# Design of Stepped Patch Ultra Wideband Antenna with WLAN Band Notch Characteristics

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***Abstract*— The paper presents the design and performance measures of a printed stepped patch monopole antenna with semi-elliptical ground plane and band notch for ultra wideband applications. The proposed antenna operates in the frequency range 3.15 ~ 12.2 GHz with average gain of 4.27 dBi. Inverted U - shaped slot is introduced in the feed line for WLAN band rejection and the rejection band ranges from 5.08 GHz to 5.93 GHz. The radiation pattern is directional in the elevation plane and omnidirectional in the azimuth plane. The consistency of the radiation pattern exists within the operating band. The performance of the proposed antenna is confirmed by simulation and experiment results.**

**Keywords- Inverted U slot, monopole antenna, stepped patch, ultra wideband**

## I. INTRODUCTION

Present time is witnessing a very rapid growth in wireless communications, for which antennas with very large bandwidth are in strong demand, so that various wireless services are covered with fewer or preferably with a single antenna. Out of all existing wireless systems, ultra wideband (UWB) wireless technology is most sought after for very high-data-rate and short-range wireless communication systems, secured information transmission and low probability of interception, rejection of multi path effect, etc. Due to the extremely low emission levels currently allowed by regulatory agencies [1], UWB systems tend to be used for short-range and indoor wireless applications. UWB poses several challenges and among them is the design of UWB antennas. It is considerably more challenging than conventional antennas. Conventional antennas cannot transmit UWB signals without distortion. It is more difficult to characterize UWB antenna, as traditional narrow band antenna parameters are not directly useful to UWB. The design of UWB antennas is even more challenging for mobile terminals and portable devices. In the recent years, researchers, engineers and scientist have tried to solve UWB antenna problem in different ways. Various types of antennas have been investigated for UWB systems and among the printed monopole antennas have been considered as a suitable candidate because of their inherent characteristics, compact size and ease of integration with transceiver circuits of UWB systems [2]-[11]. However, the challenge for UWB antenna design is the inclusion of band reject effect on antenna structure itself to overcome the electromagnetic interference arising from the existing wireless local area network (WLAN) allocated from 5.15-5.825 GHz, thereby avoiding the insertion of additional band stop filters in the transceivers. Several approaches have been proposed to achieve band notch characteristics. Some of the approaches are split ring resonators, tuning stubs, parasitic elements and slots for realizing notched band [ 12]-[17].

This paper focuses on the design and performance analysis of band notched stepped square patch monopole antenna with semi-elliptical ground plane and highlights the multi-resonance effect that contributes ultra wideband. The bandstop resonating structure proposed for WLAN band rejection is the inverted U- slot which is simple and easily realizable. As the slot is created in the feed line, the characteristics of the antenna are less disturbed and hence it exhibits wide bandwidth, consistent gain and efficiency characteristics in the operating band. These inherent characteristics of the proposed antenna make it suitable for efficient transmission and reception of high data rate signals. As the size is small, it can be easily integrated with portable UWB devices. Antenna design and parametric studies are described in section 2 and 3. Comparison of measured and simulated results of the proposed antenna are presented in section 4 followed by conclusion.

