International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org
Volume 6, Issue 5, September- October 2017 ISSN 2278-6856

Design of Reconfigurable Notch Band Antenna for UWB Application using P-I-N Diodes

Praveen Kumar chakravarti[1], Garima Saini[2]

[1]M.E Scholar , Department of Electronics & Communication Engineering
National Institute of Technical Teacher's Training & Research Chandigarh, U T, India

[2]Assistant Professor, Department of Electronics & Communication Engineering
National Institute of Technical Teacher's Training & Research Chandigarh, U T, India

Abstract- ***The advantage of the antenna with reconfigurable band notch is to ably make use of the frequency spectrum resources and work collectively well along with the presented narrowband wireless services. In this article a compact design and analysis of reconfigurable triple notch band antenna using DGS for UWB applications is proposed. The basic design has main feature to reduce interference from narrow band applications after that design has ability to recall notch bands according to different states of switches placed on defected ground plane. The presented design consist of microstrip feed line reconfigurable antenna having size of*** **16 ×12.4 mm^2.**

Keywords: DGS, Microstrip, Gain, Reconfigurable antenna, P-I-N diode

1. INTRODUCTION

In any wireless communication system, when a radio frequency (RF) signal is generated in a transmitter, some device must be used to spread out this signal through space to a receiver. The device that does this work is the antenna. Microstrip antenna contains a radiating patch on one surface of a dielectric substrate and a ground plane on other surface. The patch conductor is of copper. Relative permittivity of the substrate must be low to increase the fringe fields which are responsible for radiation. They have several applications over the band of frequency range starting from 100 MHz to 50 GHz but main disadvantage is bandwidth of small extent. In 2002 FCC has stated the band of frequency starting from 3.1 GHz to 10.6 GHz for ultra wide band (UWB) [1].

The main advantage of UWB antenna is that they are capable to utilize the complete ultra wide band spectrum and when an interfering signal shows up, the antenna can alter its arrangement in order to produce a notch band which removes the interference from the coexisting system. Because of huge applications found in ultra wide band, UWB antenna has involved a plenty of research. Main problem with the ultra wide band antenna is interference from various applications with narrow band.

Frequency bands allocated in ultra wide band are 1) Wi-Fi / WLAN, IEEE 802.11 used: 2.4 GHz frequency band (2.4 GHz to 2.5 GHz) and 5 GHz or 5.8 GHz frequency band (5.15 GHz to 5.35 and 5.725 GHz to 5.875 GHz). 2) Wi-MAX, IEEE 802.16 used different frequency ranges of 2.3 GHz, 2.5 GHz, 3.3 GHz, 3.5 GHz and 5.8 GHz in various regions. 3) Bluetooth, IEEE 802.15.1 has frequency band at 2.4 GHz. 4) C band for satellite communication in range of 3.7 GHz to 4.2 GHz. 5) X band for down link satellite communication in the 7.25 to 7.75 GHz. 6) High performance LAN (HIPERLAN) operating in the 5.15 to 5.825 GHz. These will cause interference to the presented wireless communication systems. So the UWB antenna with a band stop performance is essential to produce the frequency band notch function [2-5].

There are several methods for analysis of microstrip antennas. The most popular are the transmission line, cavity and full wave. The transmission-line model is the easiest among all because of good physical insight. The design procedure assumed that information which includes the dielectric constant of the substrate (ε), the resonant frequency (f) and the height of the substrate (h). A rectangular microstrip antenna is defined according to an array of two radiating narrow apertures, each of width w and height h, separated by a distance L [6-10].The antenna design procedure is as follows:

A practical width of the patch that leads to good radiation efficiencies is given as

$$w = \frac{1}{2f\sqrt{\varepsilon_0\mu_o}}\sqrt{\frac{2}{\varepsilon+1}} \quad (1)$$

where $\varepsilon_o\mu_o = c = 3\times 10^8$ m/s and f defined resonant frequency.

Effective dielectric constant of antenna for w/h > 1 is given as

$$\varepsilon_{reff} = \frac{\varepsilon+1}{2} + \frac{\varepsilon-1}{2}\frac{1}{\sqrt{1+12\frac{h}{w}}} \quad (2)$$

Extension of length ΔL is given as

$$\Delta L = 0.412\, h\,\frac{(\varepsilon reff+0.3)(\frac{w}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{w}{h}+0.8)} \quad (3)$$

