

# Design and Analysis of Switchable Filtenna with Triple Band Notch Characteristics

Saurabh Mehta<sup>1</sup>, Vartika Tyagi<sup>2</sup>, Heena Choudhary<sup>3</sup>

M. Tech Scholar, Dept. of Electronics & Communication Engineering, Swami Vivekananda Subharti University,  
Meerut, India<sup>1</sup>

Assistant Professor, Dept. of Electronics & Communication Engineering, Swami Vivekananda Subharti University,  
Meerut, India<sup>2,3</sup>

**ABSTRACT:** In this paper, a compact ultra-wideband (UWB) filtenna with triple notch bands is proposed. By embedding two T shaped resonator in the radiating patch; two band-notched properties in the Wi-MAX (3-3.7 GHz), WLAN (5.125-5.825 GHz) are obtained. Furthermore, by etching out a U shaped slot in feed-line of the patch antenna, band notch property for the 7.3–8.7-GHz X-band frequencies is achieved. Design guidelines for implementing the notch-bands at the desired frequency regions are provided. The notched frequencies can be adjusted according to specification by altering the parameters of the resonators. The realized antenna achieved an operating bandwidth (VSWR < 2) ranges from 2.39 to 16.25 GHz with switchable notched bands at 3.0-3.72GHz, 5.0-5.8 GHz and 7.4-8.71 GHz. The simulation results are given to verify that the proposed antenna is suitable for modern high data rate UWB communication applications. The maximum measured gain for the fabricated antenna is around 11.54 dBi with an average efficiency above 80.97% throughout the bandwidth.

**KEYWORDS:** Ultra Wide Band (UWB), Filtenna, Notch Band, Worldwide Interoperability for Microwave Access (Wi-MAX), Wireless Local Area Network (WLAN), International Telecommunication Union (ITU)

## I. INTRODUCTION

Ultra-wideband (UWB) technology has recently received much attention due to the characteristics such as low cost, low complexity, low spectral power density, high precision ranging and become the most potential candidate for short-range high speed wireless communication systems. Stemming from military radar applications, ultra wideband (UWB) communications are being researched intensively in both academic and industrial environments since the Federal Communications Commission (FCC) released 3.1 to 10.6 GHz unlicensed band for radio communication(1). Researchers have made many efforts to investigate different UWB antennas. Until now, various structures have been developed to achieve wideband antennas. However, in practical applications, antenna design for UWB systems is still facing many challenges. The designs of antenna for ultra-wideband (UWB) applications face many challenges including their impedance matching, radiation stability, compact size, low manufacturing cost, and EMI problems. The EMI problems are quite serious for UWB systems since there are several other existing narrowband services, which occupy frequency bands within the UWB bandwidth [2]. A few examples of hostile systems are IEEE 802.16 Wi-MAX (3.3–3.7 GHz), IEEE 802.11a wireless-LAN (WLAN) 5 GHz (5.15–5.825), and ITU 8 GHz (8.025–8.4 GHz) band [3]. Therefore, it is necessary for UWB antennas performing band notch characteristics in those narrow frequency bands to avert the potential interferences. Several UWB antennas have been attempted to overcome interference problem using frequency band rejected characteristics design.

In these cases, UWB filtennas with notched characteristics at certain bands are desired. Filtennas are antennas that also perform filtering operations. Filtennas are employed to relieve the necessity of a band-pass (or band-stop) filter in the receiver front end. Ultra-wideband (UWB) frequencies (3.1 to 10.6 GHz) often employ filtennas to notch out the IEEE 802.16 Wi-MAX (3.3–3.7 GHz), IEEE 802.11a wireless-LAN (WLAN) 5 GHz (5.15–5.825), and ITU 8 GHz (8.025–8.4 GHz) band to remove EMI problems. Hence, in order to keep the antenna footprint unaltered, designers have

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

resorted to the approach of embedding parasitic strips or slots of different shapes in the radiating element or ground plane of the antenna systems [4]–[7].

The main problem of band rejection design is the difficulty of controlling the bandwidth of the notched band in a limited antenna space. Moreover, while adequate band rejection is highly desirable, the performance of the antenna should remain essentially the same for the rest of the band.

## II. RELATED WORK

Recently, a number of UWB antennas with band-notched properties were presented where various methods have been used to achieve the band notching. Examples of approaches used are:

- cutting slots with different shape in the radiation patch (4-8)
- inserting slits on the feed line (9-10)
- adding parasitic strips or split rings near the feed line or around the ground plane (11-12)
- embedding resonator to filter to achieve the desired band rejection (13-16)
- combination of above mentioned any two techniques (17-21)

Integration of external band-reject filters increases system complexity and size. Hence, in order to keep the antenna footprint unaltered, designers have resorted to the approach of embedding parasitic elements or slots of different shapes in the radiating element or ground plane of the antenna systems.

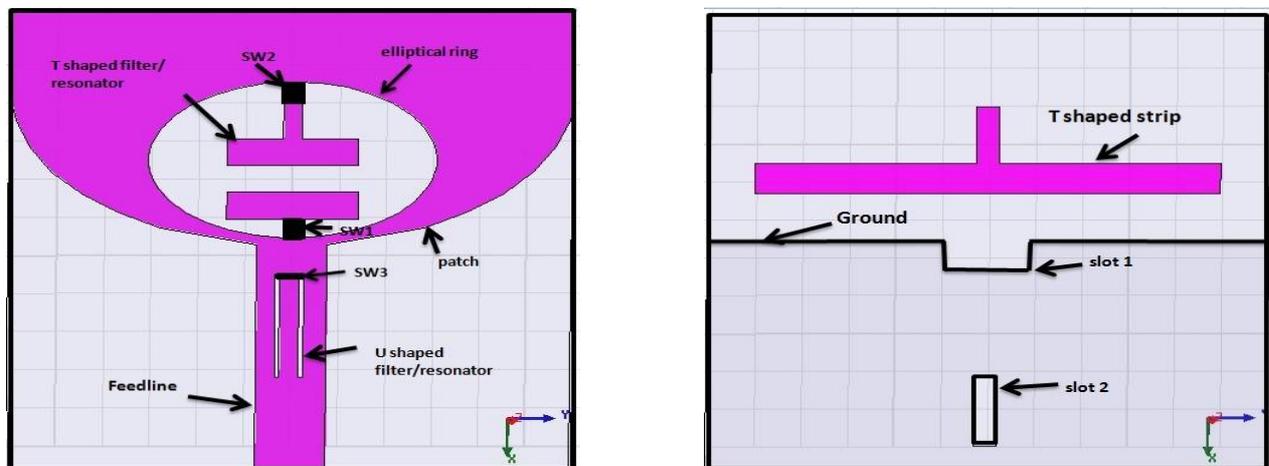
In the present paper, a compact, (24×24) mm<sup>2</sup> filtenna fed by a 50Ω micro-strip feed line is presented. The band-notching is implemented using a U-shaped slot in the feed line and a pair of T shaped resonator in the radiator. The proposed antenna is designed using Ansoft’s High Frequency Structure Software (HFSS). Section III presents the geometry, the antenna model and various antenna dimensions. Section IV discusses the simulated and the experimental results performed and Section V is summarized the final conclusions of this study.