## II. ANTENNA DESIGN THEORY

The geometry of the proposed antenna is shown in Fig. 1a. The antenna design is based on multi resonance effect. Multi resonance effect in the antenna not only reduces the size but also increases the gain of the antenna. By perturbation technique, multi resonance effect can be initiated in antenna to obtain UWB characteristics. At lower frequency, antenna operates in oscillating mode and at higher frequency it operates in hybrid mode where standing wave and oscillating wave exists. Due to the existence of these waves, multiple resonances occur simultaneously and the combined effect of adjacent resonance leads to ultra wide impedance bandwidth. Feed length, the bottom contour of the printed monopole antenna and the ground plane dimension support traveling wave very well and they also act as an impedance matching network. Stepped patch monopole antenna with semi elliptical ground plane is the upgraded configuration of rectangular patch monopole antenna with rectangular ground plane. The modified ground plane plays an important role in the broad band characteristics of the antenna as it helps to match the patch with the feed line for a wide range of frequencies. This is because the truncation creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly resistive input impedance. To further enhance the bandwidth, stepped notches were introduced. These notches increase the antenna perimeter. As the current distribution is mainly concentrated on the edges, the surface current path increases which in turn decreases the lowest resonance frequency. The disturbance in the electric field also introduces additional resonances which enhances the bandwidth. A rectangular slot was created in the modified ground plane to control the impedance bandwidth and return loss level. To eliminate the WLAN frequency band, inverted U slot of half wavelength ($L_{Slot}$) has been etched in the microstrip feed line. As the dimensions of the slot controls the centre frequency and rejection bandwidth, slot thickness ($t$) was optimized for WLAN band rejection. The dimensions of the antenna and inverted U-slot were calculated using equation (1) and (2). The proposed antenna was realized on a low cost FR4 substrate of relative permittivity ($\varepsilon_r$) 4.4 and thickness (h) 1.6 mm. The width of the feed line is 3 mm.

$$Lp = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \quad (1)$$

$$L_{Slot} = \frac{\lambda}{2\sqrt{\varepsilon_{eff}}} = 2L_S + W_S - 2t \quad (2)$$

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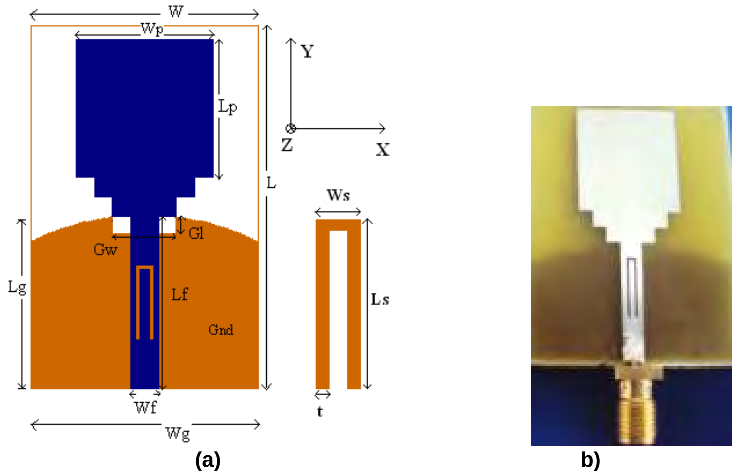


Fig. 1. (a) Proposed antenna geometry (b) Photograph of the fabricated antenna

## III. PARAMETRIC STUDIES

To explore how the dimensions of the antenna have effect on antenna performance parameters, a parametric study was carried out for the proposed antenna. The proposed antenna structure was simulated and dimensions of the antenna were optimized for better performance characteristics using IE3D software.

### A. *Effect of modified ground plane*

As the ground plane configuration and patch configuration affects the impedance bandwidth of the antenna, study was carried out for different ground configuration (Fig. 2.). Initially the patch antenna with partial ground plane of rectangular shape was simulated. As the bandwidth was lower than expected, upper surface of the rectangular ground plane were flared to semi elliptical shape to improve the impedance bandwidth. The flaring in the ground plane creates a capacitive load effect and minimizes the inductive nature of the patch at higher frequency. Hence the return loss of the modified antenna is better at higher frequency compared to the antenna with rectangular ground plane. The modified ground plane acts as a matching element and controls the impedance bandwidth of the antenna. To further enhance the bandwidth, multi resonance mode was initiated by truncating the lower portion of the rectangular patch.