The real length of the patch is determined according to

$$L = \frac{c}{2f\sqrt{\varepsilon reff}} - 2\Delta L \quad (4)$$

Thus, most important aim of antenna design is to define an ultra wide band antenna which covers about the complete ultra wide band with smallest interference from presented narrow band applications. For reducing EMI, frequency bands of offered applications should be detached from ultra wide band. DGS has been emerged as most common choice due to enhance of bandwidth and introduce of stop bands (notch bands). Diverse DGS structures have been used in the literature such as rectangular shaped, square shaped , circular shaped , dumbbell shaped , spring , L shaped , U shaped , V shaped , hairpin shaped , hexagonal shaped , cross shaped and combined DGS [2]. The DGS is equivalent to L-C resonance circuit. The inductance value and capacitance value depends upon the area and size of the defect. DGS is described by using parameters: the etched lattice dimension and the gap distance. The values of inductance (Ls) and capacitance (Cs) for DGS are given by:

$$Ls = \frac{1}{\omega^2\ C} \quad (5)$$

$$Cs = \frac{f_c}{2Z_0}\cdot\frac{1}{2\pi(f_o^2 - f_c^2)} \quad (6)$$

Reconfigurable notch bands in UWB antennas are dynamic research area. The advantage of the antenna with reconfigurable notch band is to ably exploit the frequency spectrum resources and work collectively well with the presented narrowband wireless services. On the other hand, the frequency of band notch UWB antennas is unmanageable after their manufacture, which fails to fulfill the requirements of the reconfigurable notch band in real time. Thus reconfigurable techniques have accepted major attentions in the field of wireless communications. A number of reconfigurable notch bands UWB antennas have been **discussed**, the notch band frequency can be constantly tunable with varactor diode and discretely tunable with P-I-N diode [14].

Reconfiguring property of antenna is classified in four fundamental types, Antenna with frequency reconfigurable, Antenna with polarization reconfigurable, Antenna with pattern reconfigurable and Antenna with hybrid reconfigurable (those are the combinations of any of the above three). Frequency reconfigurable antennas are capable of changing their resonant frequency for various operating bands. In long-age, improvement in frequency reconfigurable has been developed.

Several switching techniques are employed to obtain any operating condition of reconfigurable antenna. A patch antenna uses PIN diode for several modes of switches to control the surface current path length. Coaxial feed is slipped over the feed of the micro strip line which is controlled by Microcontroller. Position of the feed which is changed by coaxial feed is used to build antenna resonate at several frequencies. Resonant frequency of microstrip patch antenna is also changed by photo conductive switch which is optically controlled [19].

Varactor diodes are also used for reconfigurability which is positioned between each radiating stem and bias voltage of varactor diodes can be controlled separately. Then resonant frequency can be assorted by changing the bias voltage. In addition, frequency reconfigurable antennas using field effect transistor switches are also presented. In this, changing the state of field effect transistor switch could break rectangle ring radiator [26-31].

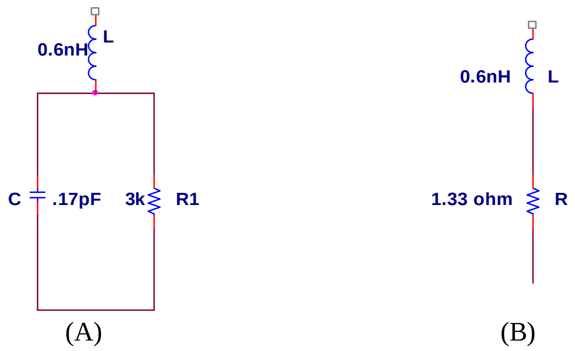


Fig.1. (A) Equivalent Circuit of P-I-N diode in Reverse biased Condition (B) Equivalent Circuit of P-I-N diode in Forward biased Condition

The reconfigurability can be achieved in the antenna by using P-I-N diodes. PIN diodes are used for the reason that of high speed switching, reliability and compacted size. P-I-N diodes are used as switching elements. Slot length is changed due to ON state of diodes. During ON state diode behave like a short circuit and there is a flow of current, due to this effective length of the slot decreases. In ON state of diodes, antenna resonates at higher frequencies. During OFF state, length of the slot increases so antenna resonates at lower frequencies.

The antenna covers higher operating frequency bands when more switches are in ON state. The equivalent circuit of PIN diode in reverse biased condition and forward biased condition is shown in Fig. 3.3 (A) and (B) respectively. The equivalent circuit of P-I-N diode contains an inductance L of value 0.6 nH in series with resistance R of value 1.33 ohm and in reverse biased condition it consists of Capacitance C of value 0.17 pf in parallel with resistance R of value 3 kohm with inductance L of value 0.6 nH in series with parallel combination of capacitance and resistance.