## III. ANTENNA DESIGN

This section describes the antenna geometry and the design process. A full wave analysis of the proposed structures is obtained by using the electromagnetic software, Ansys HFSS™ v13.1 which is based on Finite element method (FEM) numerical technique. The design goals are to achieve impedance bandwidth cover the wide frequency spectrum with good gain, stable radiation patterns across the whole desired band excluding the rejected band (the band-notch) that obtained by two different techniques.

### A. Antenna geometry

The proposed antenna is described in this section. The design starts with a micro-strip patch antenna where Figure 1(a) demonstrates the top view & Figure 1(b) depicts bottom view of proposed switchable filtenna structure.



(a) Top-view

(b) Bottom-view

Fig.1 Top & Bottom view of proposed antenna

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

The antenna is printed on 24mm × 24mm FR4 epoxy substrate with the relative permittivity  $\epsilon_r = 4.4$ , a loss tangent  $\tan \delta = 0.02$  and a thickness  $h = 1.6$  mm. It is composed of a 50Ω micro-strip feed line with the width of  $W_f$  and length of  $L_f$  to couple the input signal to the radiating patch, a planar modified elliptical shaped radiating patch with pair of T shaped resonator and a U shaped resonator. Partial rectangular ground plane with two rectangular shaped slots has been used for better impedance matching.

Several aspects were considered to optimize the final design like the overall impedance bandwidth of the antenna, bandwidth of the notched bands and the level of band rejection at notched frequency. Proper impedance matching produces the best return loss at the wanted frequency. In the micro-strip feed line, the impedance of the micro-strip line is given by –

$$Z_c = \frac{120 \pi}{\sqrt{\epsilon_{eff}}} \left\{ \frac{1}{\frac{W_f}{h} + 1.393 + 0.667 \ln \left( \frac{W_f}{h} + 1.444 \right)} \right\} \quad (1)$$

The analysis of the proposed antenna structure is based on transmission line modal analysis. Figure 2 shows the geometry of proposed antenna structure used for simulation in next section.

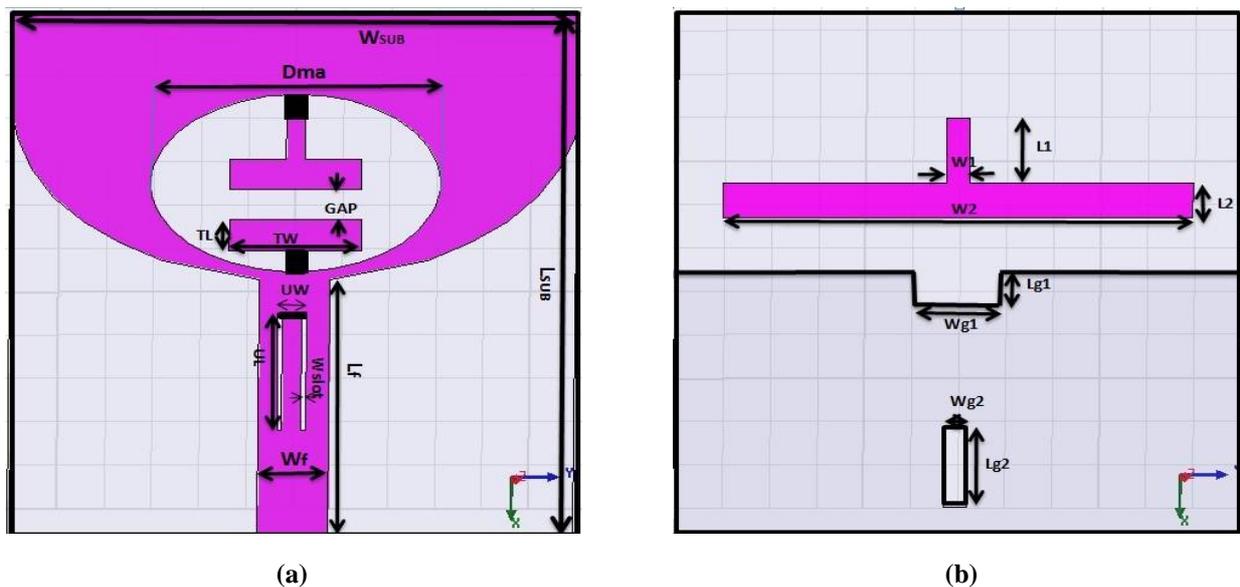


Fig.2.Geometry of (a) Radiating patch & Resonators (b) Ground & Substrate

The optimal antenna parameters are tabulated in Table1.

Table 1: Summary of Dimension parameter of switchable filtenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
$W_{sub}$	24	$W_{SLOT}$	0.3
$L_{sub}$	24	TL	5.6
$W_f$	3	TW	1.4
$L_f$	11.8	UL	5.4
h	1.6	UW	1.2

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

<b>Lg</b>	12	<b>GAP</b>	1.4
<b>Lg1</b>	1.4872	<b>K=Dma/Dmi</b>	1.5
<b>Lg2</b>	3.6	<b>Dma</b>	8.2
<b>Wg1</b>	3.6	<b>SW1 &amp; SW2</b>	0.8×1.1
<b>Wg2</b>	1	<b>SW3</b>	0.3×1

Figure 3 shows the 3-D structure of simulated Reconfigurable UWB Filtenna with RF MEMS switches.

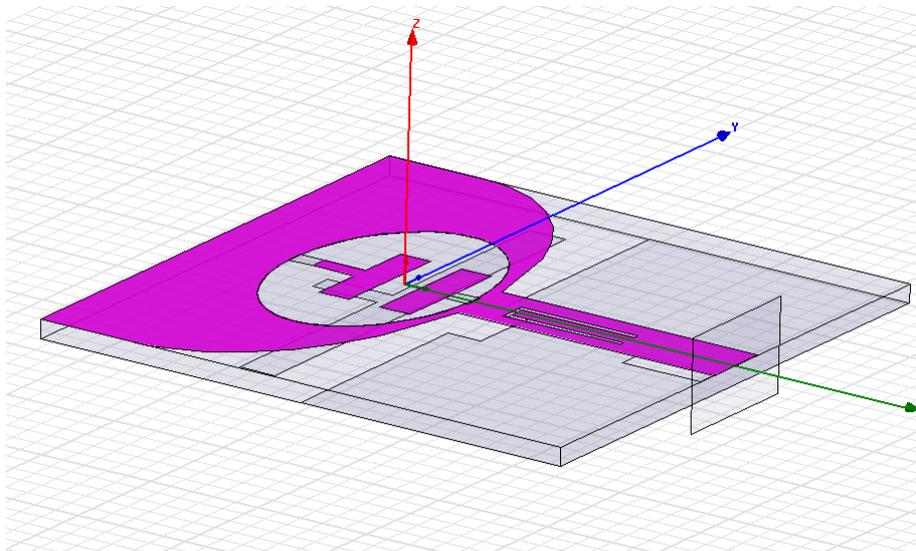


Figure: 3 3-D structure of simulated Wide Band antenna\

### III. SIMULATION RESULTS AND DISCUSSION

The analysis of proposed filtenna is done using the simulation performed on Ansys HFSS EM simulator for the frequency range of 1 to 25 GHz. During the simulation and measurement, the presence of a metal bridge represents ON state and the absence of a metal bridge represents OFF state. The various switch configurations are tabulated in table no. 2.

