# Characterization and Performance Analysis of the Band-Notched Ultra-Wideband Elliptical Patch Antenna

G. A. Akpakwu,
Dept. of Electrical and Electronics Engineering,
University of Agriculture,
Makurdi, Nigeria.

P. O. Omolaye,
Dept. of Electrical and Electronics Engineering,
University of Agriculture,
Makurdi, Nigeria.

E. Idoko,
Dept. of Electrical and Electronics Engineering,
University of Agriculture,
Makurdi, Nigeria.

***Abstract*: A performance analysis was carried out to investigate the effect of Band-Notched Characteristics on Ultra-Wideband Antennas. Various configurations of the Patch Antenna structureembedded and stacked with a Notch-Cut and a U-Like Slot beneath the Notch were simulated and analyzed. Depending on the Ultra-Wideband Antenna and the Notch configuration, the results indicated improvement in the Reflection Coefficient – Return Loss (S11), Voltage Standing Wave Ratio, and Bandwidth when integrated for Patch Antenna to prevent interference with wireless systems of 5GHz band.***

***Keyword - Band-Notched, Patch Antenna, Reflection Coefficient, Ultra-Wideband (UWB) Antenna.***

## I. INTRODUCTION

On February the 14th 2002, the United States (US) Federal Communication Commission (FCC) officially approved and adopted the use of the very controversial Ultra-Wideband (UWB) technology for its commercial applications[1]. A "First Report and Order" that permitted and authorized a proposal for the Part 15 Rule amendment has been released to take effect in April 2002 [2]. The possibility of interference which can occur with other related wireless systems due to the wideband nature of the approved UWB emissions caused a lot of fear and generated a heated debate.

The department of a field that addresses UWB RF Signal started in late 1960's which was on time-domain electromagnetic [3] as base-band, impulse technology or carrier-free [4]. A lot of research efforts have been carried out for the design of UWB Antennas and systems for the great demand of communication, which are very important for the provision of wireless wideband communications. It is noted that for UWB applications, a wide variety of these antennas are very suitable for use [5]. In 2004 Kamya, Y. Y. and Ryuji Kohno [6], carried out a comparison study to investigate between the UWB antennas and the Conventional antennas. The authors described a study of conventional antennas and why these antennas are not suitable for system of UWB.

Today, the trend in UWB antenna is towards the design of Band-Notched Antennas [7], which is made insensitive to specific frequency band. Since this inception of design, most researchers have broadened their scope of research to investigate the possibility interference that may occur between UWB system and existing wireless communication systems such as WLAN/HYPERLAN systems. The common technique applicable is by adding a half-wavelength slot to the radiating patch antenna. This slot added to the patch antenna is intended for rejecting the required frequencies for the proposed design [8] – [10]

In 2007 a novel type and Compact Microstrip-fed Monopole Antennas with a frequency band-stop rejection function was proposed and presented in [11]. In this paper, the stop-band effect was actualized using modified planar monopoles with inverted U-slot, small strip bar and ^/4C shaped slot were used to obtain an impedance bandwidth of about 3 – 11GHz, with a sharp band-stop characteristics of 5.0 – 5.9GHz frequency band.

Having voiced out strong concerns over the problem of interference, the U.S. Department of Defense (DoD), finally obtained from the FCC a low frequency bound of 3.1GHz for UWB commercial applications.

This paper looks at a Patch Antenna Structure which was integrated with a stacked Notched-cut and a U-Like slot beneath the Notch-cut in various configurations to observe the characteristics on the properties of the proposed antenna. Extensive simulation was carried out using CST Microwave Studio. It was observed that with the integration of the patch antenna structure various improvements were noted in terms of Reflection Coefficient (S11), Voltage Standing Wave Ratio (VSWR), and Impedance Bandwidth.

## II. PATCH ANTENNA DESIGN

The UWB Antenna structure is composed of Elliptical Patch with Notch - cut, partial finite – size ground plane, a substrate and a U-Like slot which is embedded beneath the notch– cut in the elliptical radiating patch antenna and a metallic via connecting the patch to the ground plane to optimize the band – rejection performance.
The parameters which were utilized for the design are shown in the table I.