2. PROPOSED STRUCTURE DESIGN

The design consists of frequency notching structures. In this design U slot in the ground plane is used for notching Wi-Fi frequencies (2.4 GHz to 2.483 GHz) and Wi-Fi (5.1 GHz to 5.825 GHz), Wi-MAX (3.2 GHz to 3.6 GHz) and

X band for down link satellite communication in the 7.25 to 7.75 GHz. The dimension of slot determines the frequencies to be notched and the width of slots decides the bandwidth of the notched frequency. The given antenna geometry is shown in figure 2 for back view and figure 3 for front view.

Rectangular patch is used as radiating element. The substrate used is FR4 with dielectric constant of 4.4 and loss tangent of 0.02, which helps in achieving higher efficiency. The thickness of the substrate chosen is 1.6 mm to achieve low profile of the proposed antenna. Dimension of the patch can be calculated by using equations 3, 4, 5 and 6. These equations are widely used for initial approximation of dimension of rectangular patch antennas. Afterward the dimensions and shapes of patch can be modified and optimized according to desired performance parameters.

Reconfigurability is achieved by using two P-I-N diodes on defected U slot. This structure shows significant improvement in achieving notched frequencies. Figure 4 perform notching for Wi-Fi (5.1 GHz to 5.825 GHz) and radiates in Wi-Fi (2.4 GHz to 2.483 GHz) band and Wi-MAX (3.2 GHz to 3.6 GHz) band. The proposed antenna is first designed, simulated and analyzed in HFSS v 13 and later fabricated. Fig 3.6 shows the fabricated microstrip patch antenna with defected ground structure on ground plane side and rectangular shaped top patch structure to achieve desired notch bands.

Figure 5, 6 and 7 shows the fabricated reconfigurable microstrip patch antenna to achieve notch bands. As from these figures, the material used for fabrication is FR4 substrate of thickness 1.6 mm. A patch antenna was designed using HFSS (software) and it has been tested using VNA. To evaluate the proposed antenna structure, the design is fabricated on FR4 dielectric substrate, with an overall area of 16 ×12.45 mm^2.

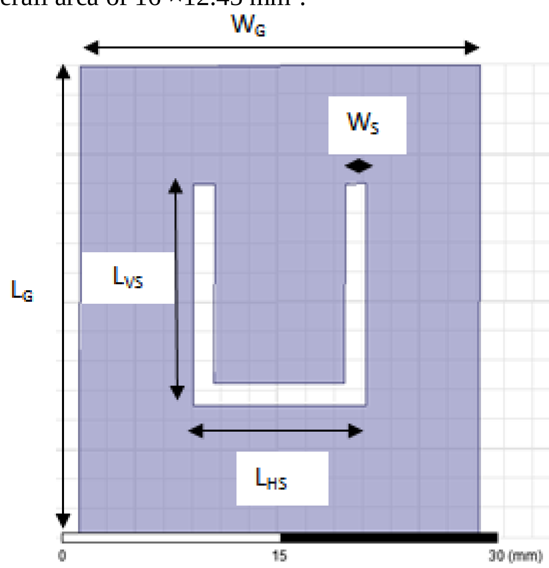


Figure 2: Back View of Triple Notch Band Antenna

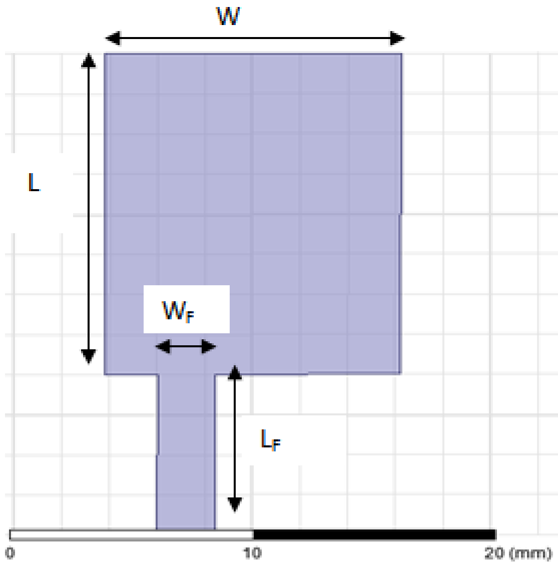


Figure 3: Front View of Triple Notch Band Antenna

Table 1: Dimension of the Reconfigurable Antenna with DGS

Parameters	Dimensions
L	16 mm
W	12.4 mm
L_{VS}	15 mm
L_{HS}	10 mm
W_S	1.5 mm
L_G	32 mm
W_F	2.46 mm
L_F	8 mm
W_G	28.1 mm