Table 2: Switch configuration and their respective function

Switch Configuration		Function
Configuration I	(SW1-OFF) (SW2-OFF) (SW3-ON)	Wide-band antenna
Configuration II	(SW1-ON) (SW2-OFF) (SW3-ON)	Single band notch wideband filtenna
Configuration III	(SW1-ON) (SW2-ON) (SW3-ON)	Double band notch wideband filtenna
Configuration IV	(SW1-ON) (SW2-ON) (SW3-ON)	Triple band notch wideband filtenna

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

### Graph of S11 & VSWR Vs frequency (Switch Configuration I)

Figure 4 shows the simulated return losses (S parameter) of the antenna having multi-band characteristic in the UWB spectrum in switch configuration-I.

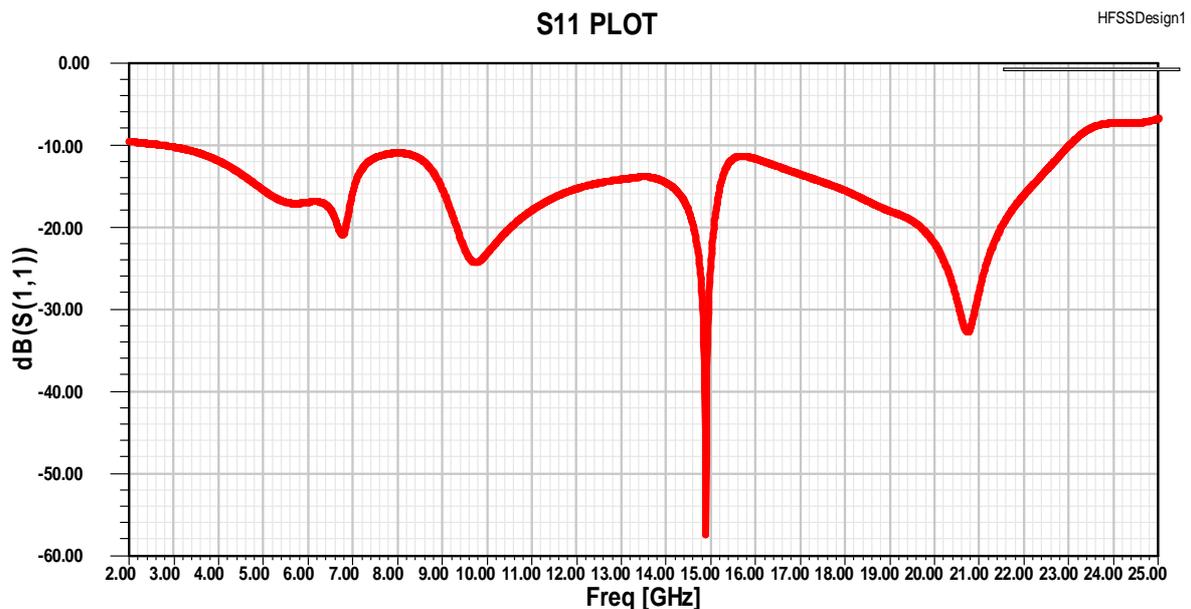


Figure: 4 graph of S11 Vs frequency in switch configuration I.

It is observed from Figure 6.1 that the UWB antenna covers 2.96 –23 GHz range with a return loss less than –10 dB providing enhanced ultra-wide bandwidth. The result indicates that the proposed antenna structure is having return loss less than –10 dB, which is fairly low over the entire UWB range.

The VSWR of the proposed antenna structure with optimized parameters in switch configuration-I is shown below in Figure 5.

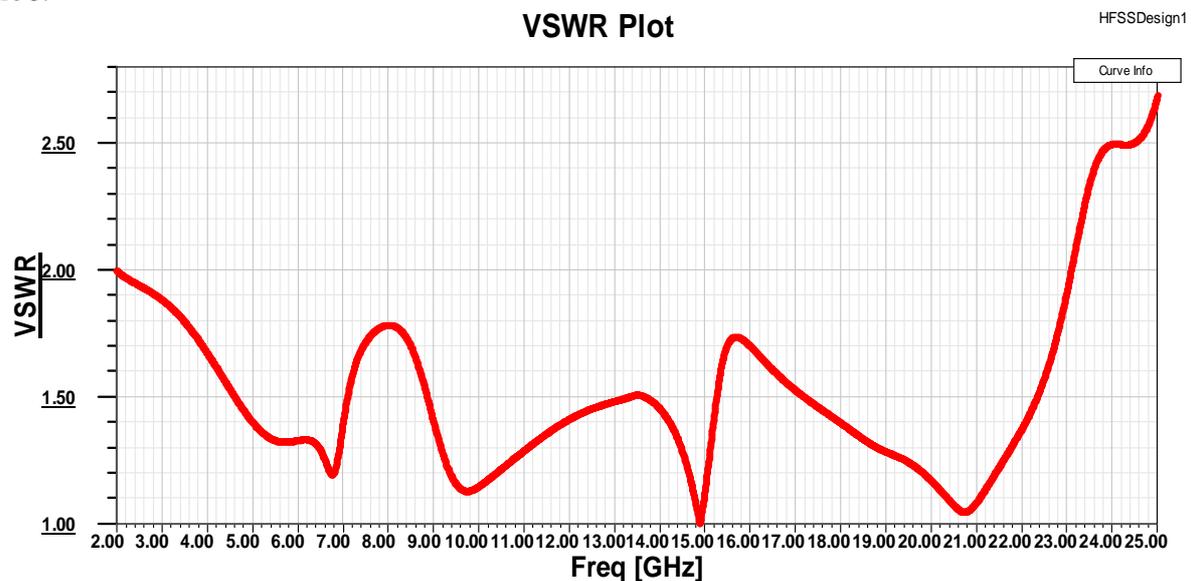


Figure: 5 graph of VSWR Vs frequency in switch configuration I.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