Table I. Parametric Analysis Utilized for Proposed Antenna Design

| **Description** | **Symbol** | **Size ($mm^2$)** |
|---|---|---|
| Substrate | $L_s * W_s$ | 38 * 35 |
| Elliptical Patch | $R_b * R_a$ | 11.5 * 11 |
| Notch Cut | $L_n * W_n$ | 13 * 10 |
| Slot | $L_1 * L_2 * L_3$ | 4 * 4 * 13 |
| Slot Width (Proposed) | $S_W$ | 1 |
| Ground Plane | $L_g * W_g$ | 14.7 * 35 |
| Feed | $L_f * W_f$ | 15 * 3.6 |
| Gap | G | 0.3 |

The Printed Elliptical Patch Antenna Structure's dimensions were designed and optimally configured after a parametric sweep as illustrated in Fig.1.

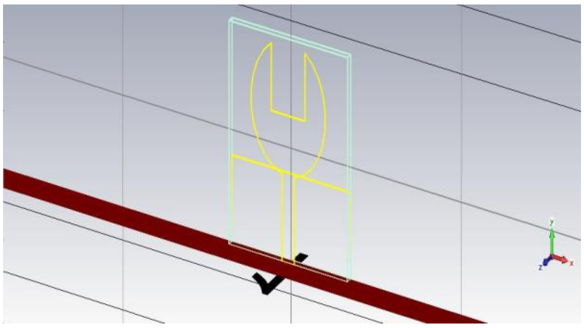

Fig.1. Geometry of Elliptical Patch Antenna(ReferenceAntenna)

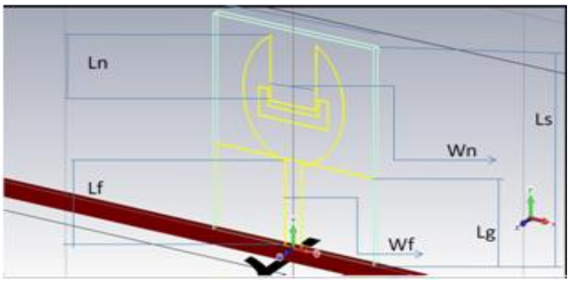


Fig.2.Geometry ofProposedElliptical Patch Antenna

Subsequently, a dispersion analysis was done on the designed Printed Elliptical Patch Antenna to confirm the Reflection Coefficient (S11) and VSWR. A sharp band-rejection performance existed from 4.74 – 6.07 GHz as observed in Fig.3

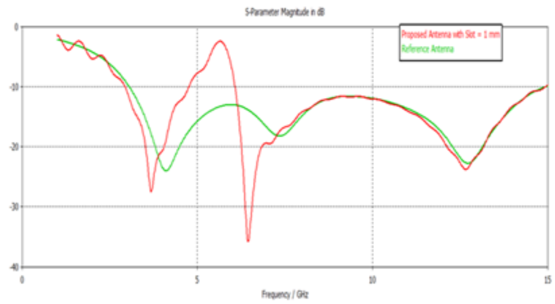

Fig.3.(a) Simulated Return Loss for Proposed Elliptical Patch Antenna

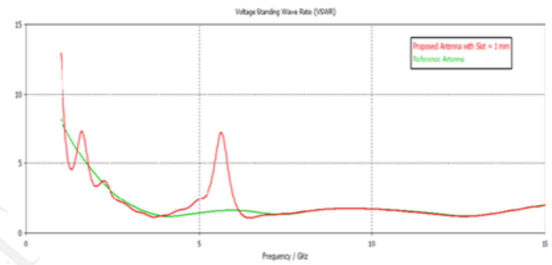

Fig.3.(b) Simulated VSWR for Proposed Elliptical Patch Antenna.



## III. NUMERICAL SIMULATIONS AND DESIGN CONSIDERATION

The wideband antennas which are required for UWB applications for both indoor and outdoor handheld operations have to be designed considering all the antenna parameters. The techniques which have been adopted for the study of band-notched characteristics on wideband antennas include notch cut with a U-Like Slot, the use of a Vertical Coupling Strip and the use of Slots with bevels at the top ground plane.

The U-Like Slot technique was used for modeling the design to achieve the band notched rejection function and to enhance the impedance bandwidth of the proposed UWB antenna. Subsequently, the analysis was conformed to the following:

### A. U-Like Slot At Constant Width (1mm)

The effect of positioning the U-Like Slot, which is varied from the centre of the substrate at 0mm to the notch cut in the elliptical patch at 5mm while maintaining the width at 1mm, was investigated to see the effect on the rejected frequency band. A parametric analysis was carried out from 0mm to 5mm and the positionof the U-Like Slot at 5mm provided the most optimal performance in terms of return loss as shown in Table II.