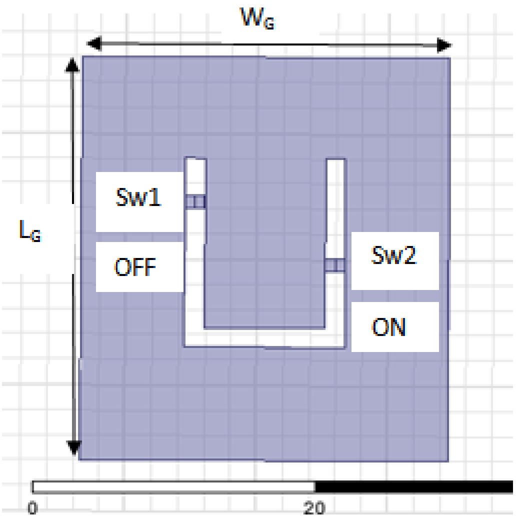


Figure 4: Back View of Reconfigurable Antenna with Two P-I-N Diodes

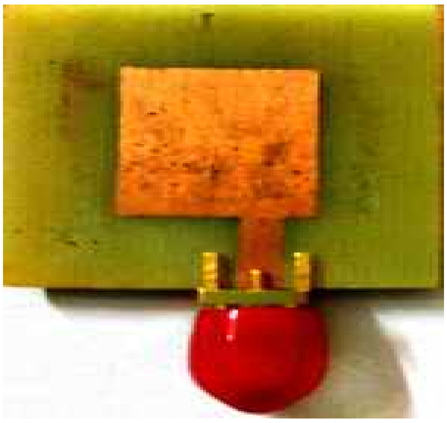


Figure 5: Prototype of Triple Notch Band Antenna (Front View)

Figure 6: Prototype of Triple Notch Band Antenna (Back View)

Figure 7: Prototype of Reconfigurable Antenna (Back View)

Table 2: Different configurations and operations based on the status of two P-I-N Diodes

Sw1	Sw2	Operations
OFF	OFF	• X band (7.25 to 7.75) passed
OFF	ON	• Wi-Fi (2.4 GHz to 2.483 GHz) and Wi-MAX (3.46 GHz to 3.6 GHz) passed • Wi-Fi (5.1 GHz to 5.825 GHz) notched • X band (7.25 to 7.75) Passed
ON	OFF	• Wi-Fi (2.4 GHz to 2.483 GHz) notched • Wi-MAX (3.2 GHz to 3.6 GHz) passed • Wi-Fi (5.1 GHz to 5.825 GHz) notched • X band (7.25 to 7.75) notched
ON	ON	• Wi-Fi (2.4 GHz to 2.483 GHz) passed • Wi-MAX (3.2 GHz to 3.6 GHz) notched • Wi-Fi (5.1 GHz to 5.825 GHz) notched • X band (7.25 to 7.75) notched

When the statuses of all switches are OFF the antenna performs triple notch band operation. If all switches are ON antenna radiates in Wi-Fi band from 2.4 GHz to 2.483 GHz.

Figure 8 shows Simulated Return loss S_{11} of Microstrip Patch Antenna with Defected Ground Structure. The antenna resonates at 1.82 GHz, 4.19 GHz, 6.66 GHz and10.02 GHz having return loss value of -15.15 dB, -11.93 dB, -36.22 dB and -21.43 dB respectively. The bandwidth of the antenna can be for those range of frequencies over which the return loss is not as much of -10 dB. Therefore bandwidth of the antenna can be considered from return loss against frequency plot. The antenna has wide bandwidth from frequency range 1.53 GHz to 10.67 GHz.

The following plot in Figure 9 shows the return loss for proposed reconfigurable triple notch band antenna with two P-I-N diodes on defected U slot. In configuration 7 (Sw1-OFF, Sw2-ON) , the antenna resonates at 2.37 GHz, 4.54 GHz, 7.21 GHz and 9.74 GHz having return loss value of -16.16 dB, -15.03 dB, -34.04 dB and -20.15dB respectively. The antenna has wide bandwidth from frequency range 1.98 GHz to 10.62 GHz.