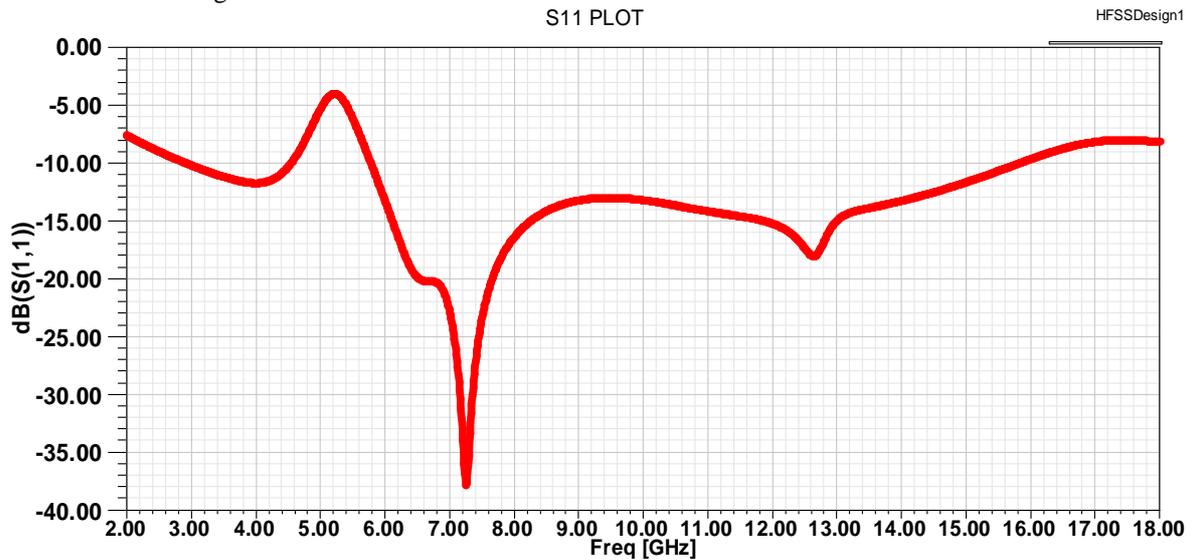
Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

From the plot of simulated VSWR Vs frequency of proposed antenna structure, it is seen that antenna covers wide bandwidth i.e. 2.96-23.1 GHz for VSWR < 2 dB for the switch configuration I.

### Graph of S11 & VSWR Vs Frequency (Switch Configuration II)

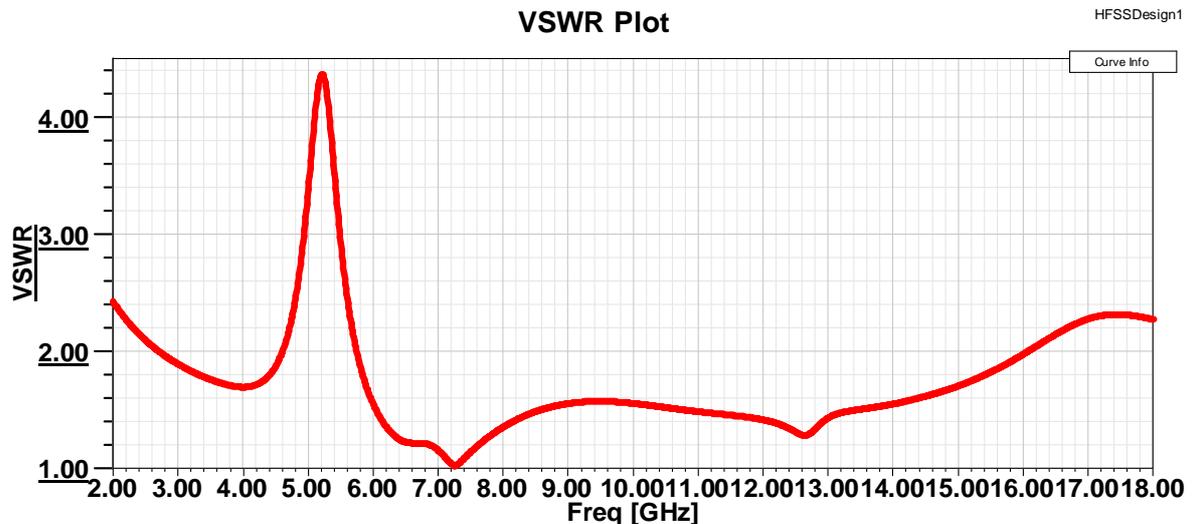
Figure 6 shows the simulated return losses (S parameter) of the antenna having multi-band characteristic in the UWB spectrum in switch configuration-II.



**Figure: 6 graph of S11 Vs frequency in switch configuration II.**

It is observed from Figure 6 that the UWB antenna covers 2.62 –16 GHz range with a return loss less than –10 dB except a band notch centered at WLAN band.

The VSWR Vs frequency curve for the proposed antenna with optimized parameters in switch configuration II is depicted below.



**Figure: 7 graph of VSWR Vs frequency in switch configuration II.**

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

### Graph of S11 & VSWR Vs Frequency (Switch Configuration III)

Figure 8 shows the simulated return losses (S parameter) of the antenna having multi-band characteristic in the UWB spectrum in switch configuration-III.

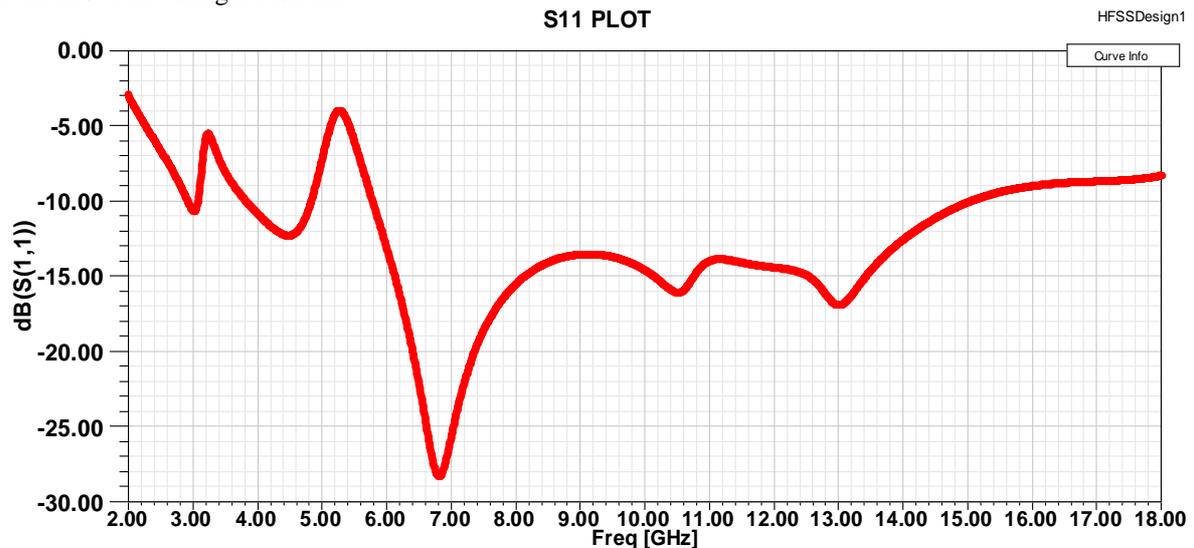


Figure: 8 graph of S11 Vs frequency in switch configuration III.

It is observed from Figure 8 that the UWB antenna covers 2.62 –16 GHz range with a return loss less than –10 dB except two band notches centered at WLAN band & Wi-max.

