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Design of Band-Notched Monopole Antenna with Semi-Ring Slot for Ultra-Wideband and 2.4 GHz WLAN Applications

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ABSTRACT: In this paper, a novel design of a compact band-notched monopole antenna with semi-ring slot for ultra-wideband and 2.4 GHz WLAN applications is proposed. The proposed antenna is mainly consists of partial truncated ground plane on the bottom surface of a dielectric substrate and the modified structure of circular radiating patch with embedded semi-ring slot at the centre of the patch on the top surface of a dielectric substrate. The antenna structure is designed on a 50 × 38 mm^{2}commercial modified glass epoxy dielectric substrate having thickness of 1.6 mm and relative permittivity 4.2. The antenna is fed by a 50Ω microstrip-line feed. The IEEE 802.11a or HIPERLAN/2 band-notched characteristic is realized by properly etching the semi-ring slot on the radiating patch. The proposed antenna can operates over the frequency band between 2.3 to more than 11 GHz except the interference band at frequency range of 3.35 to 5.2 GHz. Also, the designed antenna shows the near omni-directional radiation characteristics in X-Y plane and slightly bidirectional radiation characteristics in Y-Z plane and the gain is remained stable at entire UWB band (3.1 to 10.6 GHz) except around the notched band frequency range of 3.35 to 5.2 GHz.

KEYWORDS: Ultra-wideband, semi-ring slot, band-notched characteristics, UWB band-notched antenna.

I. INTRODUCTION

On February 14, 2002 the Federal Communication Commission (FCC) of United State has released a First Report and Order regarding the Ultra-Wideband (UWB) [1]. This Commission regulates and authorized the unlicensed exert of UWB Communication technology within the range of 3.1 to 10.6 GHz frequency band for low and high data rate personal area network (PAN) wireless devices, long distance range, radar and imaging systems. Over the past ten years, the UWB is receiving much attention and has experienced impressive technological developments for wireless connectivity high tech gadgets because of their significant features such as secure short range high data rate transmission, large bandwidth, inexpensive and low power consumption [2]. For the reliable usage and the desired requirement of UWB communications systems, the responsible component is UWB antenna which is considered as current research interest and must meet the requirement of high impedance bandwidth and omnidirectional radiation characteristics with stable gain over the entire UWB antenna. Recent studies reveal that, the UWB antenna engineers have been proposed a lot of printed monopole antenna for ultra-wideband applications with omnidirectional radiation patters with stable gain [3-8]. Despite all the advantages of UWB technology over the 3.1-10.6 GHz communication system there exist an electromagnetic interference (EMI) problem with coexisting narrow frequency band such as IEEE 802.11b worldwide interoperability for microwave access (WiMAX) for 3.3-3.8 GHz and C-band satellite communication system for 3.7-4.2 GHz services respectively. To overcome the problem of interference the band-notched property is most adoptable technique to solve these potential problems. Recently, the numerous UWB antennas with single, dual and multi notch-band characteristics have been reported [9-15]. The simple method to achieve a notched band is engraving the various slots on the radiating patch such as U-shape and V-shape slots on both radiating patch and ground plane [16-17], C-shape [18-19], circular and ring type slots [20-22] have been studied. In [23], the notch function is achieved by attaching a parasitic patch to the bottom layer of the UWB antenna.

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In this paper, a simple design of segmental arch shape monopole antenna with band-notched characteristics is proposed for 2.4 GHz WLAN and UWB wireless systems. The UWB antenna consists of an arch shape radiating patch and partially truncated ground plane which is fed by 50Ω microstripline feed. By embedding the semi-ring slot on center surface of the segmental arch shape radiating patch, the band-notch characteristics can be achieved. Moreover, with the change of the antenna parameters the band rejection property is realized and finally the optimized antenna is designed for the requirement of UWB applications. The antenna is simulated using Ansoft 3-D full-wave electromagnetic high frequency structural simulator (HFSS) [24]. All obtained simulation results are verified with experimental results and are presented and discussed.