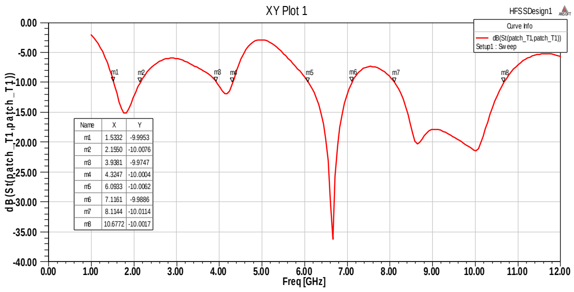


Figure 8: Simulated Return loss S_{11} of Triple Notch Band Antenna

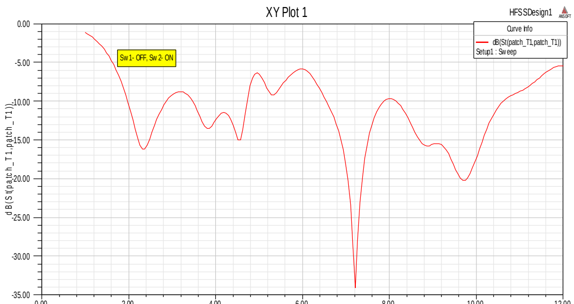


Figure 9: Simulated Return loss S_{11} of Reconfigurable Antenna

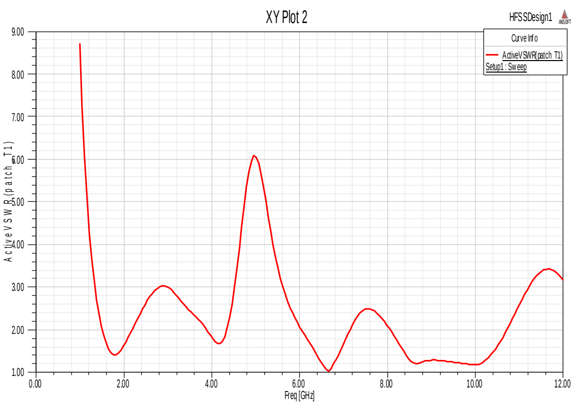


Figure 10: VSWR plot of Triple Notch Band Antenna

The plot in Figure 10 shows the VSWR for the patch antenna with defected ground structure. The assessment of VSWR is done under 2 that are viewed clearly from the graph. It shows 1.42, 1.67, 1.03 and 1.18 at resonant frequencies 1.82 GHz, 4.19 GHz, 6.66 GHz and 10.02 GHz respectively. The following plot in Figure 11 shows the VSWR for proposed reconfigurable triple notch band antenna with two P-I-N diodes on defected U slot. It shows 1.36, 1.43, 1.04 and 1.22 at resonant frequencies 2.37 GHz, 4.54 GHz, 7.21 GHz and 9.74 GHz respectively

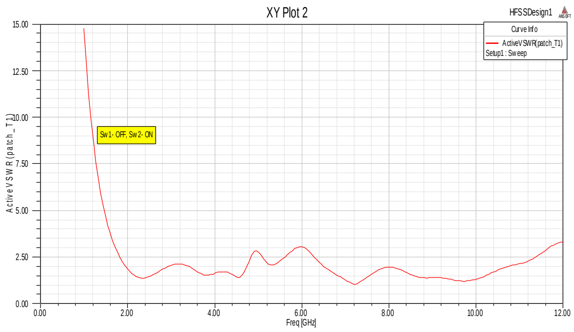


Figure 11: VSWR plot of Reconfigurable Antenna

3. ANALYSIS OF PROPOSED STRUCTURE

From polar plot graph of radiation pattern as shown in Figure 12, it can be observed that radiation pattern obtained is omni directional at resonant frequencies.

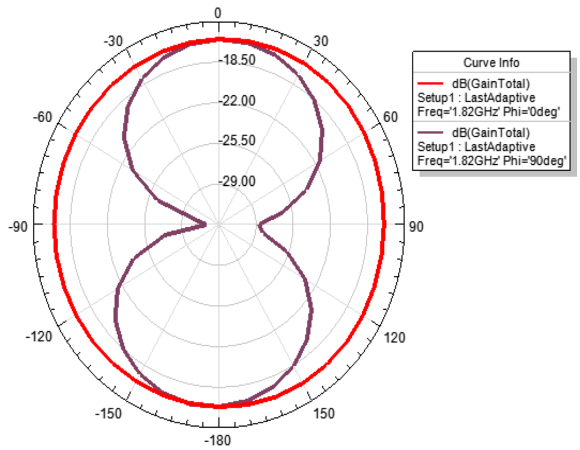
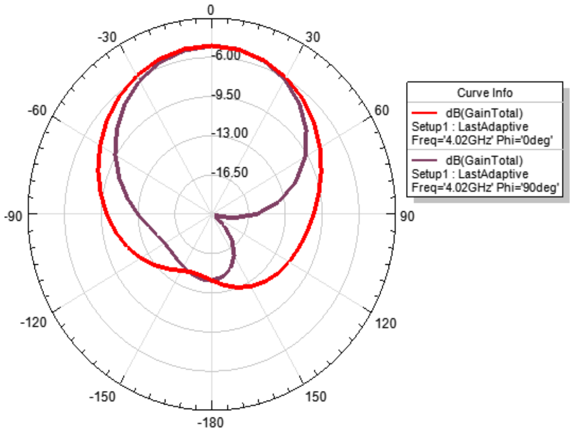
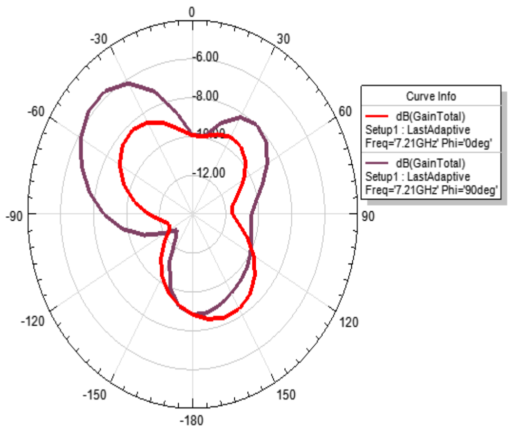