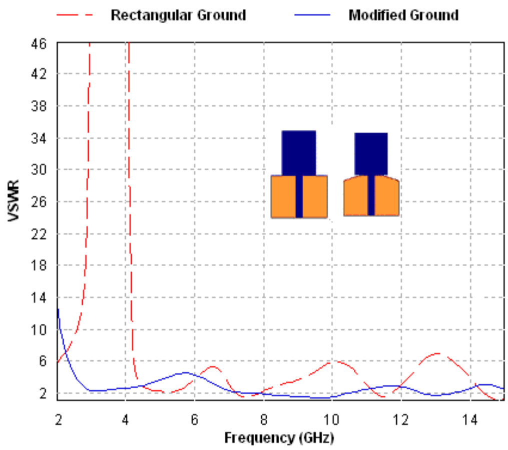


Fig. 2. Effect of different ground plane configuration on VSWR characteristics (L=40, W=25, Lg=16, Wg=25, Lp=19.4, Wp= 15, h=1.6 (All are in mm), $\varepsilon_r$ =4.4)

### *B. Effect of step notches*

Patch antenna designed to resonate at one frequency can be initiated to operate in multi resonance mode by truncating nearly square notches. The truncated portion disturbs the field distribution and hence additional resonance occurs depending on their size and the number of such notches. Steps of size of 2.2 mm × 2 mm were created at the lower portion of the patch. Presence of step notches varies the distance between the lower part of the antenna and the ground plane thereby improving its capacitive coupling and widening its impedance bandwidth. For one and three step notches, capacitive coupling effect is less compared to two step notches resulting in poor bandwidth enhancement (Fig. 3), whereas for two step notches, impedance bandwidth is 139.5 % due to the maximum capacitive coupling and nearly resistive input impedance.

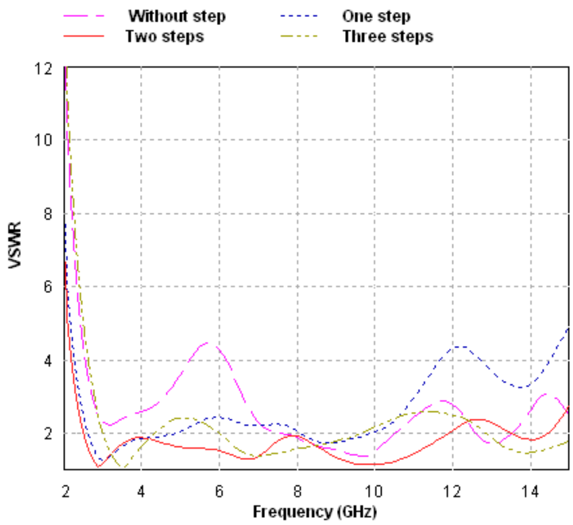


Fig. 3. Effect of steps on VSWR characteristics

### *C. Effect of slotted ground plane*

As the impedance bandwidth of the modified ground plane antenna does not cover the complete UWB range and the return loss is poor at center resonant frequency, improvement in antenna performances were carried out by truncating rectangular slots in the modified ground plane. The slot creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly pure resistive input impedance. Keeping slot width(Gs) as 7 mm, its length (Gl) was varied and optimized for better performance. Fig. 4 illustrates the simulated VSWR characteristics for different slot dimension. For VSWR ≤ 2, the impedance bandwidth is 11.271 GHz (2.682 GHz to 13.953 GHz) that covers the entire UWB range. The optimal slot dimension is 1.8 mm × 7 mm.