Table II. Performance Analysisofthe Simulated - 10dB Stop-Band at Constant Width

| U Slot Position (mm) | $F_L$ (GHz) | $F_U$ (GHz) | Notch Center Freq. (GHz) | Notch BW (GHz) |
|---|---|---|---|---|
| 0 | 3.550 | 4.980 | 4.265 | 1.430 |
| 1 | 3.960 | 5.170 | 4.565 | 1.210 |
| 2 | 4.160 | 5.410 | 4.785 | 1.250 |
| 3 | 4.370 | 5.710 | 5.040 | 1.340 |
| 4 | 4.770 | 6.050 | 5.410 | 1.280 |
| 5 | 5.150 | 6.540 | 5.845 | 1.390 |

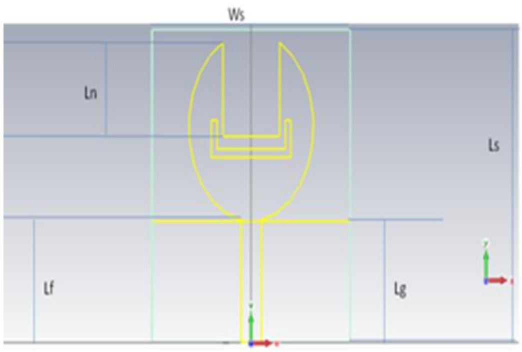


Fig.3.Proposed Elliptical Patch Antenna with U-Like Slot at 5mm

B. U – Like Slot at Varied Width (0.5mm – 2mm)

The values of the width for the U-Like Slot ranging from 0.5mm to 2mm were simulated to see if the thickness of the slot affected the performance. A parametric analysis was carried out at various positions of the slot while varying the slot width to ascertain the optimal performance in terms of return loss.Table III shows the effect of U-Like Slot widths of the simulated -10dB stop-band at various positions.

Table III.(a)Performance Analysis of the Simulated - 10dB Stop-Bandat 0mm

| Slot Width (mm) | $F_U$(GHz) | $F_L$(GHz) | Notch Center Freq. (GHz) |
|---|---|---|---|
| 0.5 | 4.930 | 3.670 | 4.300 |
| 1 | 5.030 | 3.560 | 4.295 |
| 1.5 | 5.110 | 3.560 | 4.335 |
| 2 | 5.160 | 3.470 | 4.315 |

Table III. (b) Performance Analysis of the Simulated - 10dB Stop-Band at 5mm

| Slot Width (mm) | $F_U$(GHz) | $F_L$(GHz) | Notch Center Freq. (GHz) |
|---|---|---|---|
| 0.5 | 6.520 | 5.320 | 5.920 |
| 1 | 6.520 | 5.100 | 5.810 |
| 1.5 | 6.570 | 4.940 | 5.755 |

## IV. RESULTS AND DISCUSSION

The simulated results for the return loss (S11) and its VSWR curves for the reference antenna, without the U-Like slot,(Fig.1) and its proposed UWB antenna (Fig.2) depicted in Fig.3 (a) and Fig.3 (b) show that for an UWB bandwidth which is defined by 2:1 VSWR covering 3.1 – 10.6 GHz of the allocated band is achieved for the reference antenna (without the U-Like slot).

Improvement in the -10dB return loss was also observed with an impedance bandwidth from 2.95 – 14.94GHz while maintaining a sharp band rejection performance of 4.74 – 6.07GHz for the proposed UWB antenna.



A. U-Like Slot at Constant Width (1mm)

It was observed that by adjusting the position and length of the U-Like Slot while maintaining the width at 1mm (as proposed) is capable of achieving a tunable stop-band range as shown in the Fig.4.

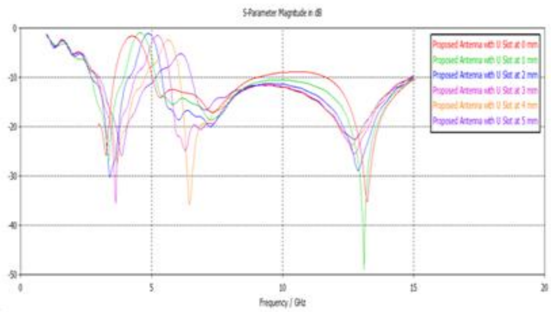

Fig.4(a)Simulated Return Loss for Elliptical Patch Antenna at various U-Slot Positions.