II. ANTENNA DESIGN AND CONFIGURATION

The deigned geometry and its configuration of proposed UWB monopole antenna is as shown in Fig. 1. The overall size of the antenna including bottom ground plane is 35 × 50 mm^2 ($W_g \times L_g$), which is printed on commercially available modified glass epoxy dielectric substrate with a relative permittivity (ε_r) of 4.2, tangential loss (*tan* δ) of 0.02 and thickness (h) of 1.6 mm. On top surface of the dielectric substrate the segmental arch shape radiating patch with a semi-ring slot and bottom side of the surface the partial finite conducting ground plane of length (T_g) 20.45 mm is placed. The arch radiating patch is connected to a 50Ω microstripline feed of width (W_f) and length (L_f) which is equal to (T_g+ g). The microstripline L_f and W_f is fixed at 20.95 mm and 3.17 mm respectively. The gap 'g' is maintained as 0.5 mm between radiating patch and the bottom ground plane. The arch shaped radiating element which is modified from the conventional circular radiating patch having actual radius 'R'. The L_1, L_2 and L_3 are the truncated top and side lengths, S_1 and S_2 are segmental portions of the slot. In order to produce band-notched characteristics, a semi-ring slot is implanted at middle of the radiating patch. In this design, the band-notch function is particularly affected by the location of the slot length L_s. The optimized outer diameter (D) of the semi- ring slot is 14 mm. The length of the semi-ring slot (L_s) is about half wavelength of centre frequency of 3.3-5.1 GHz i.e. at 4.3 GHz. The rejected frequency can be postulated as,

$$f_{rejection} = \frac{c}{2L_{slot} * \sqrt{\varepsilon_{eff}}} \quad (1)$$

$$\therefore \quad \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}$$

where, L_{slot} is the length of the slot, 'ε_{eff}' is the effective relative dielectric constant and 'c' is the velocity of light. The proposed band-notched UWB antenna is simulated and parametric study is carried out by using Ansosft 3D electromagnetic high-frequency structure simulator (HFSS) software package. The optimized design parameters of the proposed antenna are as follows:
W_g=38 mm, L_g= 50, W_f=3.17 mm, L_f=20.95 mm, R= 10.7 mm, h= 1.6 mm, g = 0.5 mm, W_s=0.2 mm, T_g=20.45 mm, L_s= 21.2 mm, D= 14 mm, L_1= 12.46 mm, L_2=14.86 mm, L_3= 12.46 mm and S_1 = S_2= 1.94 mm. Figure 2 shows the top and bottom view photographs of the fabricated antenna with SMA connector is mounted at the centre tip of the microstripline and ground plane.

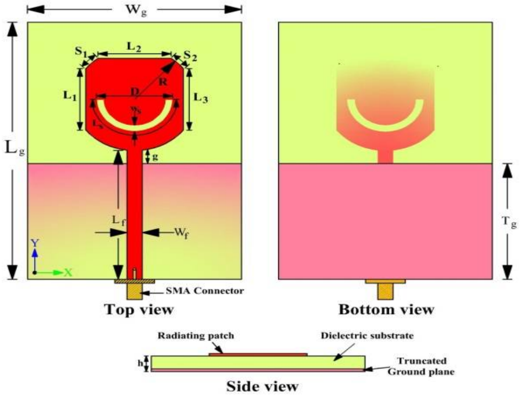

Fig.1. Geometry of proposed UWB band-notched antenna.

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(a) (b)

Fig. 2. Photograph of the fabricated UWB antenna (a) Top view (b) Bottom view

III. RESULTS AND DISCUSSIONS

The prototype of the proposed UWB antenna is fabricated for validating the realistic design which is shown in Fig. 2 and experimentally analysed by measuring various parameters with the help of Rohde & Schwarz ZVK model 1127.8651 German make Vector Network Analyser (VNA). The effect of notch-band characteristics is also studied by varying the dimension of one parameter at a time and by keeping the other parameters constant.

