International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Ultrawideband Dielectric Resonator Antenna based on Meandered Dielectric Resonator with Band Rejection Characteristics

Piyali Chakraborty[1], Jhuna Debbarma[1], Shabana Huda[3], Utsab Banerjee[1], Anuradha Saha[2], Anirban Karmakar[1]*

[1]Corresponding Author, Electronics & Communication Engineering Department, Tripura University (A Central University), Tripura, India
[1]*anirban.ece@gmail.com (Corresponding Author)
[2]Netaji Subhash Engineering College, Kolkata, India
[3]Camellia Engineering College, Kolkata

Abstract: ***A new compact band-notched S-shaped Dielectric Resonator Antenna (DRA) for ultra wideband (UWB) applications is presented. An excellent notch band characteristic is achieved by implanting an inverted T-shaped parasitic strip on the front plane of dielectric substrate. By etching a rectangular slot on the ground plane, the width of the notch band characteristics can be controlled. The overall size of the antenna is 11×23×0.75mm³.The results obtained by measurement depict that the presented DRA achieves satisfactory radiation characteristics along with UWB impedance bandwidth of around 135% with a sufficient band rejection in the band of 5.15-5.825GHz, high radiation efficiency and nearly constant gain.***

Keywords: Ultra wideband (UWB), Band notched, Dielectric Resonator Antenna (DRA)

1. Introduction

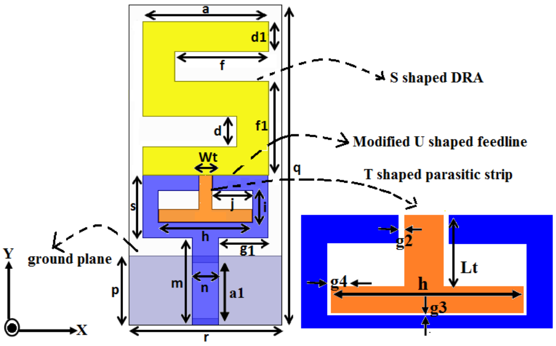
In February 14, 2002 the Federal Communication Commission (FCC) of the United States proposed the First Report and ordered the unlicensed usability of (ultra wideband) UWB technology in the frequency range between 3.1 GHz and 10.6 GHz [1].Since then, UWB communication systems have received immense attention because of remarkable advantages such as low power consumption, high data rate, low complexity, low cost etc [2-5]. Over the last two decades, Dielectric Resonator Antenna (DRA) became one of the most attractive candidate for UWB communication systems as it offers high radiation efficiency, zero conductor loss and surface wave loss, nearly constant gain, compact size and high degree of design flexibility [6-10, 19].

On the other side, some critical problems have been identified for UWB application due to the presence of electromagnetic interferences from interfering narrowband systems such as WiMAX (3.3-3.8GHz), WLAN (5.15-5.825GHz) etc [11-12]. To minimize the interference problem, several design methodologies have been proposed as like creating different slots on the ground plane [13-14], embedding different stubs [15-16] as well as embedding various kind of parasitic strip [17-18].

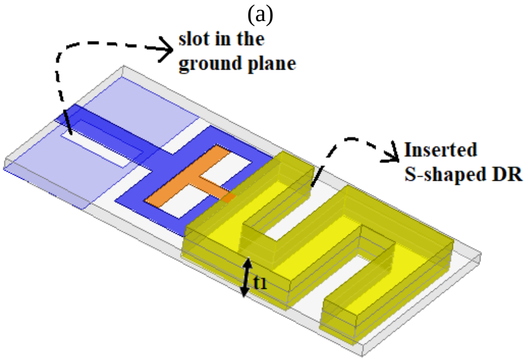
In this letter, a novel design of compact S-shaped UWB DRA with band notched characteristics is presented. By inserting S-shaped DR on a dielectric substrate UWB has been achieved. A modified U-shaped microstrip feed line has been used for wideband impedance matching. A T-shaped inverted parasitic strip along with a rectangular slotted ground plane has been implemented to achieve controllable band notch characteristics. After all, the antenna comes with a compact size of 0.132λ×0.41λ×0.06λ calculated at 3.1GHz.