Figure 12: Radiation Pattern of Triple Notch Band Antenna (2D View) for phi =0^{0} and 90^{0}

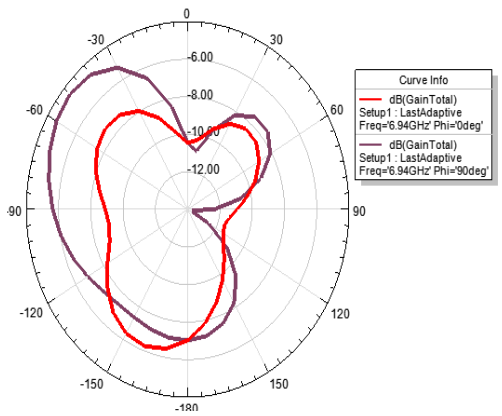
From polar plot graph of radiation pattern as shown in Figure 13, it can be seen that radiation pattern obtained is omni directional at resonant frequencies.



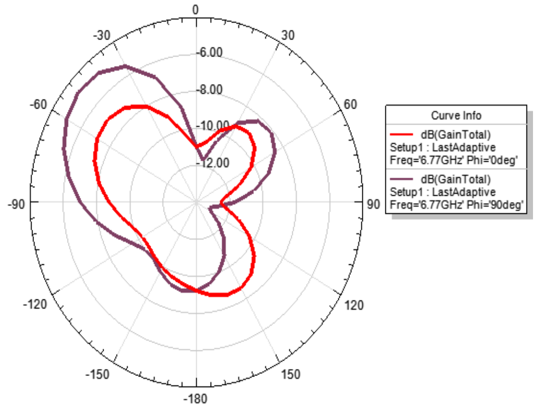
(a) Sw1 - OFF, Sw2 - OFF



(b) Sw1 - OFF, Sw2 - ON



(c) Sw1 - ON, Sw2 - OFF



(d) Sw1- ON, Sw2 – ON

Figure 13: Radiation Pattern of proposed Reconfigurable antenna with two P-I-N diodes

4. CONCLUSION

Asia pacific region (India, China) used frequency bands of 2.3, 2.5, 3.3, 3.5, 5.8 GHz for Wi-max. Two bands of (2.4 to 2.5 GHz and 5.725 to 5.825 GHz) are mainly used for Wi-Fi. Bluetooth, IEEE 802.15.1 used frequency band at 2.4 GHz (2.4 to 2.483 GHz). Ultra wide band have the required bandwidth to accommodate future wireless traffic with improved energy efficiency. Electromagnetic interference (EMI) from Bluetooth, Wi-Fi (2.4 GHz to 2.483 GHz), Wi-Fi (5.1 GHz to 5.825 GHz), Wi-MAX (3.2 GHz to 3.6 GHz) and X band for down link satellite communication in the 7.25 to 7.75 GHz. restricts the use of entire ultra wide band all the time. Thus reconfigurable antenna is required to notch the interference to improve the performance of ultra wide band antenna. A DGS shape reconfigurable antenna is designed, analyzed and fabricated. The overall size of proposed antenna is 16 ×12.4 mm^2. The simulated return loss plot of triple notch band antenna in result section shows resonance at 1.82 GHz, 4.19 GHz, 6.66 GHz and10.02 GHz having return loss value of -15.15 dB, -11.93 dB, -36.22 dB and -21.43 dB respectively. The antenna has wide bandwidth from frequency range 1.53 GHz to 10.67 GHz in UWB band. Simulations are done using HFSS and the results are verified through measurements. Due to the use of P-I-N diodes on DGS, the antenna is achieved different notch bands according to states of switches. The resulting structure is compact in size and shows significant recalling of notch bands.