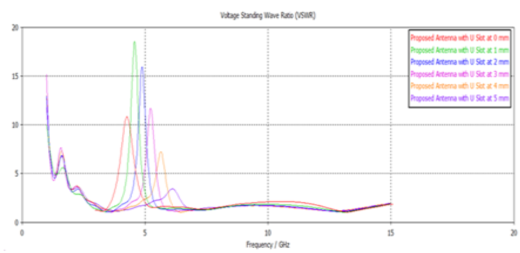

Fig.4(b) Simulated VSWR for Elliptical Patch Antenna at Various U-Slot Positions.

Fig.4 shows that the simulated return loss and VSWR curves for the proposed antenna with U-Like slot at 0mm has the worst curve with respect to –10dB which is due to the variation of its position, therefore, having a smaller impedance bandwidth. As the position of the slot increases from the center of the substrate (0mm), the U-Like slot at 4mm and 5mm shows an improvement and perfect return loss curves for bandwidth covering 2.95GHz – 14.92GHz frequency range with a sharp stop-band that can easily be adjusted from 4.770GHz – 6.540GHz for a good frequency rejection characteristic as observed from the parametric analysis shown in Table II.

Hence, it was also observed from Table IIthat by maintaining the width while adjusting the positions and length of the U-Like Slot the stop-band rejection performance increases as the position increases from 0mm to 5mm beneath the notch-cut.

B. U-Like Slot at Varied Width (0.5mm – 2mm)

The figures 5-8 illustrate the effects of U-Like Slot width for the proposed antenna. With the width varied from 0.5mm – 2mm, the band-notched effect due to changes of width are discussed as observed from the return loss and VSWR curves figures 5-8 and tables IV-VII.

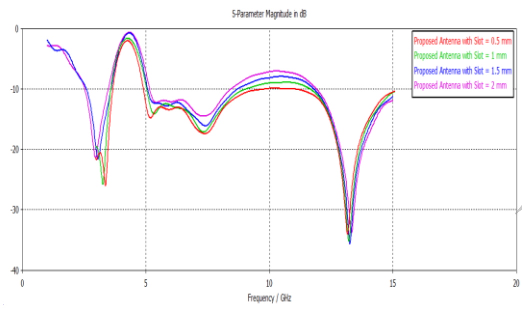

Fig.5(a) Simulated return loss for proposed antenna of various slot widths at 0mm

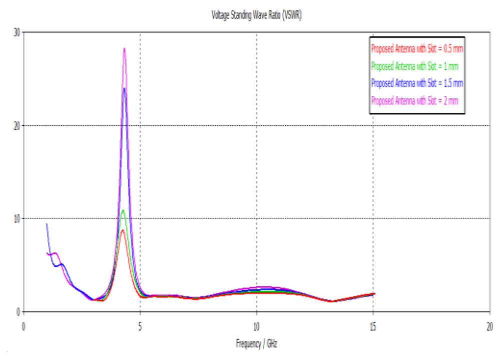

Fig.5(b) Simulated VSWR for proposed antenna of various slot widths at 0mm

Table IV. Performance Analysis of the simulated -10dB Stop-Band at 0mm

| Slot Width (mm) | $F_U$ (GHz) | $F_L$ (GHz) | Notch Center Freq. (GHz) |
|---|---|---|---|
| 0.5 | 4.93 | 3.67 | 4.300 |
| 1 | 5.03 | 3.56 | 4.295 |
| 1.5 | 5.11 | 3.56 | 4.335 |
| 2 | 5.16 | 3.47 | 4.315 |

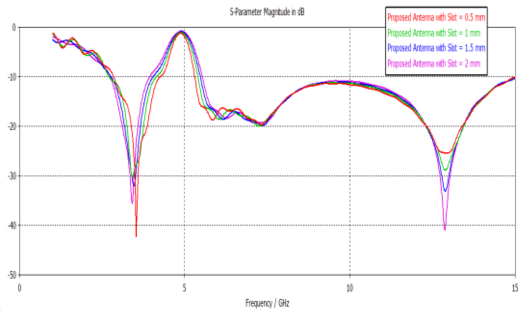



Fig.6(a) Simulated return loss for proposed antenna of various slot widths at 2mm