2. Antenna Design

Fig. 1 represents the configuration of the proposed S-shaped DRA which is excited by a modified U-shaped microstrip feedline. The antenna is based on dielectric substrate Rogers RO3003 (11×23×0.75mm³) with relative permittivity of ε_r =3.0 and loss tangent δ =0.0013. The material used for RDR is ECCOSTOCK HiK of dielectric constant ε_r=20 and Loss tangent of tan δ=0.02. An air gap has been created by etching RDR into S-shaped DR to lower the Q factor and broaden the impedance bandwidth. A S-shaped DR has been inserted into the dielectric substrate in order to minimize the total volume of the antenna. An inverted T shaped parasitic strip is embedded on the front plane of dielectric substrate to achieve band notch characteristics at the frequency of 5.5GHz used for WLAN.A partial ground plane (5×11mm²)with rectangular slot (4×1.9mm²) has been etched at the back side of the dielectric substrate which controls the width of the band notch characteristics. Meanwhile, it should be also indicated that the proposed antenna is mechanically strong as it is not required to use any adhesive to implant S shaped DR into dielectric substrate. S shaped DR can be inserted into the dielectric substrate by using a little glue in the sides of DRA which will not affect the results. The antenna has been optimised by ANSYS HFSS version 17.



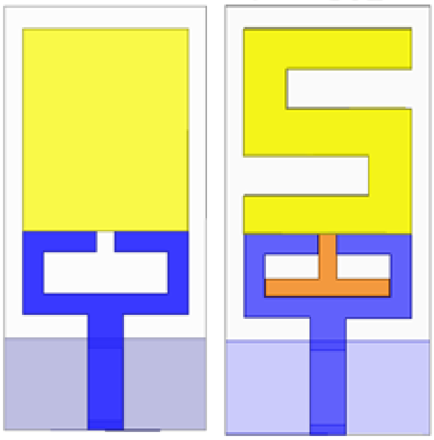
(a)



(b)

Figure 1: (a) Geometry of the proposed S-shaped DRA (b) 3D-view of the DRA.

Fig. 2 depicts the evolution of the proposed S shaped DRA. The optimised dimensions of the proposed antenna are as follows: *a*=9mm, *b*=11mm, f_1=6.7mm, d_1=2.15mm, *g1*=3.55mm, *h*=6.8mm, *i*=2.3mm, *j*=2.9mm, *m*=7mm, *n*=1.9mm, *p*=5mm, *q*=23mm, *r*=11mm, *s*=4.5mm, L_t=2.43mm, W_t=0.94mm, a_1=4mm, *t*=0.75mm, t_1=2mm, g_2=0.02mm, g_3=g_4=0.05mm.



(a) (b)

Figure 2: Evolution of the proposed UWB S shaped DRA (a) Planar RDRA (front view) (b)Inserted S shaped DRA with T shaped parasitic strip

Fig. 3 depicts the return loss characteristics of the proposed antenna with RDR and S shaped DR. It is observed that the RDR covers the frequency band of 4.4-13.5 GHz but doesn't contribute to lower part of UWB band. After introducing the S-shaped DR, bandwidth has been enhanced in the range of 3.1-15.75 GHz which is covering the band more than UWB.

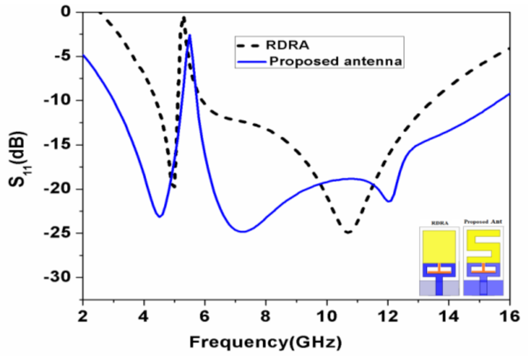


Figure 3: Simulated reflection coefficient characteristics of the RDRA and the proposed antenna.

