Dual Band Rejected Low Profile Planar Monopole Antenna for UWB Application

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***Abstract* – In this paper, a new design of ultra-wideband band (UWB) antenna with dual band rejection characteristics and size-miniaturization approach has been presented. The proposed antenna consists of unique patch of trapezoidal shape, 50 Ω impedance triple down step microstrip feed line (on top plane) and partial ground plane (on bottom plane). The patch tapering results to bandwidth (BW) improvement. It works efficiently over the impedance bandwidth of 3-13 GHz and gives Fractional Bandwidth (FBW) of 125% that covers the entire UWB band. It provides nearly omnidirectional radiation pattern, has good realized gain and impedance matching. A triple step feed increases electrical length of patch, which leads to antenna size miniaturization. Therefore, the proposed antenna has been designed with dimensions of 22 mm × 28 mm × 1.6 mm, dielectric constant (Ɛr) of 4.4 and tangent loss of 0.02. For wireless applications, some specific UWB systems suffer from strong narrowband interference of unlicensed (ISM band) wireless communication devices. To avoid this unwanted interference, band rejection characteristics should be inserted into the antenna patch structure. The proposed antenna has designed with dual-band rejection capability that efficiently avoids Wi-MAX and WLAN interference. The V-slot is etched on patch radiator to reject Wi-Max (3.15–4 GHz) and single C-strip pair besides feed line is used to reject WLAN (5.18-5.95 GHz) band. The output performance has measured in terms of simulated reflection coefficient and VSWR.**

Index Terms - Compact, Dual Band-Notched, Monopole antenna, UWB, V-slot, Wi-MAX, WLAN

I. Introduction

In last two decades, UWB systems have been great attraction especially from 2002, since the US federal communication commission (FCC) permits the authority to use 3.1 GHz-10.6 GHz as an unlicensed frequency band [1]. These are popular due to their several advantages like high speed data rate, larger bandwidth, low transmission power, high precision ranging, light weight, compact structure, low cost, simple architecture design and can be easily configured with active devices. The bandwidth of microstrip antenna plays an important role to calibrate antenna performance in wireless communication. The CPW, aperture coupled and proximity feed are most commonly used to enhance the BW [2]. The BW also improved with the use of thick substrate & by lowering dielectric constant (εr), or by using multi-resonator gap-coupled & stacked configurations, or by inserting resonant slots inside the patch such as U, C, L, H, I, Y, Ring etc. However, with all these methods, bandwidth of the antenna is limited because probe inductance increases by taking substrate thicknesses greater than 0.06 λ0 to 0.07 λ0 [3]-[5].

In recent years, different type of antennas like Vivaldi antenna, bi-conical antenna, log-periodic antenna and spiral antennas were designed to achieve large bandwidth for UWB systems [6]-[10]. The Vivaldi antennas [5, 6] play an important role in UWB to achieve directional radiation properties. However, these have not good selection for portable or mobile application because it needs an omni-directional radiation pattern for indoor wireless communication. The mono-conical and bi-conical antennas [7] have bulky structure & are large in size, which limits their application. The log periodic antenna [8] and spiral antenna [9] are two different antennas that can operate over the frequency range of 3.1-10.6 GHz, but these are large in physical size as well as have dispersive characteristics with frequency and severe ringing effect. Due to these drawbacks, these are also not suitable for portable & mobile applications or indoor wireless communication. This problem was solved by invention of new printed planar monopole UWB antennas [11]-[24]. The printed circular disc monopole antenna with double stepped geometry as well as circular slot, maple-leaf shaped, butterfly shaped and trapezoidal shaped monopole antennas were presented [11]. Those were light in weight, small in size and provides good impedance matching over entire UWB band. In addition, coplanar waveguide (CPW) feed [12], proximity feed [13]-[14] techniques are widely used to enhance the bandwidth because of several advantages over microstrip line feed such as, low spurious radiation, low feed line scattering and easy control of characteristic impedance etc.