The simulated VSWR of filtenna structure in switch configuration III is depicted below-

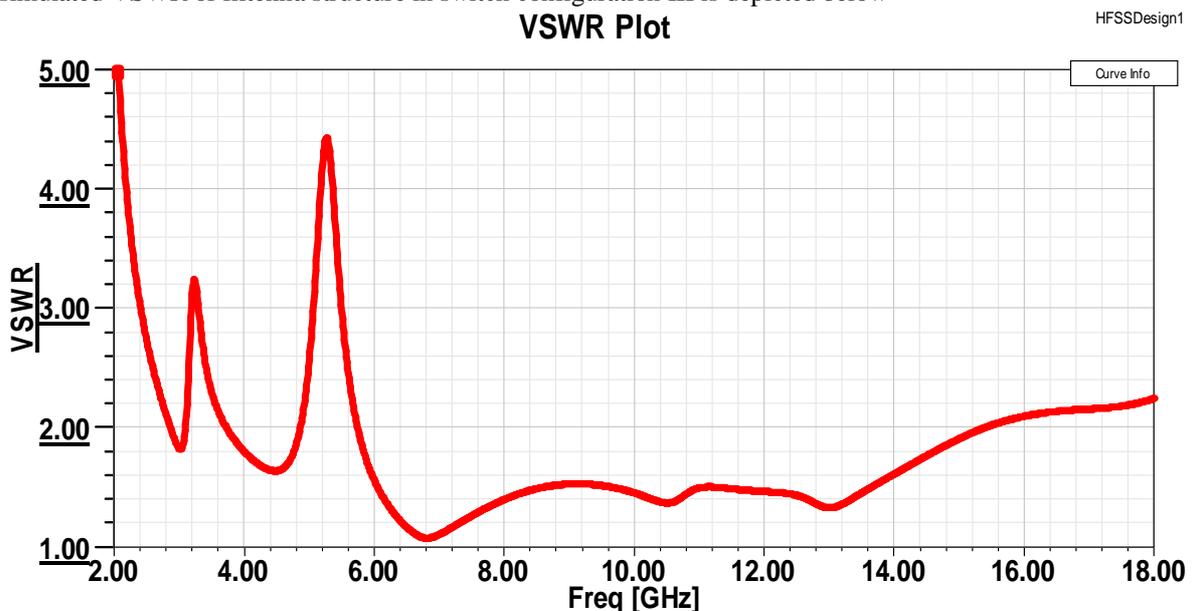


Figure: 9 graph of VSWR Vs frequency in switch configuration III.

It can be seen that the proposed antenna in switch configuration III behaves as dual band notched UWB antenna, which has a bandwidth ranging from 2.6 to 15.84 GHz with the VSWR less than 2 except a notch band at 3.2–3.7 GHz & other one at 4.88 to 5.8 GHz to filter out the potential interferences from Wi-MAX and WLAN communication systems.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

When the antenna has SW1 & SW2 in ON state; pair of T shaped resonator forms which results in having two band stops.

### Graph of S11 & VSWR Vs Frequency (Switch Configuration IV)

Figure 10 shows the simulated return losses (S parameter) of the antenna having multi-band characteristic in the UWB spectrum in switch configuration-IV.

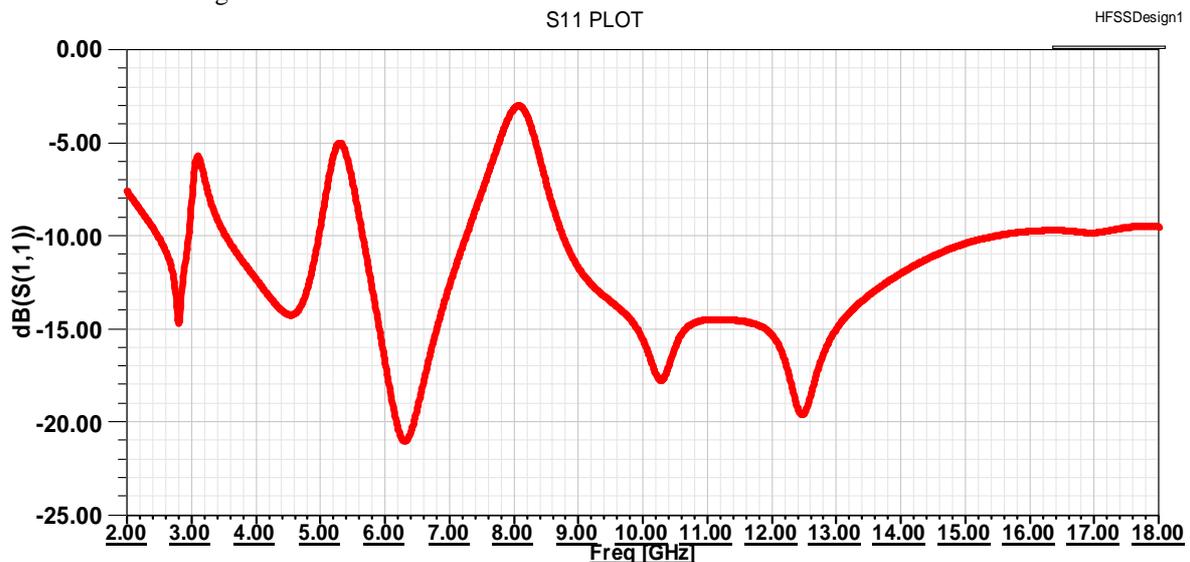


Figure: 10 graph of S11 Vs frequency in switch configuration IV.

It is observed from Figure 6.5 that the UWB antenna covers 2.62 –16 GHz range with S11 less than –10 dB except three band notches centered at WLAN, Wi-max & ITU-8 GHz band.

The simulated VSWR of wide-band antenna structure in switch configuration IV is depicted below-.

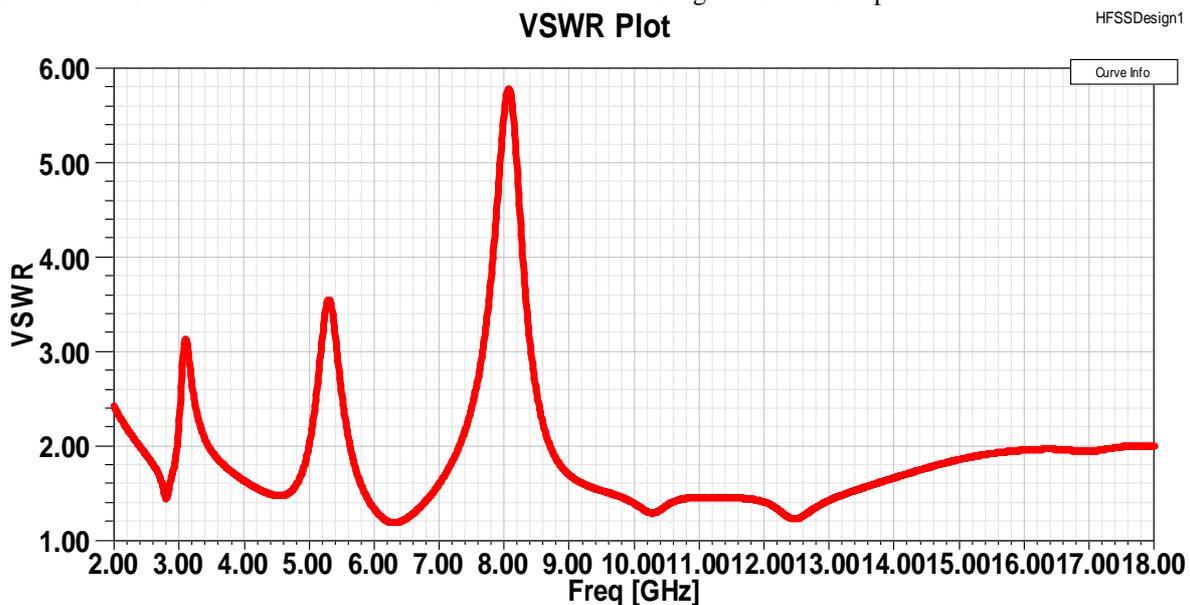


Figure: 11 graph of VSWR Vs frequency in switch configuration IV.