Figure 3 presents the simulated return loss versus frequency curves for different values of L_s. From this figure, it is shown that length of the semi-ring slot (L_s) is varied from 19.9 mm to 21.9 mm by keeping values of W_s and T_g constant at *2 mm* and *20.45 mm* respectively. By increasing the length of L_s the notch bandwidth decreases from *5.8 GHz* to *5.15 GHz* is prior to reached near the magnitude of the return loss of $|S_{11}| > -5$ *dB*. The optimum slot length is found to be at $L_s = 21.5$ *mm* which gives IEEE 802.11a or HIPERLAN/2 notched frequency range. Figure 4 illustrates the simulated return loss versus frequency curves for different values of $W_s$when L_s and T_g are fixed at *21.5 mm* and *20.45 mm* respectively. As observed that, the central notch frequency is shifted below from *5.2 GHz* to *5.12 GHz* by increasing the width of W_s. The optimised value of W_s is found to be *2 mm*. From these results, it is evident that, the bandwidth of notched-band may be easily varied by changing the length and width of the semi-ring slot.

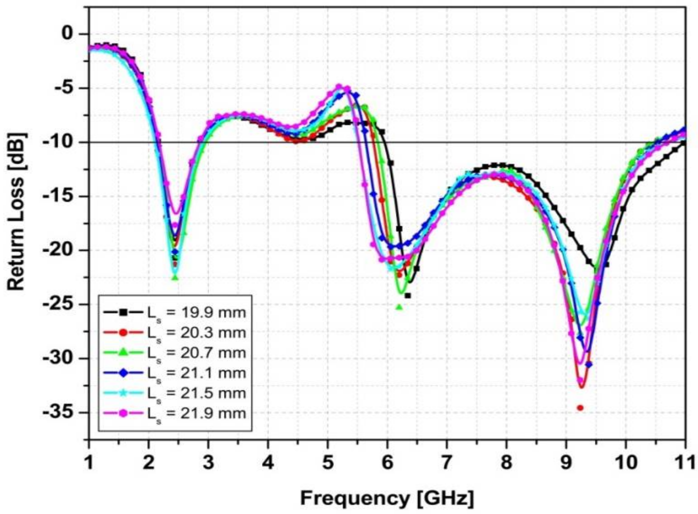

Fig. 3. Simulated return loss versus frequency plots of proposed UWB antenna for the various values of L_S by keeping $W_S = 2$ *mm* and $T_g = 20.45$ *mm*

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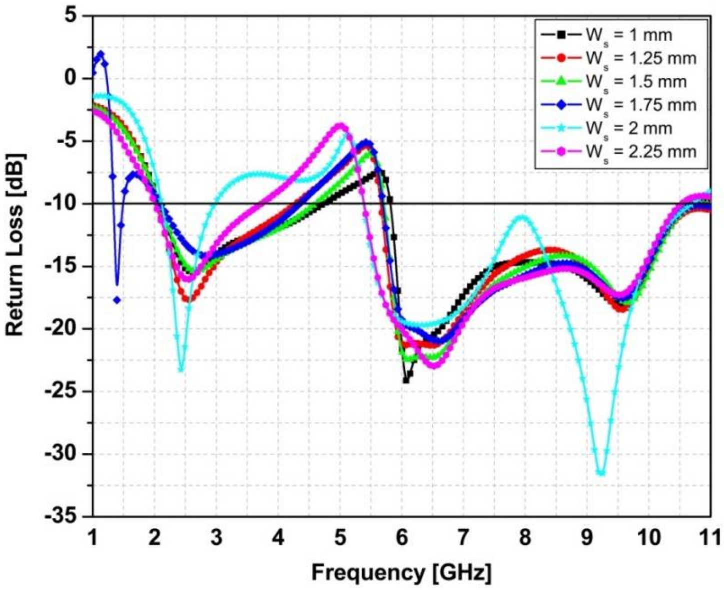

Fig. 4. Simulated return loss versus frequency plots of proposed UWB antenna for the various values of W_S by keeping $L_S = 21.5$ *mm* and $T_g = 20.45$ *mm*