The UWB is a very large band i.e. from 3.1GHz to 10.6 GHz. This band also includes unlicensed ISM bands like Wi-Fi, Wi-MAX and WLAN, which are widely used. In order to prevent unwanted signals interference from these bands, it is required to have band notching characteristics in the proposed antenna. This is done by inserting different type of slots, strips or slits on radiating patch. The dimensions of these slots are varied in such a way, that these act as a notch resonator. The optimization of these slots can be done by using hit & trail method, artificial neural network (ANN) estimation [15]-[16] and nature inspired optimization algorithms [17]-[20]. In [21]-[28], several antennas have been designed with different type of slots such as fractal [21], EBG with C-slot [22], inverted U-slot in feed line [23], L-slot in ground plane [24], U & I-shape slots on radiating patch [25], Dual Y-shaped slot [26] and Ω-shaped slot [27]. In [28], triple band notched characteristics have been achieved by using two round shape slots and one C-strip pair. The round slots are used to reject Wi-Max and WAN bands whereas C-strip pair is used to reject X-band of satellite communication. The size of the antenna was 22 mm × 31 mm of 682 mm^2 that can be further reduce.

In this article, a dual-band notched (DBN-UWB) printed UWB antenna has presented. Section II describes the design structure of basic UWB antenna. Section III illustrates the concept of dual band notching which has clearly understood from reflection coefficient, VSWR, surface current distribution and realized gain. The last section leads to conclusion of the proposed work.

II. Basic Trapezoidal UWB Antenna Design Structure

The first stage of an UWB antenna design starts with the design of basic rectangular monopole patch structure with size of W × L as 22mm × 28mm. Then it is modified to trapezoidal patch shape geometry as shown in Fig. 1. A 50 Ω microstrip feed line is etched on top plane to deliver the signal from microwave source to antenna patch radiator. The ground is designed partially on the bottom plane. Between these two layers, FR-4 (flame retardant) dielectric substrate with relative permittivity (ε_r) of 4.4, a tangent loss of 0.02 and thickness (h) of 1.6 mm is used. Modify the feed line to triple down steps with optimized values of width & length selected as 3.316 mm & 14 mm respectively. It enhances the impedance matching of patch with feeding source, which increases the antenna radiation. Secondly, it increases antenna electrical length that reduces the physical size that means it helps in antenna size miniaturization. However, size reduction should not to decrease antenna gain in addition to bandwidth because antenna gain and bandwidth are directly affecting by the antenna size. The optimized parameters of proposed UWB antenna are listed in Table I. The ground plane top edges tapering also helps to enhance the bandwidth of proposed antenna. The patch and ground metal is designed with copper layer width of 35-micron.

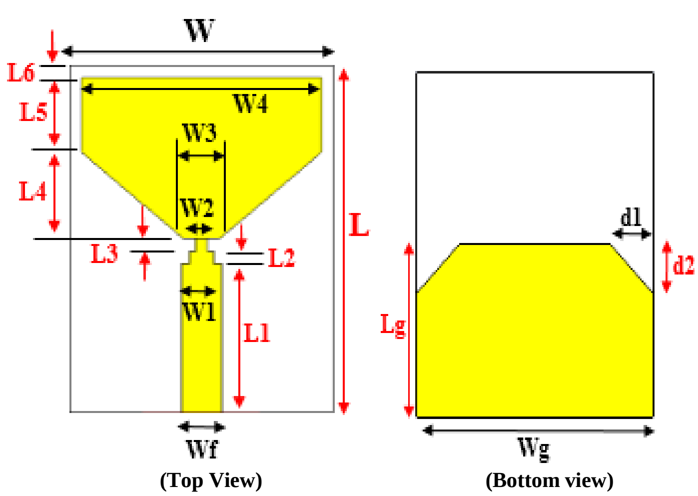

Fig. 1 Proposed Basic Trapezoidal UWB antenna structure design.