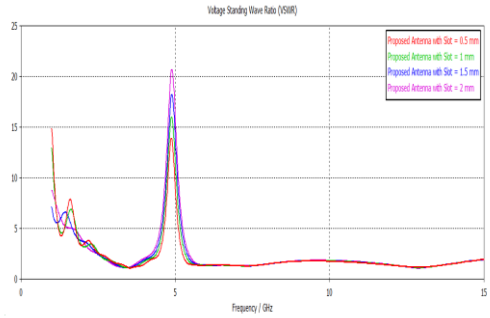

Fig.6(b) Simulated VSWR for proposed antenna of various slot widths at 2mm

Table V. Performance Analysis of the simulated -10dB Stop-Band at 2mm

| Slot Width (mm) | $F_U$ (GHz) | $F_L$ (GHz) | Notch Center Freq. (GHz) |
|---|---|---|---|
| 0.5 | 5.280 | 4.280 | 4.780 |
| 1 | 5.420 | 4.130 | 4.775 |
| 1.5 | 5.470 | 4.060 | 4.765 |
| 2 | 5.550 | 3.890 | 4.720 |

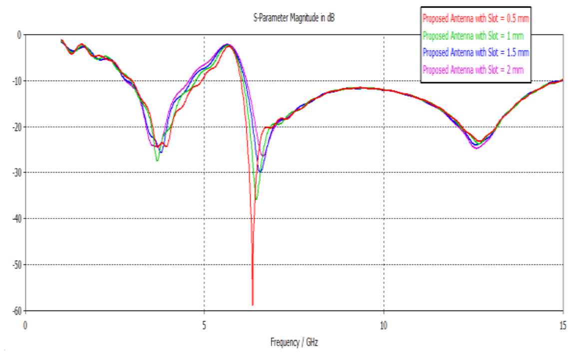


Fig.7(a) Simulated return loss for proposed antenna of various slot widths at 4mm

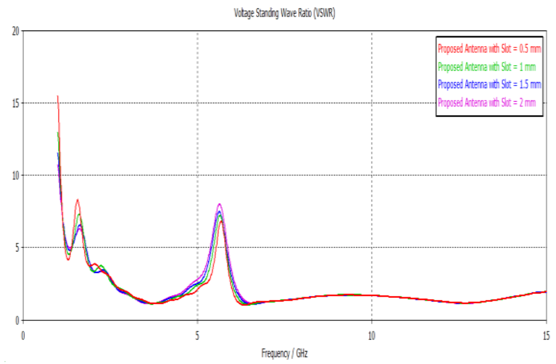


Fig.7(b) Simulated VSWR for proposed antenna of various slot widths at 4mm

Table VI. Performance Analysis of the simulated -10dB Stop-Band at 4mm.

| **Slot Width (mm)** | **$F_U$ (GHz)** | **$F_L$ (GHz)** | **Notch Center Freq. (GHz)** |
|---|---|---|---|
| 0.5 | 6.010 | 4.920 | 5.465 |
| 1 | 6.060 | 4.760 | 5.410 |
| 1.5 | 6.130 | 4.640 | 5.385 |
| 2 | 6.180 | 4.600 | 5.390 |

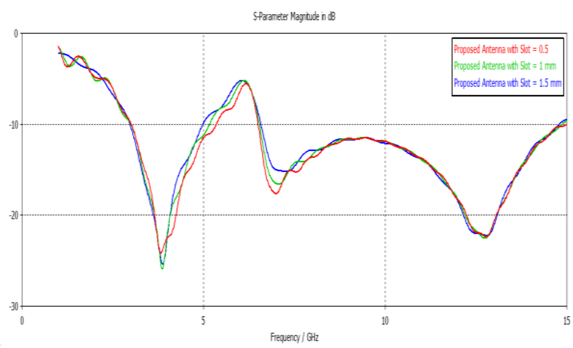


Fig.8(a) Simulated return loss for proposed antenna of various slot widths at 5mm

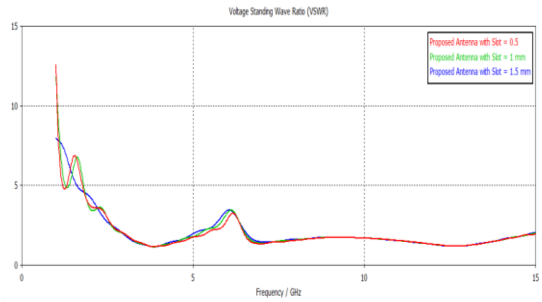


Fig.8(b) Simulated VSWR for proposed antenna of various slot widths at 5mm

Table VII. Performance Analysis of the simulated -10dB Stop-Band at 5mm

| **Slot Width (mm)** | **$F_U$ (GHz)** | **$F_L$ (GHz)** | **Notch Center Freq. (GHz)** |
|---|---|---|---|
| 0.5 | 6.520 | 5.320 | 5.920 |
| 1 | 6.520 | 5.100 | 5.810 |
| 1.5 | 6.570 | 4.940 | 5.755 |

