang, "A novel band-notched elliptical ring monopole antenna with a coplanar

parasitic elliptical patch for UWB applications," *Journal of Electromagnetic Waves and Applications*, Vol. 22, No. 4, 517–528, 2008.

18. Gao, G.-P., M. Li, S.-F. Niu, X.-J. Li, B.-N. Li, and J.-S. Zhang, "Study of a novel wideband circular slot antenna having frequency band-notched function," *Progress In Electromagnetics Research*, Vol. 96, 141–154, 2009.
19. Weng, Y. F., S. W. Cheung, and T. I. Yuk, "An antenna for UWB and bluetooth standards with band-notched characteristic," *ICUWB-2009*, 170–174, 2009.
20. Yang, Y.-B., F.-S. Zhang, F. Zhang, L. Zhang, and Y.-C. Jiao, "Design of novel wideband monopole antenna with a tunable notched-band for 2.4 GHz WLAN and UWB applications," *Progress In Electromagnetics Research Letters*, Vol. 13, 93–102, 2010.
21. IE3D release 14.0, Zeland Software Inc., Fremont, CA., USA, 2008.