Figure 5 shows the simulated return loss curves for the different values of T_g when $L_s = 21.5$ *mm* and $W_s = 2$ *mm*. It can be seen that, the impedance bandwidth is significantly changes by increasing the size of T_g values from 17.45 mm to 20.45 mm. The optimal value of T_g is found be at *20.45 mm* for better impedance matching where we get desired notch band frequency range of 3.3-5.1 GHz. The experimental and simulated return loss versus frequency response of the proposed UWB antenna for the optimized dimensions is plotted in Fig. 6. The plot indicates that, the antenna reveals a dual band characteristics which covers the 2.4 GHz WLAN and ultra-wideband impedance bandwidth having $|S_{11}| < -10$ dB over an operating frequency range of 2.35 to more than 11 GHz expect around band-notched frequency of 3.3 – 5.1 GHz. From this figure it is also clear that, there is a qualitative agreement between the measured and simulated results. However, there is a slight difference between the experimental and simulation results at the higher frequency. This is mainly due to influenced by the coupling effect of the 50Ω SMA connector and physical tolerance in relative permittivity of dielectric material.

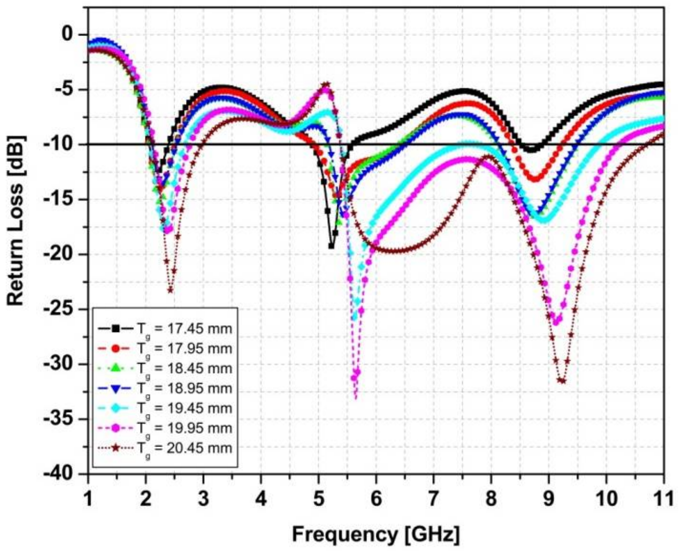

Fig. 5. Simulated return loss versus frequency plots of proposed UWB antenna for the various values of T_g and keeping $L_S = 21.5$ *mm* and $W_S = 2$ *mm*

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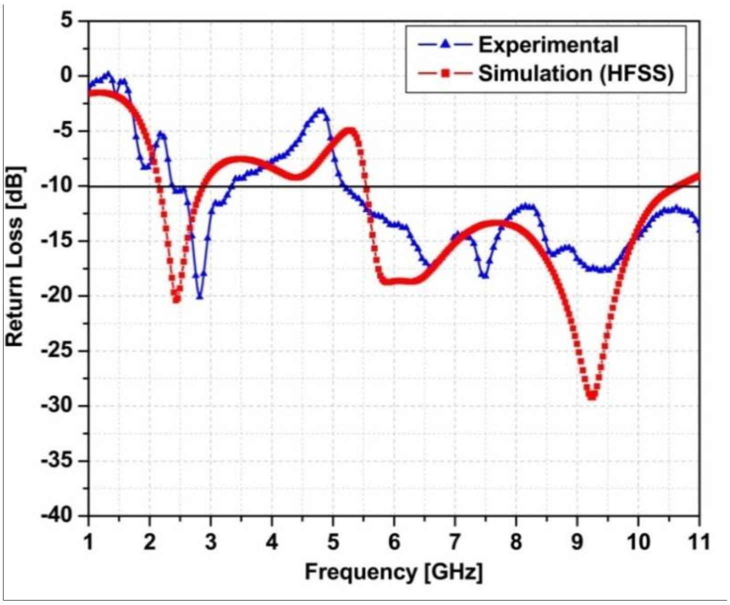
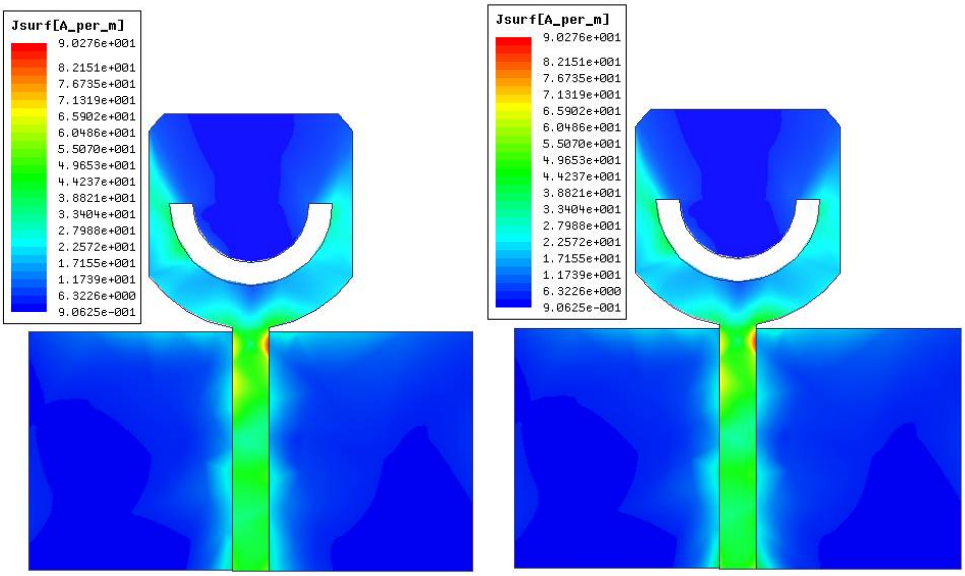