TABLE I
Proposed UWB Antenna Geometry Parameter Values

Parameter	Value	Parameter	Value
L1	12	W1	2
L2	1	W2	1
L3	1	W3	3
L4	7	W4	20
L5	6	Wf	3.316
L6	1	W	22
L	28	Wg	22
d1	4	Lg	14
d2	4		

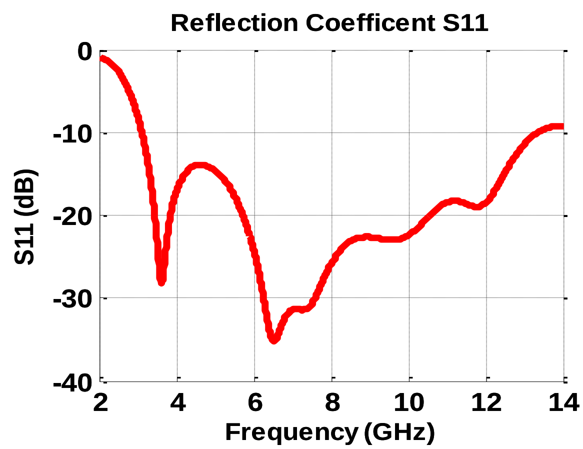

Fig. 2 Simulated Reflection Coefficient of Basic UWB.

The patch dimensions are calculated using electromagnetic design equations [1]. The simulation of the proposed antenna has done with microwave studio tool of CST-2016 software. The proposed trapezoidal monopole planar UWB antenna performance has measured in terms of reflection coefficient & voltage standing wave ratio (VSWR). Fig. 2 shows working range of proposed antenna is from 3.05 - 13 GHz ($|S_{11}|$< -10 dB) which covers the UWB band of 3.1 - 10.6 GHz.

III. Dual Band-Notched UWB (DBN-UWB) Antenna Design Structure

For some wireless applications, UWB systems suffer from the unwanted interference of ISM band wireless communication devices. To avoid this interference, there is a need to insert in-built band rejection characteristics in to the patch geometry. In this paper, the proposed UWB antenna has designed with dual-band rejection capability. The proposed antenna structure consists of V-shape slot and single C-shaped strip pair as shown in Fig. 3.

The V-slot cut on upper side of the radiating patch on top plane is used to reject 3.5 GHz Wi-MAX (worldwide interoperability for microwave access) band. The C-strip pair (two symmetrical C-strips) also on top plane besides microstrip feed is designed to reject 5.2/5.8 GHz bands of WLAN (wireless local area network).

The dimensions of these slot and strips have calculated with following EM design equations [29]:

$$L_{NB} = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\sqrt{\epsilon_{eff}}} = \frac{c}{2 \times f_{BNCF}\sqrt{\epsilon_{eff}}} \quad (1)$$

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h_{sub}}{W}\right]^{-\frac{1}{2}} \quad (2)$$

Where ε_r, ε_{eff} and h_{sub} are dielectric constant, effective relative permittivity and height of the substrate, respectively. C is the speed of EM wave in free space and given as 3×10^8 m/s. L_{NB} is the length of corresponding notched band and it is approximately equal to half-guided wavelength. Initially the width is taken as 0.5 mm & then it is varied according to improvement in output results. To calculate length, the band notch frequencies (f_{BNCF}) are selected as 3.5 GHz and 5.5 GHz. The optimized parameters of the proposed antenna are listed in Table II.

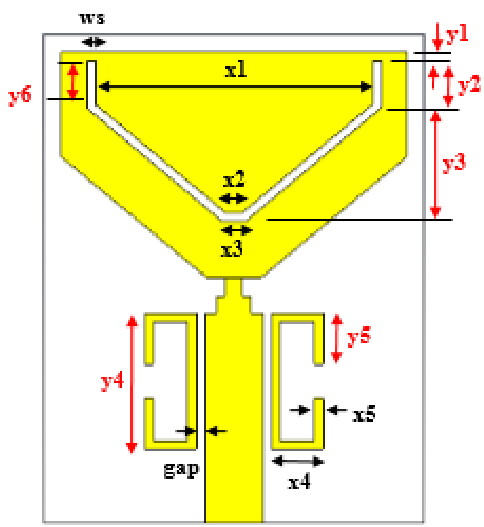

Fig. 3 Proposed DBN-UWB antenna structure top view.