# International Journal of Innovative Research in Science, Engineering and Technology

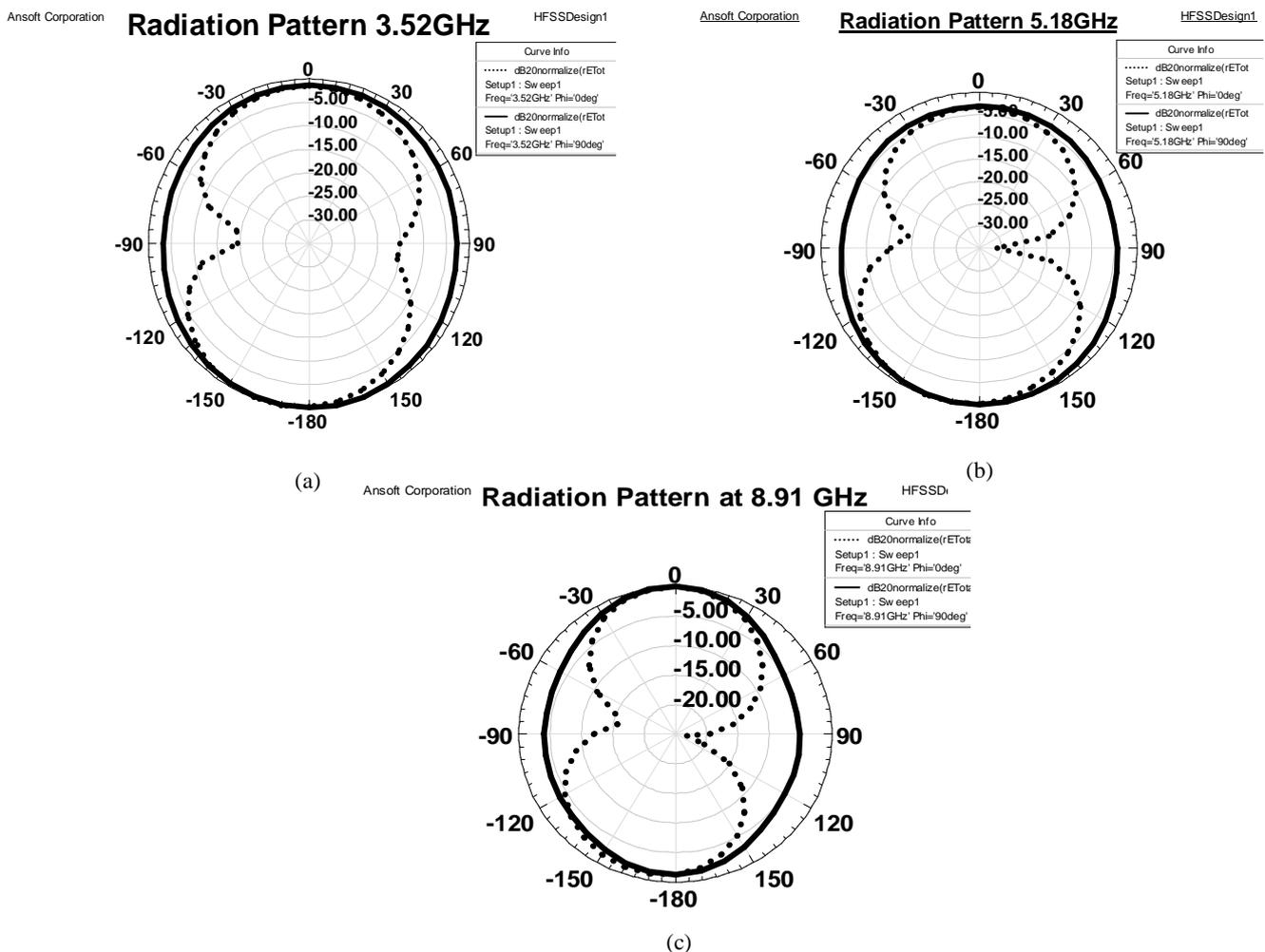
(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

It can be seen that the proposed antenna; in switch configuration IV is a triple band notched UWB antenna, which has a bandwidth ranging from 2.38 GHz to 16.24 GHz with the VSWR less than 2 except three notch bands to reject the undesired narrowband signals from Wi-MAX (3–3.7 GHz), WLAN (5–5.8 GHz) and ITU technology (7.35–8.7 GHz).

Below show the 2D radiation pattern of the antenna at the designed frequency for  $\Phi=0$  and  $\Phi=90$  degrees. The measured radiation patterns in various switch configurations are plotted in Figure 12.



**Figure.12: Simulated radiation pattern of the proposed antenna for  $\Phi=0$  and  $\Phi=90$  degrees in (a) switch configuration II at 3.52 GHz [notch frequency] (b) switch configuration III at 5.18 GHz [notch frequency] (c) switch configuration IV at 8.91 GHz [notch-band frequency]**

It can be seen that the proposed antenna has a nearly Omni-directional radiation pattern in the H-plane and a dipole-like radiation pattern in the E-plane.

The simulated surface current distributions of the proposed antenna in three switch configurations are shown in Figure 12. The current distribution at 5.5 GHz is mainly concentrated around the T shaped resonator near patch- feed line