3. Parametric Study and Key Parameters

Parametric optimizations have been performed on different structural parts of the antenna before arriving at the final structure. Basically the aspect ratio is the ratio between the thickness and the horizontal length of DR which has been calculated by using equation 1 where α is the aspect ratio, 'a' is the horizontal length of DR and t_1 is the thickness of DR:

$$\alpha = \frac{2a}{t_1^2} \approx 3.1GHz \qquad (1)$$

Here, the dimensions of 'a' and 't_1' has been chosen in a manner to get the lower end UWB band. Fig. 4 showing the effect of various lengths (a, x-axis) of S-shaped DR on S_{11} characteristics. It can be seen that as the length of S-shaped DR changes from 9mm to 10.5mm, the UWB band gets drastically deteriorated due to the reduction of the aspect ratio. From equation 1, it is also seen that by increasing the length 'a' the lower cut off frequency of UWB band gets shifted up and thus cannot contribute to UWB band. Overall, it can be observed from the analysis that the length (a) of S-shaped DR plays the role in bandwidth performance and the dimension of 'a' has chosen as 9mm to get the UWB band.

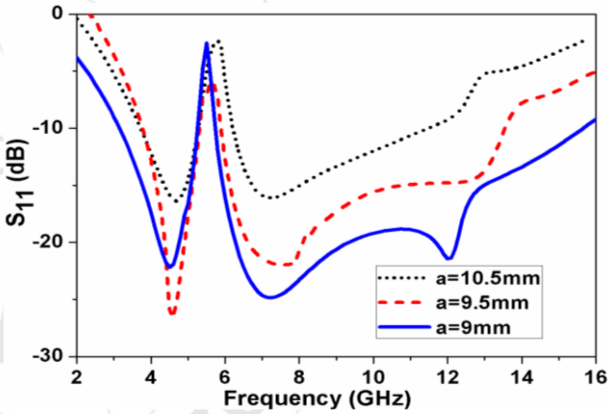


Figure 4: Simulated reflection coefficient for various horizontal length (a) of S shaped DR

To achieve controllable band notch characteristics, an inverted 'T' shaped strip has been implemented below the DR. The overall length of T shaped parasitic strip represents the quarter of the wavelength at notch frequency as depicted by using equation 2:

$$T_{strip} = h + L_t \approx \frac{\lambda_{notch}}{4} \qquad (2)$$

Where, T_{strip} is the T shaped parasitic strip, '*h'* is the horizontal length and L_t is the vertical length of T shaped parasitic strip, λ_{notch} is the wavelength of notched resonant frequency. Fig. 5illustrates the effect of varying the length of '*h*' on S_{11} characteristics which intern varies the overall length of T-shaped strip. It is observed that by increasing the length of 'h' from 5.8mm to 6.8mm, the centre of the notch frequency band gets shifted up from 5.5GHz to 6.5GHz.The notched frequency can be calculated as follows:

$$f_{notch} = \frac{c}{\lambda_{notch}\sqrt{\varepsilon_{eff}}} \approx 5.5GHz \qquad (3)$$

where f_{notch} is the notched resonant frequency, *c* is the speed of light, ε_{eff} is the effective relative permittivity.

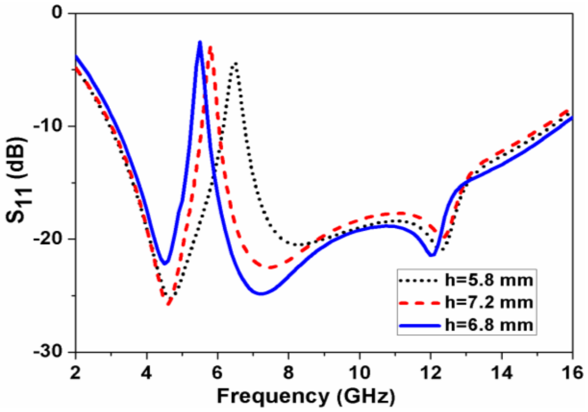


Figure 5: Simulated reflection coefficient for various length (h) of T-shaped parasitic strip

As it will be essential to control the width of band rejection, the rectangular slot on the ground plane has been implemented which can control the width of band rejection feature, so it is became necessary to carry out parametric study by implementing the effect of various lengths of rectangular slot (a_1) as depicted in Fig. 6.From the figure, it can be noticed that by increasing the length of rectangular slot (a_1) from 4mm to 5.2mm, the width of the band notched characteristics is decreased due to electromagnetic coupling.