TABLE II
GEOMETRY PARAMETER VALUES FOR DBN-UWB DESIGN

Parameter	Value	Parameter	Value
X1	16	Y1	0.5
X2	1	Y2	2.5
X3	1.4	Y3	6.2
X4	3	Y4	7.8
X5	0.5	Y5	2.9
gap	0.5	WS	0.5

The output performance has been measured in terms of S_{11} (in dB) & VSWR. Fig. 4 compares the VSWR of single and dual band notched antennas in which good band rejection with VSWR > 4 is obtained. The black color plot is representing efficient single band rejection characteristics for Wi-MAX (3.15 - 4 GHz) band because of V-slot act as a notch-resonator,

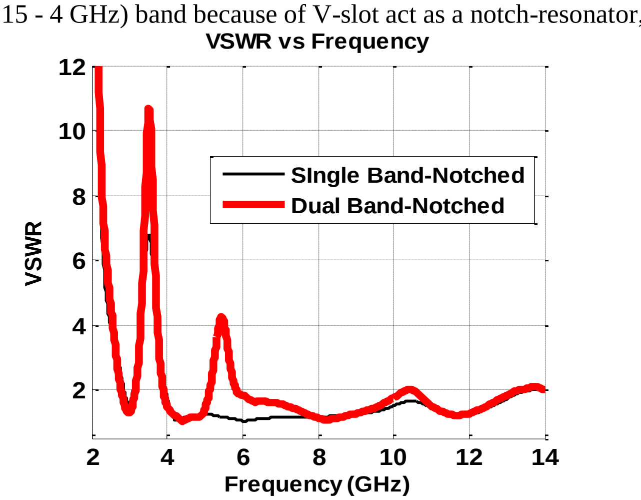

Fig. 4 Simulated VSWR of DBN-UWB Antenna.

whereas the red color shows one additional band rejection of WLAN from 5.18 - 5.95 GHz (due to C-strip pair act as notch-resonator). The maximum values of VSWR achieved as 10.8 & 4.2 for Wi-MAX & WLAN bands as shown in Fig. 4.

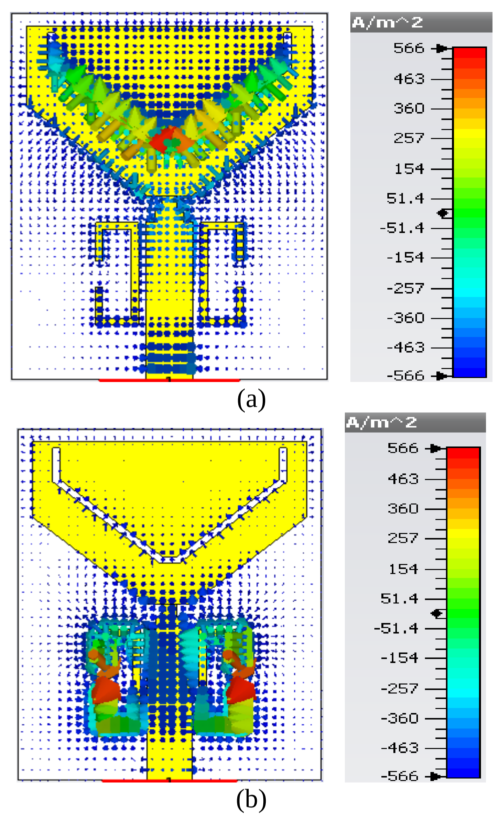

Fig. 5 Surface current distribution at (a) 3.5GHz and (b) 5.5 GHz.