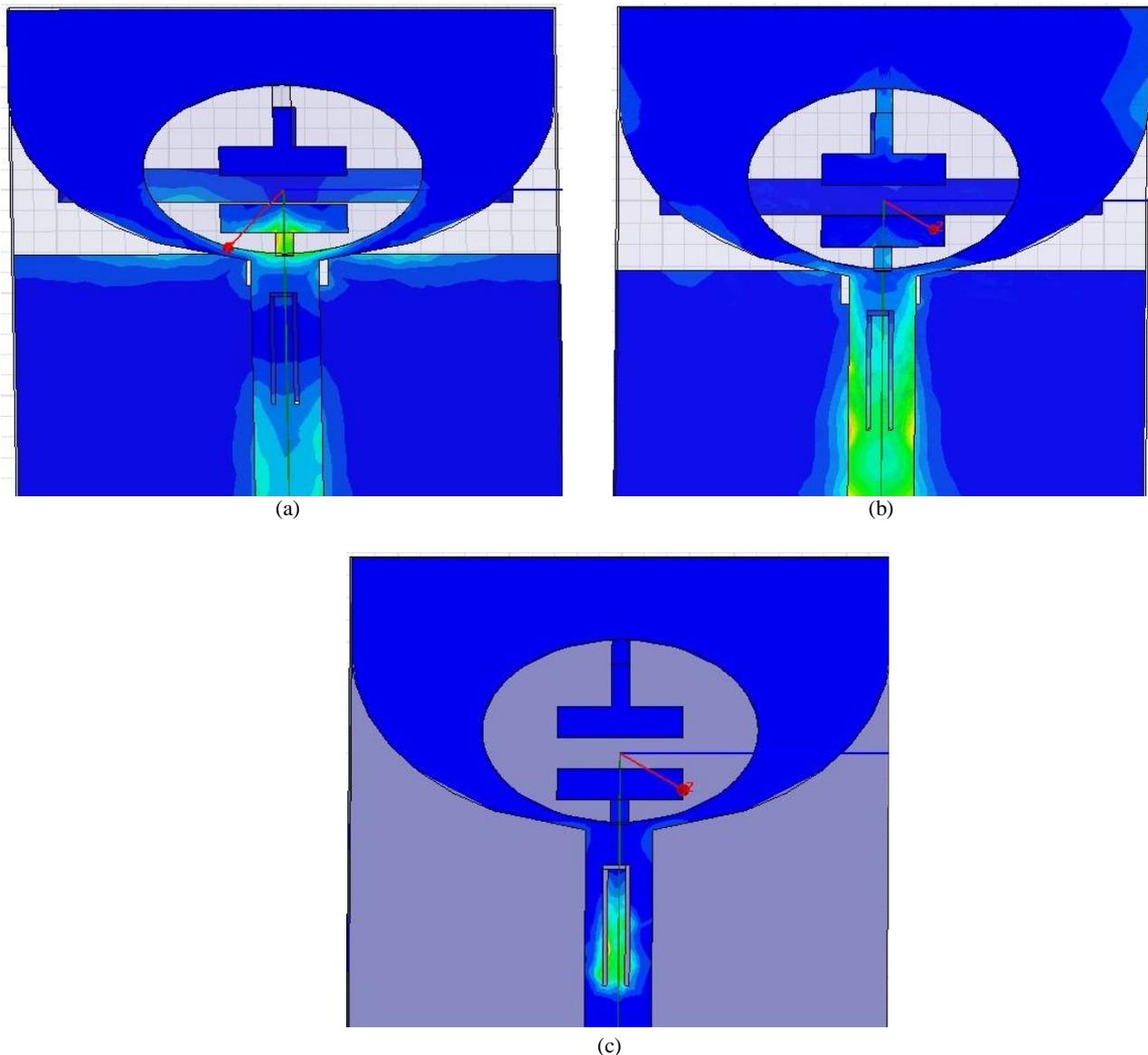
## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

junction in Figure 12(a) and the current distribution at 3.6 GHz is mainly concentrated around the outer T shaped resonator as shown in Figure 12(b). Compared with other parts of the notch structure in Figure 12(c), a significant amount of current at 8.4 GHz is distributed around U shaped resonator.



**Figure 12: Simulated current distributions for proposed antenna structure in (a) switch configuration II at 5.5GHz (b) switch configuration III at 3.6 GHz (c) switch configuration IV at 8.4 GHz**

Notch characteristic is found in this band, since the signal coupled from the main feed line to the resonator returns back to the feed line, and the two signals meet at a phase difference of  $180^\circ$ , cancels each other according to wave cancellation theory. It can be observe from the following figure that the surface current is concentrated mainly on the notched that are responsible for band rejection at that frequency.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

The comparative study graph of gain for three switch configurations with band notch characteristics shown in Figure 13. The measured peak gains curve of the designed antenna exhibits three sharp gain decreases at 3.4, 5.5 and 8.2 GHz as desired.

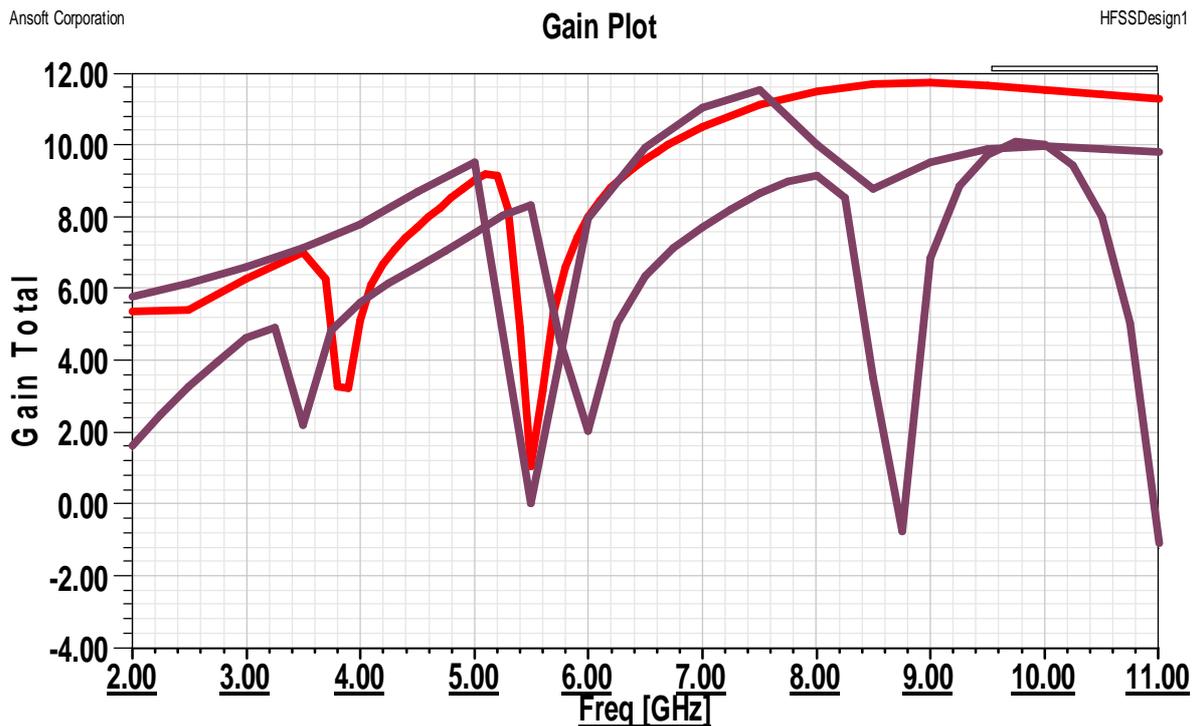


Figure: 13 graph of gain Vs frequency for three configuration of filenna

### IV. CONCLUSION

A compact planar switchable filenna with triple band notch characteristics has been proposed for UWB applications and well designed by the use of the EM simulator HFSS™ v13. To achieve triple notch band characteristics, three resonating elements are used to generate three notches separately in the Wi-MAX, WLAN and X frequency bands. The proposed antenna is able to cover bandwidth ranges from 2.39 to 16.25 GHz with switchable notched bands at 3.0-3.72GHz, 5.0-5.8 GHz and 7.4-8.71 GHz. The proposed antenna has a very compact size of  $24 \times 24 \text{ mm}^2$  which makes it useful for portable UWB devices without causing electromagnetic interference. A prototype antenna is planned to be fabricated by the authors using low-cost FR4-Epoxy substrate for further work relating to this Paper.