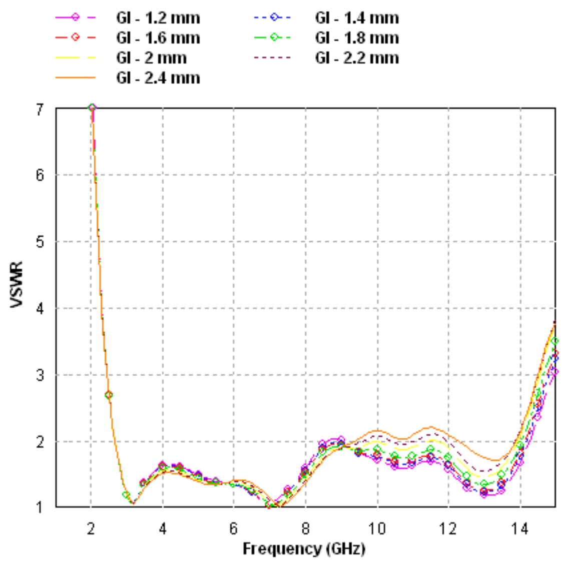


Fig. 4. Effect of slotted ground plane on VSWR characteristics

*D. Effect of inverted U slot*

To eliminate the WLAN frequency band, inverted U slot as been etched in the microstrip feed line. The total length of the inverted U slot is 16.8 mm that corresponds to the half wavelength of 5.49 GHz (WLAN centre frequency). Required rejection bandwidth can be obtained by varying the U slot thickness(t). Fig. 5 depicts the impact of inverted U-slot thickness variation on notch bandwidth. The notch band is from 4.97 GHz to 5.92 GHz and the operating frequency band for VSWR ≤ 2 ranges from 2.91 GHz to 12.98 GHz. The VSWR in the notch band is greater than two. This affects the gain and efficiency characteristics of the antenna. For rejecting WLAN frequency band, the optimized U slot dimensions are Ls = 8 mm, Ws = 1.6 mm and t = 0.4 mm.

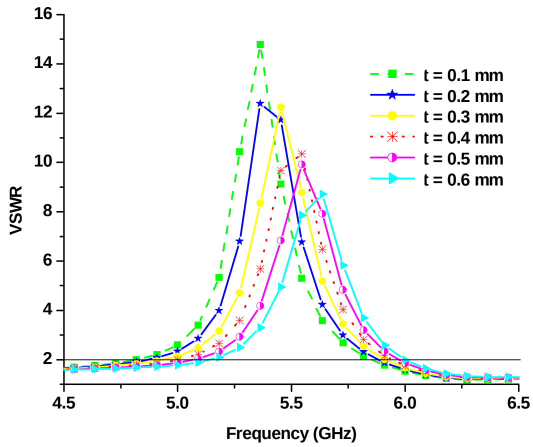


Fig. 5. Impact of U slot thickness variation on notch bandwidth

*E. Surface current distribution*

To better understand the behavior of the antenna, in particular the band rejection characteristics of the proposed antenna in the WLAN band, surface current distribution of the antenna has been studied (Fig. 6). In the pass band of 4 GHz and 7 GHz, Figures 6(a) and 6(c) show that the majority of the current flow through the microstrip feed into the antenna and then radiates. However, at notched frequency of 5.5 GHz, Figure 6(b) shows that currents are fully concentrated around the inverted U slot and do not flow into the antenna thereby preventing radiation into the free space. This indicates the non radiation mode of the antenna and the notch function of the band reject filter.

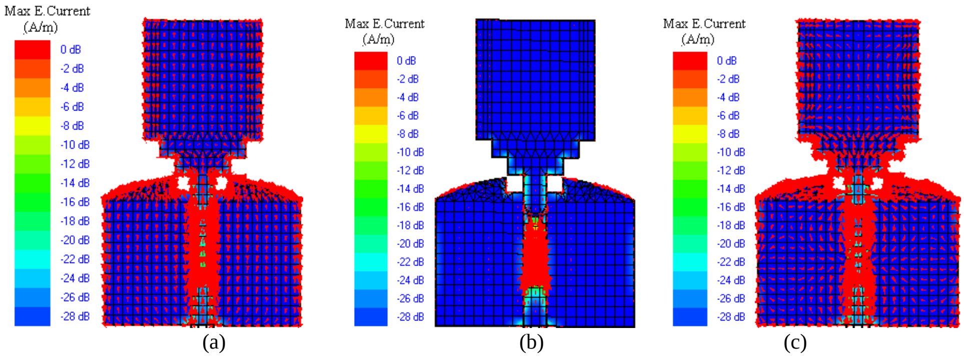


Fig. 6. Surface current distribution of proposed antenna at (a) 4 GHz (b) 5.5 GHz and (c) 7GHz