Fig. 5 shows the simulated surface current distribution, which helps to clearly understand the concept of dual band rejection. The red color vectors indicate maximum value and blue color vectors show minimum value. The surface current distribution at f_{BNCF} is collected maximum along the slots and

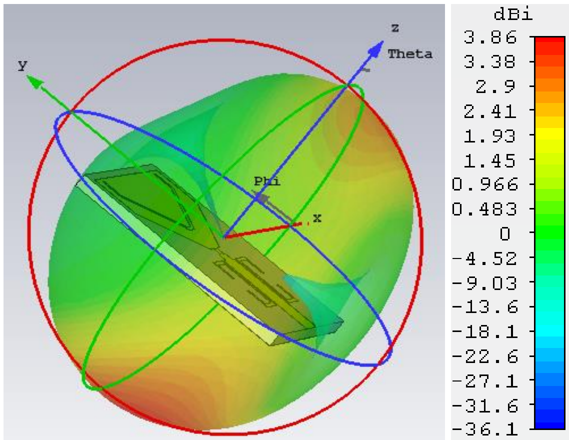

Fig. 6 3D view of Directivity at 6.5GHz.

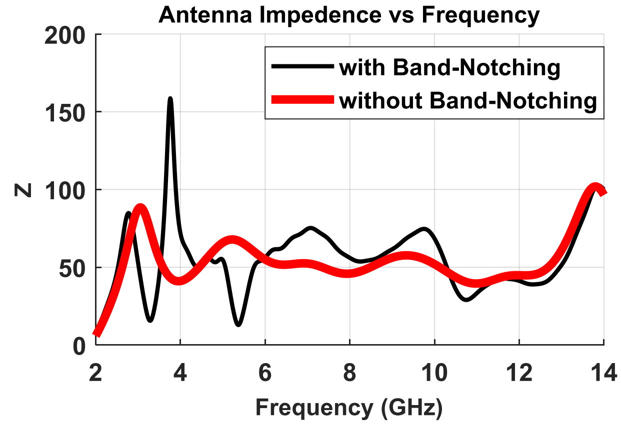

Fig. 8 Impedance comparison of proposed basic UWB & DBN-UWB antennas.

in opposite direction. Therefore, the field distribution at inner & outer edges cancels each other and there is zero radiation. As the length approaches to half guided wavelength (λ/2), it acts as a notch resonator. The slot/strip has stored in-built maximum part of EM energy. Hence, it is responsible to reject the band of corresponding center notch frequency.

The 3D radiation pattern in terms of directivity (D) is shown on Fig. 6. It attains maximum value as 3.86 dBi at 6.5 GHz frequency. It also shows the proposed monopole antenna which has been designed in XY-plane. As the feed source is connected along Y-axis, it is called as Y-polarized antenna. That is E-plane lies in YZ plane and H-plane lies in XZ plane. The E plane has nearly dumbbell shape and H plane has omnidirectional shape radiation pattern.

The directivity is a ratio of gain to radiation efficiency that means and directivity and gain are directly proportional to each other. Now as the directivity increases, the gain increases and vice versa. Fig. 7 compares the gain of basic UWB antenna without band notching to the DBN-UWB antenna. It clearly shows the gain of DBN-UWB monopole antenna sharply reduces at both the Wi-MAX and WLAN bands.

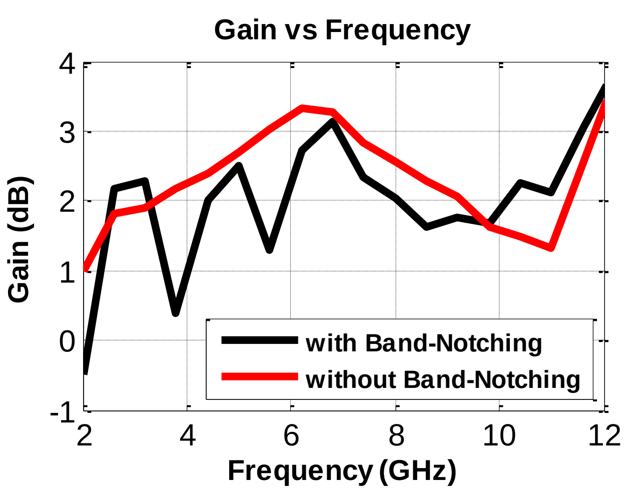

Fig. 7 Gain comparison of proposed basic UWB & DBN-UWB antennas.