Fig. 6. Experimental and simulated return loss versus frequency plot of the proposed UWB antenna

Figure 7 (a)-(d) illustrates the simulated current distributions on the surface of the radiating element and on the ground plane at desired frequencies of 2.43, 4.8, 6.29 and 9.22 GHz respectively. As shown in Fig. 7 (a), (b) and (d) is evident that, the current density is mainly flows through the microstripline feed and partial current flow is found along the edges of the slot. But, in the case of notched band at 4.8 GHz which is shown in Fig. 7(c), the large current distributed around the semi-ring slot edges is observed. This is because the more current reflected back due to mismatching of impedance at that particular frequency and consequently by inserting semi- ring slot on the radiating patch. The notched frequency is obtained at desired frequency which will enable the interference of IEEE 802.11a or HIPERLAN/2 frequency bands.



(a) (b)

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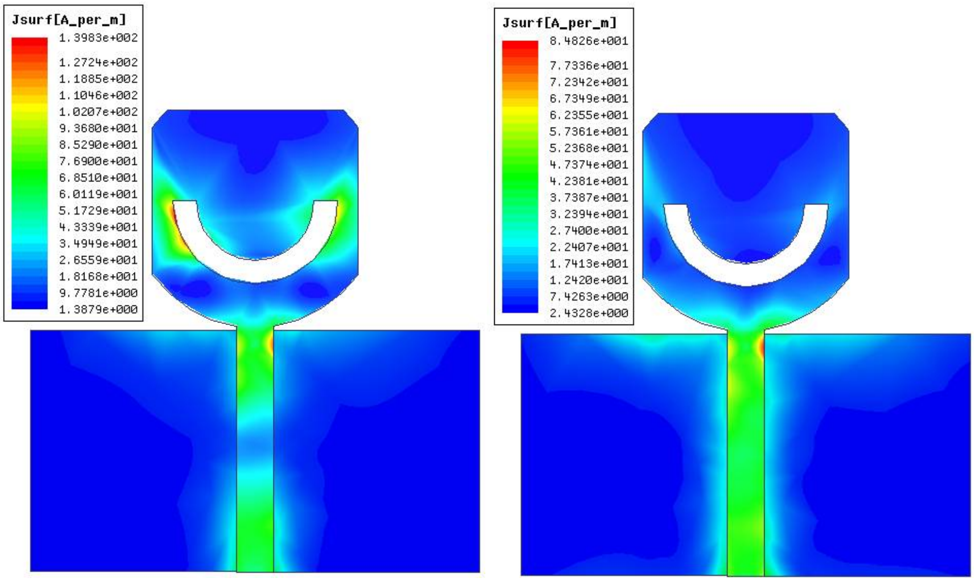
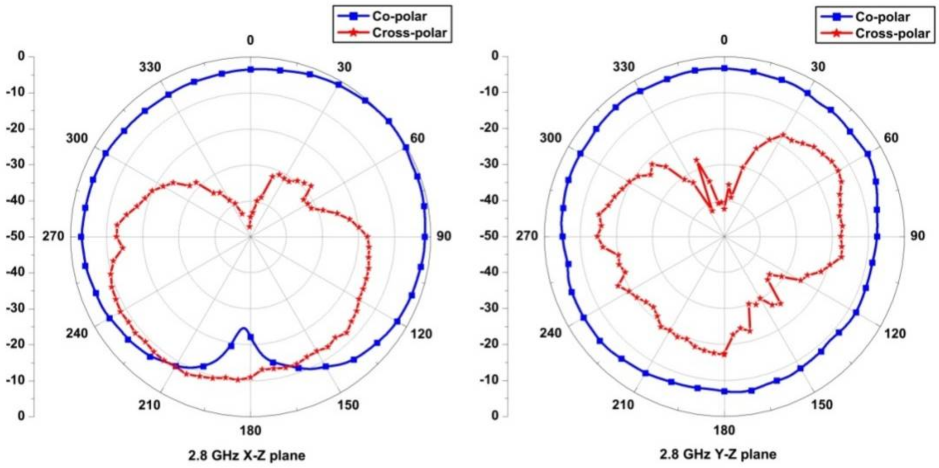