## *F. Radiation Characteristics*

Radiation characteristics of the proposed antenna for frequencies across UWB band are also examined. Fig. 7 shows the radiation patterns including the co-polarization and cross-polarization in YZ and XZ planes. At the pass band frequency of 3.5, 4.5, and 7 GHz, the pattern is nearly figure of eight in the YZ plane and omnidirectional in the XZ plane over UWB band. The cross polarization level is less than -32 dB in the YZ plane and less than -13 dB in the XZ plane. At lower frequencies, comparable magnitude difference exist between co-polar and cross polar component in both the planes. As the frequency increases, the cross polarization level also increases, thereby limiting antenna performance. At the notch frequency of 5.5 GHz, the gain is almost evenly suppressed in all directions.

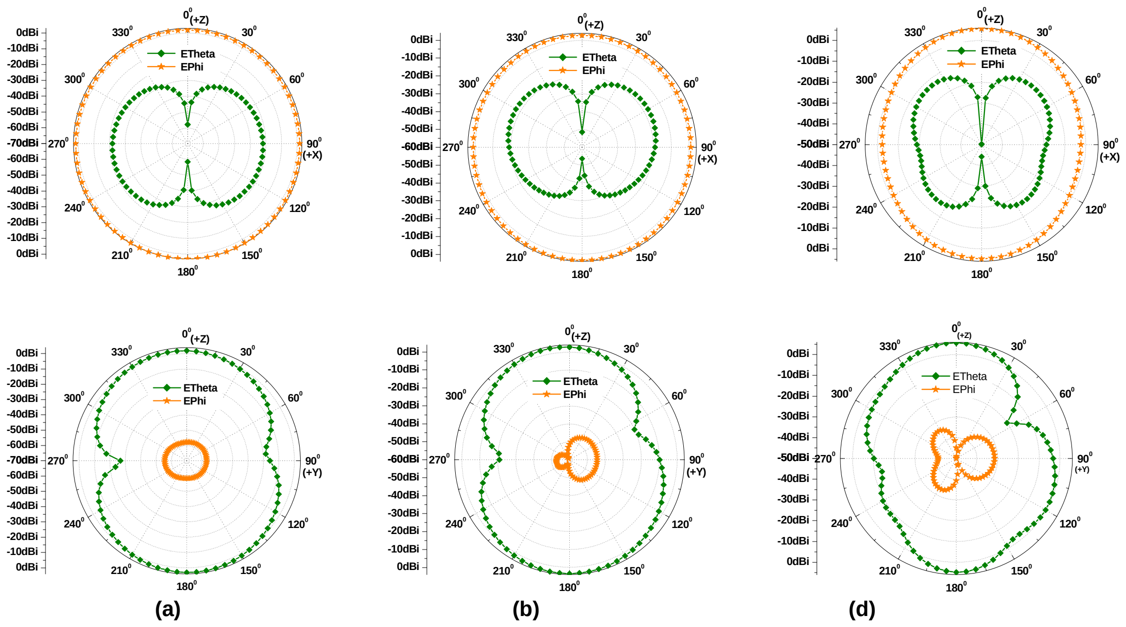


Fig. 7. Co and Cross polarized radiation patterns in the Elevation plane at (a) 3.5 GHz (b) 4.5 GHz (d) 7 GHz

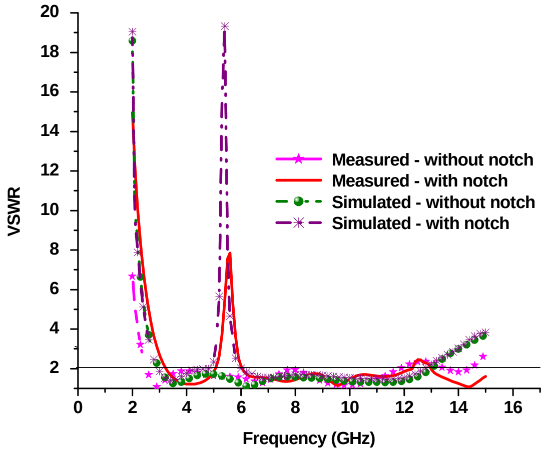


Fig. 8. Comparison of measured and simulated VSWR characteristics of the proposed Antenna