For rest of the UWB band, it is comparable to basic UWB antenna design. The gain varies between 1.85-3.35 dB but it reduces by 77.2% & 54% for Wi-Max & WLAN bands respectively. The antenna input impedance plays an important role to transfer maximum power from feeding source to antenna. It should be required as 50 ohms. Fig. 8 clearly illustrates, the input impedance of proposed basic UWB and DBN-UWB antennas varies nearly to 50-ohm throughout the entire UWB band.

IV. Conclusion

The trapezoidal monopole UWB antenna with dual-band rejection capability and size miniaturization approach has been presented. The proposed antenna has simple structure and is easy to fabricate on commercially available low cost FR-4 substrate. Due to triple step feed & DGS substrate effect, good size reduction has achieved to 22 × 28 mm^2. To avoid the unwanted interference, dual-band rejection characteristics have inserted by etching V-slot and C-strip pair on top plane patch radiator. These covers band rejection requirement of Wi-MAX (3.15–4 GHz) and WLAN (5.18-5.95 GHz) efficiently. Finally, it is concluded that the proposed antenna has compact in size, wider impedance bandwidth, nearly omnidirectional radiation pattern and good relative gain. Hence, it is a good candidate for UWB application.

References

[1] First report and order, revision of part 15 of the commission's rules regarding ultra-wideband UWB transmission systems FCC, 2002.

[2] Balanis C.A., "Antenna Theory," Wiley publications, 2nd edition, Chapter-14, 1997.

[3] G. Kumar and K. P. Ray, "Broadband Microstrip Antennas," edition-2003.

[4] B. Majumder, K. Krishnamoorthy, "Compact Broadband Directive Slot Antenna Loaded with Cavities and Single and Double Layers of Metasurfaces," IEEE Trans. on Antennas and Propagation, Vol. 64, No. 11, pp. 4595-4606, Nov. 2016.

[5] R. Ferreira, J. Joubert and J. W. Odendaal, "A Compact Dual-Circularly Polarized Cavity-Backed Ring-Slot Antenna," IEEE Trans. on Antennas and Propagation, Vol. 65, No. 1, pp. 364-368, Jan 2017.

[6] I. Linardou, C. Migliaccio, J.M. Laheurte and A. Papiernik, "Twin Vivaldi antenna fed by coplanar waveguide," Electronic Letter, 33 (22), pp. 1835-1837, 1997.

[7] S. G. Kim and K. Chang, "Ultra-Wideband Exponentially-Tapered Antipodal Vivaldi Antennas," IEEE Antenna and Prop. Society Symposium, Monterey, CA, pp. 2273-2276, June 2004.

[8] A. Sibille, "Compared Performance of UWB Antennas for Time and Frequency Domain Modulation," 28th URSI General Assembly, New Delhi, India, 3, 2005.

[9] S. Licul, J.A.N. Noronha, W.A. Davis, D.G. Sweeney, C.R. Anderson, "A parametric study of time-domain characteristics of possible UWB antenna architectures," in IEEE 58th Vehicular Tech. Conf., VTC 2003-Fall, 5, pp. 6-9, Oct. 2003.

[10] Sego, D.J, "Ultrawide band Active Radar Array Antenna for Unnamed Air Vehicles," IEEE Nat. Tele system Conference, 3, pp.13-17, 1994.

[11] O. Haraz and A.R. Sebak, "UWB Antennas for Wireless Applications," Chapter 6 of Advancement in Microstrip Antennas with Recent Applications book published by InTechopen Web of Science, pp. 125-152, March 2013.

[12] X. C. Lin and C. C. Yu, "A dual-band CPW-fed inductive slot-monopole hybrid antenna," IEEE Transaction Antenna Propagation, Vol-56, no.1, pp. 282-285, Jan 2008.

[13] A. A. Deshmukh, Mansi M. and Raj S. Shah, P. Runwal and A. A. Joshi, "Broadband Proximity Fed Gap-coupled C-shaped Microstrip Antennas," Int. Journal of Computer Applications, pp. 34-37, 2013.