### REFERENCES

- [1] Federal Communications Commission, "Revision of Part 15 of the commission's rules regarding ultra-wideband transmission systems", first note and order," ET-Docket 98-153, Washington, DC, 2002.
- [2] Hyung-Seok Choi, Tae-Woo Kim, Hee-Yong Hwang, and Kyung Choi, "An UWB Antenna Design with Adjustable Second Rejection Band Using a SIR", IEEE Transactions on Magnetics, Vol. 50, No. 2, February 2014
- [3] D. O. Kim and C. Y. Kim, "CPW-fed ultra-wideband antenna with triple-band notch functions", *Electron. Lett.*, vol. 46, no. 18, pp. 1246–1248, 2010
- [4] J. Kim, C.S. Cho. And J.W.Lee, "5.2 GHz notched ultra wide-band antenna using slot-type SRR," *Electron. Letter.*, vol.42, no.6, pp.315–316, Mar. 2006
- [5] Q. X. Chu and Y. Y. Yang, "A compact ultra wide-band antenna with 3.4/5.5GHz dualband-notched characteristics," *IEEE Trans. Antennas Propagation*, vol. 56, no. 12, pp. 3637–3644, Dec. 2008.
- [6] H. Zhang, R. Zhou, Z. Wu, H. Xin, and R. W. Ziolkowski, "Designs of ultra wide-band (UWB) printed elliptical mono pole antennas with slots," *Microwave Opt. Technol. Letter.*, vol. 52, no. 2, pp. 466–471, Feb. 2010.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 7, July 2017

- [7] D. Sarkar and K. V. Srivastava, "SRR-loaded antipodal Vivaldi antenna for UWB applications with tunable notch function," in Proc. URSI Commission BEMTS, Hiroshima, Japan, pp.466–469, 2013.
- [8] Lee, W. S., D. Z. Kim, K. J. Kim, and J. W. Yu, "Wide-band planar monopole antennas with dual band-notched characteristics," *IEEE Transactions on Microwave Theory & Techniques*, Vol. 54, No. 3, 2800–2806, 2008
- [9] Li, Y. S., X. D. Yang, C. Y. Liu, and T. Jiang, "Compact CPW-fed ultra wideband antenna with dual band-notched characteristics," *Electronics Letters*, Vol. 46, No. 14, 967–968, 2010.
- [10] Jiang, J. B., Z. H. Yan, and J. Y. Zhang, "Dual band-notched ultra-wideband printed antenna with two different typed slots," *Microwave and Optical Technology Letters*, Vol. 52, No. 9, 1930–1933, 2010.
- [11] Nguyen, D. T., D. H. Lee, and H. C. Park, "Very compact printed triple band-notched UWB antenna with quarter-wavelength slots," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 411–414, 2012.
- [12] Chung, K., H. Park, and J. Choi, "Wideband micro strip-fed monopole antenna with a narrow slit," *Microw. Opt. Technol. Lett.*, Vol. 47, No. 4, 400–402, November 20, 2005.
- [13] M. Ojaroudi, N. Ojaroudi, and N. Ghadimi, "Dual band-notched small monopole antenna with novel coupled inverted U-ring strip and novel fork-shaped slit for UWB applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 182–185, 2013.
- [14] Kim, D.-O., N.-I. Jo, H.-A. Jang and C.-Y. Kim, "Design of the ultra-wideband antenna with a quadruple-band rejection characteristics using a combination of the complementary split ring resonators," *Progress In Electromagnetics Research*, Vol. 112, 93-107, 2011.
- [15] Islam, M. T., R. Azim, and A. T. Mobashsher, "Triple band-notched planar UWB antenna using parasitic strips," *Progress In Electromagnetics Research*, Vol. 129, 161-179, 2012.
- [16] M. Al-Husseini, J. C. Ostantine, C. G. Christodoulou, S. E. Barbin, A. El-Hajj, and K. Y. Kaban, "A reconfigurable frequency-notched UWB antenna with split-ring resonators," in *Proc. Asia-Pacific Microw. Conf.*, Dec. 2012, pp. 618–621.
- [17] C. C. Lin, P. Jin, and R. W. Ziolkowski, "Single, dual and tri-band notched ultra-wideband (UWB) antennas using capacitively loaded loop (CLL) resonators," *IEEE Trans. Antennas Propag.*, vol. 60, no. 1, pp.102–109, Jan. 2012.
- [18] Y. Sung, "Triple band-notched UWB planar monopole antenna using a modified H-shaped resonator," *IEEE Trans. Antennas Propag.*, vol. 61, no. 2, pp. 953–957, Feb. 2013
- [19] Junhui Wang, Yingzeng Yin, and Xianglong Liu, "Triple Band-Notched Ultra wideband (UWB) Antenna Using a Novel Modified capacitively Loaded Loop (CLL) Resonator", *Progress in Electromagnetic Research Letters*, Vol. 42, 55-64, and 2013
- [20] Chu, Q.-X. And T.-G. Huang, "Compact UWB antenna with sharp band-notched characteristics for lower WLAN band," *Electronics Letters*, Vol. 47, No. 15, 838–839, 2011.
- [21] Wang, J. W., J. Y. Pan, X. N. Xiao, and Y. Q. Sun, "A band-notched UWB antenna with L-shaped slots and open-loop resonator," *The 2013 IEEE International Conference on Applied Superconductivity and Electromagnetic Devices (ASEMD)*, 312–315, Beijing, Oct. 25–27, 2013.
- [22] Zhang, C., J. Zhang, and L. Li, "Triple band-notched UWB antenna based on SIR-DGS and fork-shaped stubs," *Electronics Letters*, Vol. 50, No. 2, 67–69, 2014.
- [23] Debdeep Sarkar, Kumar Vaibhav Srivastava and Kushmanda Saurav, "A Compact Microstrip-Fed Triple Band-Notched UWB Monopole Antenna", *IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS*, VOL. 13, 2014
- [24] Asmaa H. Majeed, Abdulkareem S. Abdullah, Khalil H. Sayidmarie, Raed A. Abd-Alhameed, Fauzi Elmegri and James M. Noras, "Compact Dielectric Resonator Antenna with Band-Notched Characteristics for Ultra-Wideband Applications", *Progress In Electromagnetics Research C*, Vol. 57, 137–148, 2015
- [25] Heena Choudhary, Ashish Vats, Romika Choudhary; "Design of Frequency Reconfigurable Micro Strip Patch Antenna for Wireless Applications", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 4, Issue 12, December 2015
- [26] Heena Choudhary, Ashish Vats, Romika Choudhary; "Design and Analysis of Circular Patch Micro-Strip UWB Antenna for Breast cancer Detection", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 4, Issue 12, December 2015
- [27] Tejbir Singh, Heena Choudhary, D.V. Avasthi & Vishant Gahlaut, "Design & parametric analysis of band reject ultra wideband (UWB) antenna using step impedance resonator" *Cogent Engineering*, Vol.4, issue 1, 2017.
- [28] Heena Choudhary, Kunver Arif Ali & Ashish Vats, "Design And Analysis Of Triple Band-Notched Micro-Strip UWB Antenna" *Cogent Engineering*, Vol.4, issue 1, 2016.