REFERENCES

[1] J. Balcells, Y. Damgaci, B. A. Cetiner, J. Romeu, and L. Jofre, "Polarization Reconfigurable MEMS CPW Antenna for MM Wave Applications," 4th European Conference on Antennas and Propagation (EuCAP '10), April 2010.

[2] Ashwini K. Arya, M.V. Kartikeyan and A. Patnaik, "Defective Ground Structure in the Perspective of Microstrip Antenna: A Review", FREQUENZ Journal of RF-Engineering and Telecommunications, Vol. 64, Issue 5-6, pp. 79-84, Jun. 2010.

[3] Wei Qin and Juan Li, "A Novel Dual Frequency Notched UWB Antenna with dual L Shaped slots", IEEE International Symposium on Signals, Systems and Electronics, Vol. 2, pp. 1-3, 2010.

[4] Wen-Chung Liu, Chao-Ming Wu and Yang Dai, "Design of Triple- Frequency Microstrip-Fed Monopole using Defected Ground Structure", IEEE Transactions on Antenna and Propagation, Vol. 59, No. 7, pp. 2457-2463, July 2011.

[5] A. Nouri and G. R. Dadashzadeh, "A Compact UWB Band- Notched Printed Monopole Antenna with Defected Ground Structure", IEEE Antennas and Wireless Propagation Letters, Vol. 10, pp. 1178-1181, 2011.

[6] Jyoti Ranjan Panda and Rakhesh Singh Kshetrimayum, "A 3.4/5.5 GHz Dual-Band Notched UWB Printed Monopole Antenna with Two Open Circuited Stubs in the Microstrip Feedline", Microwave and Optical Technology Letters, Vol. 53, No.12, pp. 2973-2978, December 2011.

[7] Yan Zhang, Qing-lin Shi, Shan-Shan Lin, Shan-wei Lü, "A Novel Reconfigurable Notched-Band UWB Antenna", IEEE International Symposium on Antennas, Propagation & EM Theory, pp. 369-372, 2012.

[8] S. K. Mishra and J. Mukherjee, "Compact Printed Dual Band-Notched U-Shape UWB Antenna", Progress In Electromagnetics Research C, Vol. 27, pp. 169-181, 2012.

[9] Cheol Yoon, Won-Jong Lee, Woo-SU Kim, Hwa-Choon Lee and Hyo-Dal Park "Copact Band-Notched Ultra-Wideband printed Antenna using Inverted L-Slit", Microwave and Optical Technology Letters, Vol. 54, No. 1, pp. 143-144, January 2012.

[10] Wen Jiang and Wenquan Che, "A Novel UWB Antenna with Dual Notched Bands for WiMAX and WLAN Applications", IEEE Antennas and Wireless Propagation Letters, Vol. 12, pp. 293-296, 2012.

[11] Mohammad Naser-Moghadasi, Mohammad Reza Haraty, Seyed Majid Seyed Momeni and Bal S. Virdee "Novel Compact UWB Antenna with Reconfigurable Dual-Band Notches using PIN Diodes Switches Actuated without $\lambda_g/4$ DC Bias Line", Microwave and Optical Technology Letters, Vol. 54, No. 10, pp. 2392-2397, October 2012.

[12] A. A. Kalteh, G. R. Dadashzadeh, M. Naser-Moghadasi and B. S. Virdee, "Ultra-Wideband Circular Slot Antenna with Reconfigurable Notch Band Function", IET microwaves, Antennas & Propagation, Vol. 6, Issue 1, pp. 108-112, 2012.

[13] A. Zohur, H. Mopidevi, D. Rodrigo, M. Unlu, L. Jofre and B.A. Cetiner "RF MEMS Reconfigurable Two Band Antenna", IEEE Antennas and Wireless Propagation Letters, Vol. 12, pp. 72-75, 2013.

[14] Nasrin Tasouji, Javad Nourinia, Changiz Ghobadi, and Farzad Tofigh, "A Novel Printed UWB Slot Antenna with Reconfigurable Band-Notched Characteristics", IEEE Antennas and Wireless Propagation Letters, Vol. 12, pp. 922-925, 2013.

[15] R. Azim, A.T. Mobashsher and M.T. Islam, "UWB Antenna with Notched Band at 5.5 GHz", IEEE Electronics Letters, Vol. 49, Issue 15, pp. 922-924, July 2013.