The return loss curve at 0mm (centre of substrate) has the worst curve for the various widths with a smaller impedance bandwidth and stop-band rejection frequency of 3.47 – 5.16GHz. The best optimal curve for the U-Like Slot with different widths is obtained at 4mm and 5mm positions from the centre of the substrate with a wider impedance bandwidth and a sharp band rejection for the -10dB return loss.



As tabulated in Table VI, it is obvious that the return loss of the proposed antenna with respect to -10dB produced improved performance. The impedance bandwidth coverage is quite significant from 2.77 – 15GHz with a sharp stop-band rejection of 4.60 – 6.18GHz for the various slot widths at 4mm position while maintaining a significant impedance bandwidth of 2.94 – 15GHz with an adjustable stop-band of 4.94 – 6.57GHz as shown in Table VII.

Inspite of the observation of an overall improvement in performance of the antenna, with varied widths of the slot, it should also be noted that the varied widths of the slot do not promise proportional improvement. Anoptimal performance was achieved at the constant width of 1mm. Therefore, there is a unique phenomenon that occurs with the Lower frequency of the stop-band decreasing while the Upper frequency increases with respect to an increase in the slot width from 0.5mm – 2mm respectively as observed from the various positions of the slot.

## V. CONCLUSION

Based on the performance analysis carried out in this paper, the effects of band-notched characteristics on Ultra-Wideband (UWB) Antenna indicated promising results for the proposed prototypes to be fabricated.In addition, the positioning of the slot and varying of width contributed towards the performance improvement. Though, generally improved performance was noted in all analyzed cases, consideration should also be given to constant width at various positions.

The promising effects that were noted for the various configurations of the patch antenna analyzed include Improved return loss, VSWR, Bandwidth increment and Stop-band rejection.

Subsequent to this performance analysis carried out an experimental verification will be undertaken to further reinstate these outcomes towards achieving the fabricated prototypes for comparison.

## REFERENCES

[1]. FCC News, Web page, new public safety application and broadband internet access among uses envisioned by FCC authorization of Ultra Wideband technology, Announcement of Commission Action.

[2]. FCC First Report and Order, Revision of the Part 15 Commission's Rules Regarding Ultra-Wideband Transmission Systems, ET-Docket 98-153, April 22, 2002.

[3]. Fontana R. J. Recent System Applications of short - pulse UWB technology, IEEE Transaction on Microwave Theory and Techniques, Vol. 52(9), pp. 2087-2104, 2004.

[4]. ShaohuiQuan, Dong Li, and Zhengpeng Wang, Design of a Planar Ultra-Wideband Monopole Antenna with WLAN band-Notched Characteristics, IEEE Electronic Letter, 2008.

[5]. Hans Gregory Schantz, A Brief History of UWB Antennas, IEEE Aerospace and Electronics System Magazine, Vol. 19(4), pp. 22-26, April 2004.

[6]. Kamya, Y. Y. and Ryuji Kohno, Ultra Wideband Radio, MSc Thesis, Massachusetts Institute of Technology (M.I.T.), May 7, 2004

[7]. Shant H. G., Wolenec G. and E. M. Myszka, Frequency Notched UWB Antenna, Proceedings of the IEEE Conference on Ultra Wideband Systemsand Technologies, 214-218, 2003.

[8]. Su, K. L., Wong and F. S. Chang, Compact Printed Ultra-Wideband Slot Antenna with a Band Notched Operation, Microwave and Optical Techni. Letters, Vol. 45(2), pp. 128-130, 2005.

[9]. W. Choi et al, Compact Ultra-Wideband Printed Antenna with Band Rejection Characteristics, Electronics Letter, Vol. 41(18), pp. 990-991, September 2005.

[10]. Suh S. Y. et al, A UWB Antenna with a stop Band Notch in the 5GHz WLAN Band, Proceedings of IEEE/ACES International Conference, pp. 203-207, 2005.

[11]. Jaehoon Choi, Seokjin Hong, and Uisheon Kim, The Design of an UWB Antenna with Notch Characteristic, Piers Online, Vol. 3(7), 2007