(c) (d)

Fig. 7. Surface current distribution of the proposed UWB antenna observed at (a) 2.43 GHz, (b) 4.8 GHz, (c) 6.29 GHz and (d) 9.22 GHz

Figure 8 (a) – (e) shows the far-field normalized radiation patterns including co-polarization and cross-polarization E-plane (XY-plane) and H-plane (YZ-plane) measured at 2.8, 5.5, 6.6, 7.47 and 9.4 GHz respectively. From these figures, it is seen that, the proposed antenna exhibits an omnidirectional radiation pattern in H-plane (YZ-plane) and quasi-omnidirectional radiation pattern in E-plane (XZ-plane) with minimum cross-polarization. It is also observed that, the cross-polarized patterns in both planes are increasing at higher frequencies. The peak gain of the proposed UWB antenna with and without semi-ring slot is as shown in Fig. 9. It is clearly seen that, the gain is instantly decreasing in between the frequency range of 3.4 to 5.1 GHz which realized that the proposed antenna has a perfect rejection at vicinity of 4.2 GHz for IEEE 802a or HIPERLAN/2 interference frequency bands. The range of proposed antenna gain over operating frequency bands is about 2.94 to 5.65 dBi is observed except at the band notched frequency region. The maximum gain 5.65 dBi is observed at 9 GHz and minimum gain of -4.17 dBi is observed at rejected band. All of these show that, the proposed antenna has good band-notched characteristics and effectively minimize the potential interferences between UWB system and the wireless communication systems.