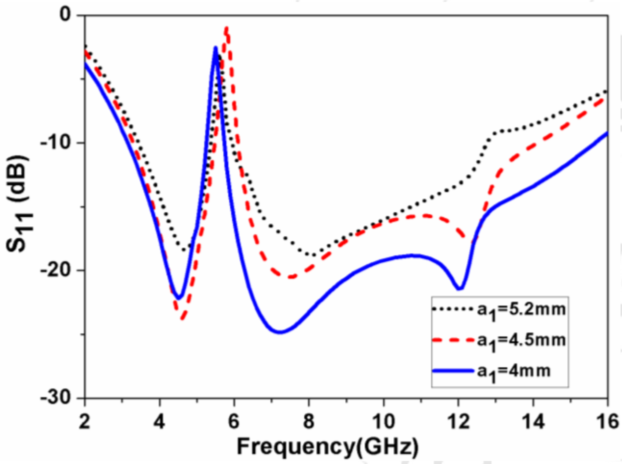


Figure 6: Simulated reflection coefficient for various lengths (a_1) of rectangular slot etched on the ground plane

4. Results and Discussions

Fig. 7 depicts the measured and simulated return loss characteristics of the antenna. The antenna covers UWB bandwidth and beyond (below-10dB) from 3.1GHz-15.75GHz or 135%. Moreover, the simulated and measured S_{11} characteristics of the proposed S shaped DRA have been compared to reasonable agreement though some mismatching may be there due to fabrication error and SMA connector losses.

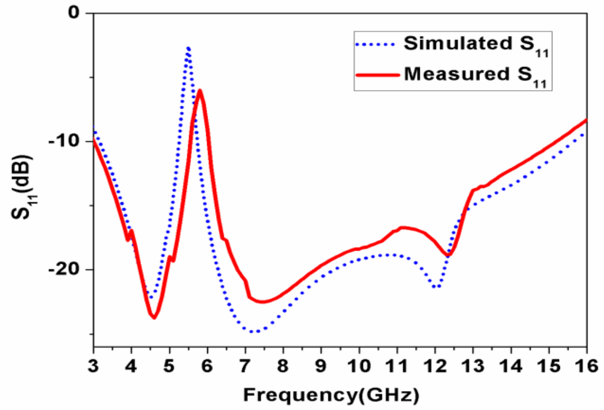


Figure 7: Measured and simulated reflection coefficient characteristics of the proposed antenna.

The simulated electric field distribution in both Rectangular Dielectric Resonator (RDR) and S shaped Dielectric Resonator at4.5GHz and 12.5GHz is shown in Fig. 8 (a-d) respectively. Since, the resonant frequency of each of the modes present inside S shaped DR will be a function of its optimised dimensions. Hence, the dimensional parameters of S-shaped DR are optimized based on different types of modes. Fig. 8 (a) demonstrates $TE^{z}_{11\delta}$ mode inside RDR. From Fig. 8 (a), it is observed that there are some disordered lower order electric field distribution concentrates mainly at the bottom of RDR that could deteriorate the radiation patterns. Hence, S-shaped DR has been introduced in order to get well structured electric field distribution that can make a balanced E-field distribution. From Fig. 8 (b), it is clearly noticed that the bottom portion of S shaped DR has strong well structured electric field distribution at 4.5GHz which helps to improve the balanced E-plane cut. As shown in Fig. 8 (c), it is also observed that there are some deformed higher order electric field distribution in RDR that could drastically affect the radiation characteristics. So, in order to eliminate disordered higher order mode at high frequency, two air gaps has been introduced by giving S-shape thus to make a balanced E-field distribution at higher frequency. Fig. 8 (d) represents $TE^{z}_{22\delta}$ mode inside S-shaped DR where E-field concentrates more at the bottom and centre part. As a consequence, the overall radiation characteristic of the antenna is mostly Omni-directional but due to the asymmetrical S-shaped structure, the radiation characteristics get slightly asymmetric.