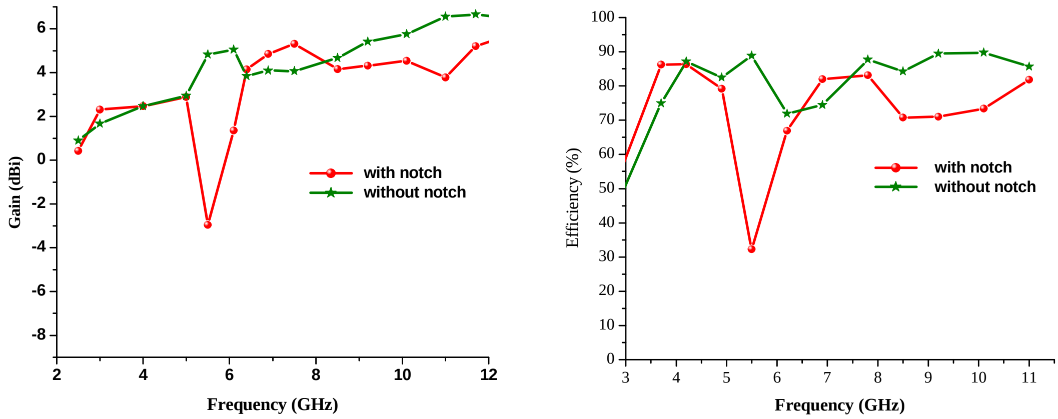


Fig. 9. Measured gain and efficiency characteristics of the proposed Antenna

## IV. EXPERIMENTAL RESULTS AND DISCUSSION

To confirm the validity of the design and simulation results, the prototype antenna with and without inverted U-slot was fabricated on a FR4 substrate of relative dielectric constant 4.4 and thickness 1.6 mm. These antennas were tested for its return loss characteristics using Agilent Network Analyzer N5230A. Radiation pattern measurement was performed in an anechoic chamber for different frequencies within the UWB and field components were measured using an 8564EC Spectrum Analyzer. From the measured components, gain and efficiency of the proposed antenna were calculated and compared with the simulation results. Fig. 8 shows the comparison of measured and simulated VSWR characteristics of the antenna with and without inverted U slot. The measured impedance bandwidth ranges from 2.56 GHz to 11.8 GHz (VSWR < 2) for antenna structure without inverted-U slot, whereas for the proposed antenna it ranges from 3.15 GHz to 12.2 GHz (VSWR < 2) covering the entire UWB frequency range with the WLAN band notch characteristics. This wide bandwidth is due to the multi resonance effect of the step notches and the square patch. The notched frequency band is 5.08 GHz to 5.93 GHz. The measured and simulated results are in good agreement. The presence of inverted-U slot not only rejects the frequency band but also enhances the impedance bandwidth. Fig. 9 shows the measured gain and efficiency characteristics of the proposed antenna as a function of frequency. The measured antenna gain ranges from 2.3 dBi to 5.3 dBi and dips to as low as -2.96 dBi in the notch band. This implies that the antenna is incapable of radiating and functions as band reject filter. The average gain of the antenna is 4.27 dBi excluding the notch band. The measured efficiency ranges from 65 to 90% in the UWB pass band, whereas it is as low as 32.27 % at the center frequency of WLAN band. As the impedance bandwidth obtained is 8.08 GHz with average gain of 4.27 dBi and nearly omnidirectional pattern in the azimuth plane and figure of eight in the elevation plane, the proposed antenna can be assigned for transfer of high data rate information for short ranges effectively. As the volume occupied by the antenna is small (25×40×1.6 $mm^3$), it can be easily integrated with the portable UWB devices.