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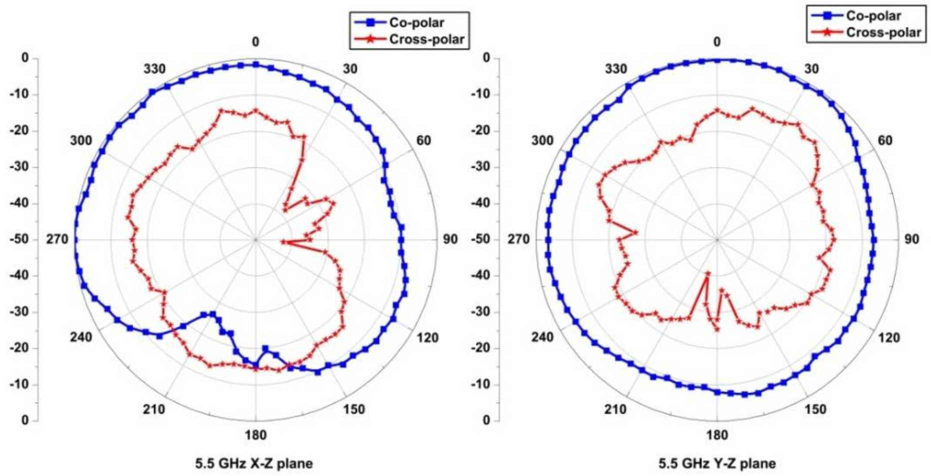
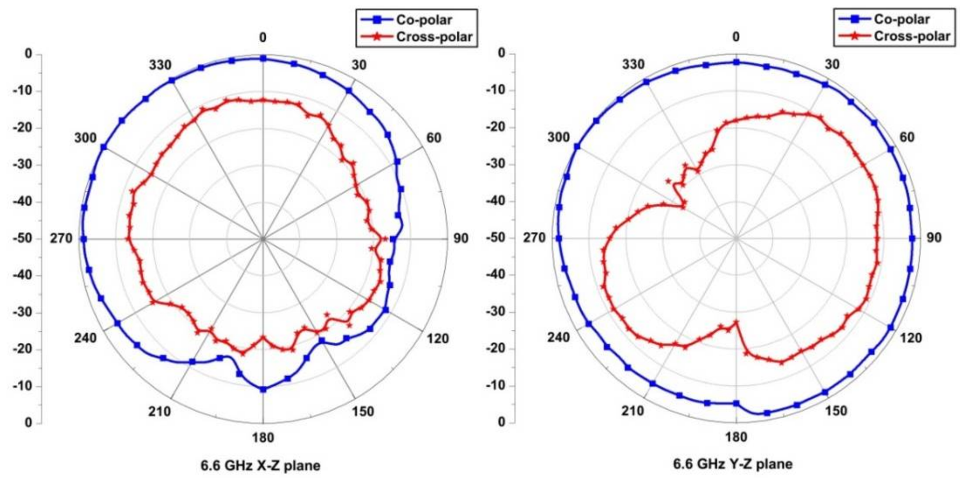
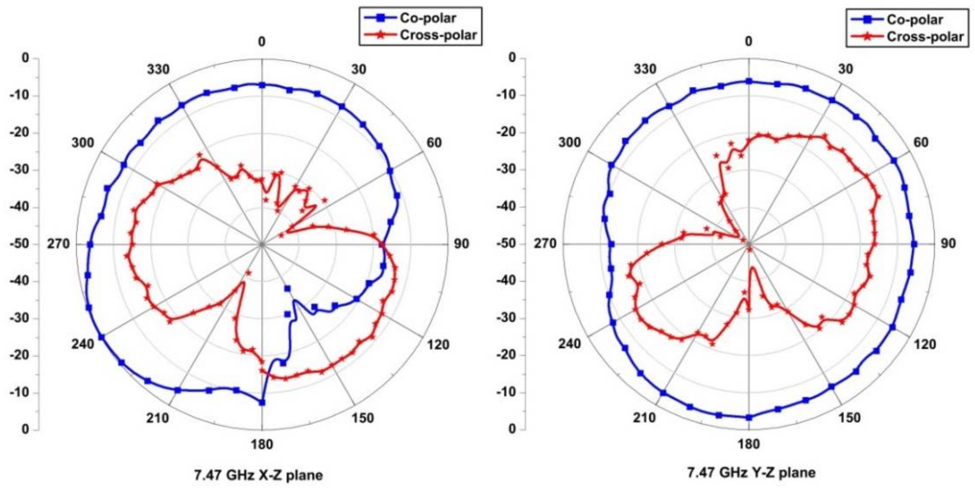


(b)



(c)



(d)