[16] Uma Shankar Modani and Anubhav Kanwaria, "Frequency Reconfigurable Multiband Microstrip Patch Antenna for Various Wireless Services", International Conference on Advanced Research in Engineering and Technology (ICARET), Vol. 2, pp. 496-500, 2013.

[17] Sai Wai Wong, Zai-cheng Guo, Kai Wang and Qing-xin Chu, "A Compact Tunable Notched- Band Ultra-Wide-Band Antenna using a Varactor Diode", IEEE Asia-Pacific conference on Antennas and Propagation, pp. 161-163, 2014.

[18] Sarang Pendharker, R.K. Shevgaonkar and A.N. Chandorkar, "Optically Controlled Frequency Reconfigurable Microstrip Antenna with Low Photoconductivity", IEEE Antennas and Wireless Propagation Letters, Vol. 13, pp. 99-102, 2014.

[19] Jazeel A and Susila M, "Compact Reconfigurable Ultra Wide Band Antenna Design for Wireless Communication", IEEE International Conference on Advanced Communication Control and Computing Technologies, pp. 734-737, 2014.

[20] Hanae Elftouh, Naima A. Touhami, Mohamed Aghoutane, Safe El Amrani, Antonio Tazon and Mohamed Boussouis , "Miniaturized Microstrip Patch Antenna with Defected Ground Structure", Progress In Electromagnetics Research C, Vol. 55, pp. 25-33, 2014.

[21] Vijai Reghunath and Upama Rajan M.N. "Band Notched UWB Antenna for Wireless body Area Network", IEEE International Conference on Advanced in Computing and Communication, pp. 305-308, 2014.

[22] Bahreh Badamchi, Javad Nourinia, Changiz Ghobadi and Arash Valizade Shahmizad, "Design of Compact Reconfigurable Ultra-Wide band Slot Antenna with Switchable single/Dual Band Notch Functions", IET microwaves, Antennas & Propagation, Vol. 8, Issue 8, pp. 541-548, 2014.

[23] Eduardo J.B. Rodrigues, Hertz W. C. Lins and Adaildo G. D. Assuncao,"Reconfigurable Circular Ring Patch Antenna for UWB and Cognitive Radio Applications", IEEE European Conference on Antennas & Propagation, pp. 2744-2748, 2014.

[24] Anil Kamma, G. Shrikanth Reddy, Rajesh singh Parmar and Jayanta Mukherjee,"Reconfigurable Dual-Band Notch UWB Antenna", IEEE National Conference on Communications, pp. 1-3, 2014.

[25] M. Abedian, S. K. A. Rahim, Sh. Danesh, S. Hakimi, L. Y. Cheong, and M. H. Jamaluddin, “Novel Design of Compact UWB Dielectric Resonator Antenna with Dual- Band-Rejection Characteristics for WiMAX/WLAN Bands”, IEEE Antennas and Wireless Propagation Letters, Vol. 14, pp. 245-248, 2015.

[26] Si-Yan Chen and Qing-Xin Chu, “A Reconfigurable Dual Notched-Band UWB Antenna”, IEEE 4th Asia-Pacific Conference on Antennas and Propagation, pp. 103-104, 2015.

[27] Babu lal Sharma, Girish Parmar and Mithilesh Kumar, “Design Frequency Reconfigurable Microstrip Patch Antenna for S-Band Applications”, IEEE 4th International Conference on Reliability Infocom Technologies and Optimization, pp. 1-4, 2015.

[28] Rachana Yadav, Sandeep Kumar Yadav and Indra Bhooshan Sharma, “Reconfigurable Single and Dual Band Microstrip Patch Antenna for Satellite Communication”, IEEE International Conference on Green Computing and Internet of Things, pp. 1565-1570, 2015.

[29] Nishant Kumar, P Ananda Raju, Santanu Kumar Behera, “Frequency Reconfigurable Microstrip Antenna”, IEEE International Conference on Communications and Signal Processing (ICCSP), pp. 370-373, 2015.

[30] Samavia Haroon, Khurram Saleem Alimgeer, Nihala Khalid, Bilal Tariq Malik, M.Farhan Shafique and Shahid A. Khan, “A Low Profile UWB Antenna with Triple Band Suppression Characteristics”, SPRINGER Wireless Personal Communications, Vol. 82, Issue 1, pp. 495-507, May 2015.

[31] Pramod singh and Rekha Aggarwal“Design of Ultra Wideband Antenna with Triple Band Notch for Minimum EMI”, Microwave and Optical Technology Letters, Vol. 58, No. 7, pp. 1521-1525, July 2016.