## V. CONCLUSION

Performance characteristics of a stepped patch monopole antenna with semi-elliptical ground plane and band rejection characteristics for UWB applications have been discussed in this paper. The proposed antenna exhibits good impedance matching, wide bandwidth, high antenna efficiency, consistent gain and radiation characteristics within the operating band. These inherent characteristics of the proposed antenna make it suitable for efficient transmission and reception of high data rate signals. The total volume of the antenna including feed structure is 25 mm × 40 mm × 1.6 mm which is very small and it can be easily integrated with the handheld UWB devices.

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## REFERENCES

[1] FCC, "*First Report and Order, Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*", FCC02-48, April 2002.

[2] K P Ray, P V Anob, R Kapur and G Kumar, "Broadband planar rectangular monopole antennas", *Microwave and Optical Technology Letters*, vol. 28, no. 1, pp. 55-9, 2001.

[3] Su S.W, et al , "Ultra-wideband square planar monopole antenna for IEEE 802.16a operation in the 2–11 GHz band," *Microw. Opt. Technol. Lett.,* vol. 42, pp. 463–466, 2004.

[4] Wong K.L et al, "A compact wideband omnidirectional cross-plate monopole antenna", *Microw. Opt. Technol. Lett.,* vol. 44, no. 6, pp. 492–494, 2005.

[5] 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 Propagat.*, Vol 53, No.11, pp.3500-4, 2005.

[6] K G Thomas, N Lenin and R. Sivaramakrishnan, "Ultra wideband planar disc monopole", IEEE Transactions on Antennas and Propagation, Vol 54, No.4, pp.1339-41, Apr.2006.

[7] D Valderas, J De No, J Melendez and I Sancho, "Design of Omnidirectional Broadband Metal plate monopole antenna" *Microwave and Optical Technology Letters*, vol. 49, no. 12, pp. 375-9, 2007.

[8] O Ahmed and A R Sebak, "A printed monopole antenna with two steps and circular slots for UWB applications", *IEEE Antennas Wireless Propag. Lett.,* vol. 7, pp.411-413, 2008.

[9] Mithilesh Kumar, Ananjan Basu and Shiban K. Koul, "Frequency and Time Domain Characterization of a Novel Hexagonal–shaped Microstrip Antenna for Ultra Wideband Applications", *IETE Journal of Research*, Vol 57, No.5, pp.452-460, 2011.

[10] K L Wong, C H Wu and S W Su, "Ultrawideband square planar metal plate monopole antenna with a trident shaped feeding strip", *IEEE Trans. Antennas Propag*., vol. 53, no.4, pp. 1262-9, 2005 .

[11] C W Ling, W H Lo, R H Yan, and S J Chung, "Planar Binomial Curved Monopole Antennas for Ultrawideband Communications", *IEEE Trans. Antennas Propag*., vol. 55, no.9, pp. 2622-4, 2007.

[12] Choi J et al, "Parametric analysis of a band-rejection antenna for UWB application," *Microw. Opt. Technol. Lett.,* vol. 47, no.3, pp. 287–290, 2005.

[13] K. Shambavi, Zachariah C Alex, "Printed Dipole Antenna with Band Rejection Characteristics for UWB Applications", *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 1029–1032, 2010.

[14] K. H. Kim, *et al.*, "Band-notched UWB planar monopole antenna with two parasitic patches," *Electronics Letters,* vol. 41, pp. 783-785, 2005.

[15] J. Kim, *et al.*, "5.2 GHz notched ultra-wideband antenna using slot-type SRR," *Electronics Letters*, vol. 42, pp. 315-316, 2006.

[16] Nader Behdad, and Kamal Sarabandi, "A Compact Antenna for Ultrawide-Band Applications", *IEEE Trans. Antennas Propag*., vol. 53, no.7, pp. 2185-2191, 2005.

[17] Y. D. Dong, W. Hong, Z. Q. Kuai, C. Yu, Y. Zhang, J. Y. Zhou, and J. X. Chen, "Development of ultrawideband antenna with multiple bandnotched characteristics using half mode substrate integrated waveguide cavity technology," *IEEE Trans. Antennas Propag.*, vol. 56, no. 9, pp.2894–2902, Sep. 2008.