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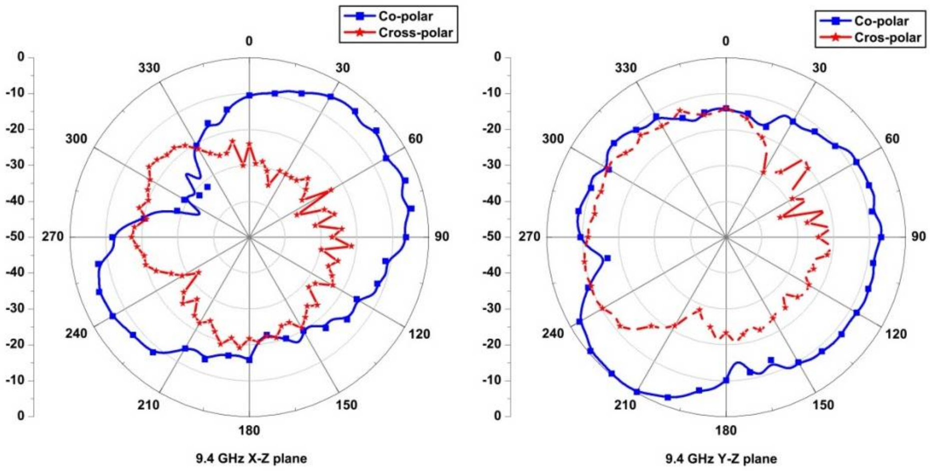

(e)

Fig. 8 Measured normalized radiation patterns in E-plane (X-Z plane) and H-plane (Y-Z) of the proposed UWB antenna at (a) 2.8 GHz, (b) 5.5 GHz, (c) 6.6 GHz, (d) 7.47 GHz and (e) 9.4 GHz

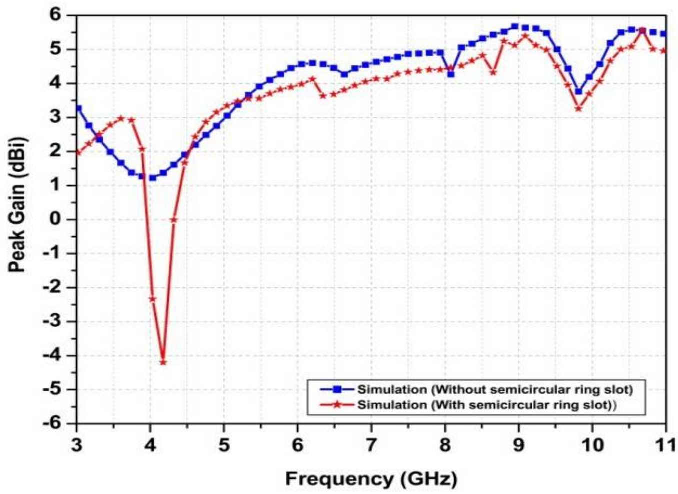

Fig. 9 Simulated peak gain of the proposed UWB antenna with and without semi-ring slot

IV. CONCLUSION

This paper proposes a novel design of band-notched printed monopole antenna which can operate for both wireless local area network (2.4 GHz WLAN) and ultra-wideband (3.1 – 10.6 GHz) frequency bands respectively. The band-notch characteristics have been realized by loading semi-ring slot on the radiating patch. Furthermore, by marginal variation of slot length and width of semi- ring slot dimensions the performance of notched bandwidths is adjustable. Return loss variation of the proposed antenna for varies values of slot parameters have been studied by using Ansoft HFSS software. Finally, the optimized UWB antenna design with bang-rejected around 3.35 to 5.2 GHz, which minimize the interference of existing IEEE 802.11a or HIPERLAN/2 (3.35 to 5.2 GHz) operating frequency band. From the obtained experimental results the proposed antenna shows a good near omni-directional radiation characteristics with stable gain throughout the UWB band except at notch-band frequency range. The proposed UWB antenna has a simple structure and inexpensive to manufacture hence it can be a good candidate for UWB communication system.

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BIOGRAPHY

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Dr. S. N. Mulgi is a Professor of Electronics at Gulbarga University, Kalaburagi since 2010. He received his M.Sc., M.Phil. and Ph.D. degrees in Applied Electronics from Gulbarga University Kalaburagi in the year 1986, 1989 and 2004 respectively. He has got more than 22 years of research and teaching experience at post-graduation level. Dr. S. N. Mulgi has authored more than 260 research papers in International, National Journals, Conferences, Symposium, Seminars etc. He has engaged research work mainly in the field of Microwave Communication Engineering for the design and development of printed monopole antennas and microstrip array antennas.