[14] A. A. Deshmukh, D. Singh, P. Zaveri, M. Gala and K. P. Ray, "Broadband Slot cut Rectangular Microstrip Antenna," Elsevier, Journal of Science Direct, Procedia Computer Science 93, pp. 53-59, 2016.

[15] G. Singh and S. Kaur "Design Analysis of an E-Shaped Slit Loaded MPA and Parameters Estimation using ANN," IEEE International Conference (ICCCA), pp. 1404-1408, ISBN-978-1-5090-1666-2/16, 2016.

[16] G. Singh, J. Singh, S. Kaur and B.S. Sohi "Performance Analysis of Different Neural Network Models for Parameter Estimation of Coaxial feed 2.4 GHz E-Shaped Microstrip Patch Antenna," IEEE International Conference (RAECS) ISBN-978-1-4673-8253-3/15, 2015.

[17] R. Salgotra and U. Singh, "A novel bat flower pollination algorithm for synthesis of linear antenna arrays," Neural Computing and Applications (Springer), vol. 30, pp. 2269-2282, 2018.

[18] R. Salgotra and U. Singh, "Synthesis of linear antenna array using flower pollination algorithm," Neural Computing and Applications (Springer), vol. 29, pp. 435-445, 2018.

[19] U. Singh, R. Salgotra and M. Rattan, "A Novel Binary Spider Monkey Optimization Algorithm for Thinning of Concentric Circular Antenna Arrays," IETE Journal of Research, vol. 62, no. 6, pp. 736-744, 2016.

[20] U. Singh and R. Salgotra, "Optimal synthesis of linear antenna arrays using modified spider monkey optimization," Arabian Journal for Science and Engineering, vol. 8, no. 41 pp. 2957-2973, 2016.

[21] FB. Zarrabi, AM. Shire, M. Rahimi and NP. Gandj, "Ultra-wideband tapered patch antenna with fractal slots for dual notch application," Microwave Opt Tech Letter, vol. 56, pp. 1344-1348, 2014.

[22] L. Peng and CL. Ruan, "UWB band-notched monopole antenna design using electromagnetic bandgap structures," IEEE Transaction Microwave Theory Tech., vol. 59, no. 4, pp. 1074-1081, April 2011.

[23] YK. Choukiker and SK. Behera, "Modified Sierpinski square fractal antenna covering ultra-wide band application with band notch characteristics," IET Microwave Antennas Propagation Letter, no. 8, pp. 506-512, 2014. 41

[24] E. Pancera, D. Modotto, at.al, "Novel design of UWB antenna with band notch capability," Int. European Conf. on Wireless Tech., pp. 48-50, 2007.

[25] HS Mewara, D. jhanwar, MM Sharma and JK Deegwal, "A printed monopole ellipsoidal UWB antenna with four band rejection characteristics," Int. J. of Electronics and Communications (AEU), vol. 83, pp. 222-232, 2018. 46

[26] JB. Jiang, ZH. Yan and C. Wang, "A novel compact UWB notch filter antenna with a dual Y-shaped slot," Propagation EM Research Letter, vol. 14, pp. 165-170, 2010. 47

[27] MA Salamin, Sudipta Das and Asmaa Zugari, "Design and realization of low profile dual wideband monopole antenna incorporating a novel Ohm (Ω) shaped DMS, and semi-circular DGS for wireless applications," Int. J. of Electronics and Communications (AEU) vol. 97, pp. 45-53, 2018.

[28] Pritam S. Bakariya, Santanu Dwari and Manas Sarkar, "Triple band notch UWB printed monopole antenna with enhanced bandwidth," Int. J. of Electronics Communication (AEÜ), vol. 69, pp. 26–30, 2015.

[29] G. Singh, J. Singh, "Comparative Analysis of Microstrip Patch Antenna with Different Feeding Techniques," In Int. J. of Computer Applications (IJCA) and Proceedings of Inter. Conf. on Recent Advances and Future Trends in Information Technology (iRAFIT-2012), PU Patiala, March, 2012.