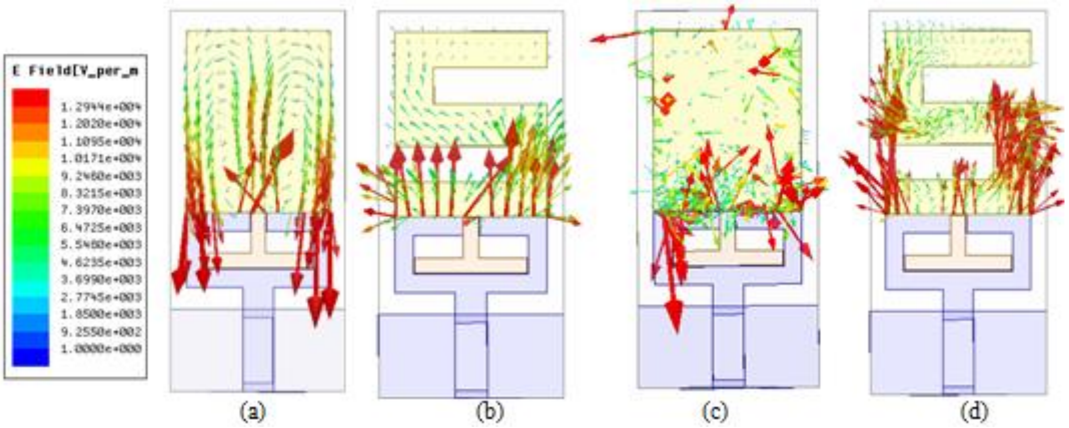


Figure 8: Electric field distribution inside (a)RDR at 4.5GHz (b)S-shaped DR at 4.5GHz (c)RDR at 12.5GHz (d)S-shaped DR at 12.5GHz

Fig. 9 demonstrates the E-field distribution on T-shaped parasitic strip at the notched frequency of 5.5GHz.It is clearly seen that the density of E-field concentrates mainly on T shaped parasitic strip at 5.5GHz.This circumstance has been raised due to the radiated power reduction across the notched frequency of 5.5GHz by encapsulating electromagnetic wave.

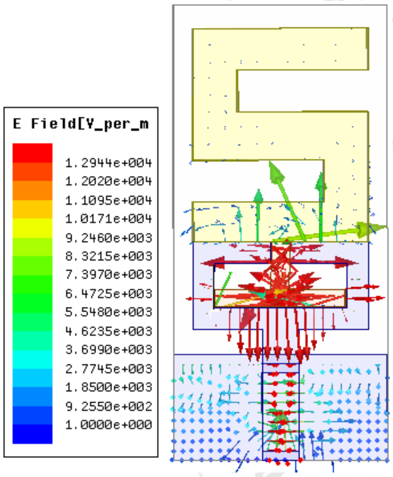
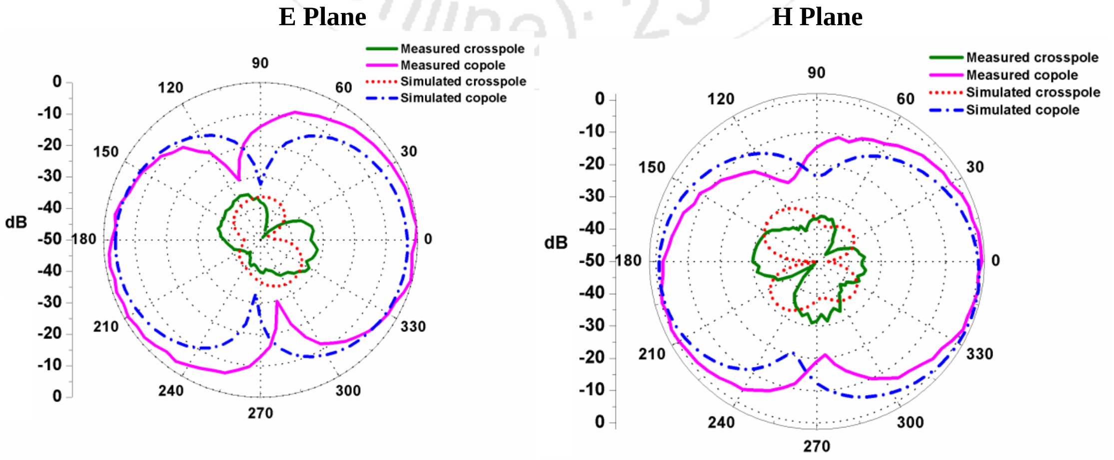
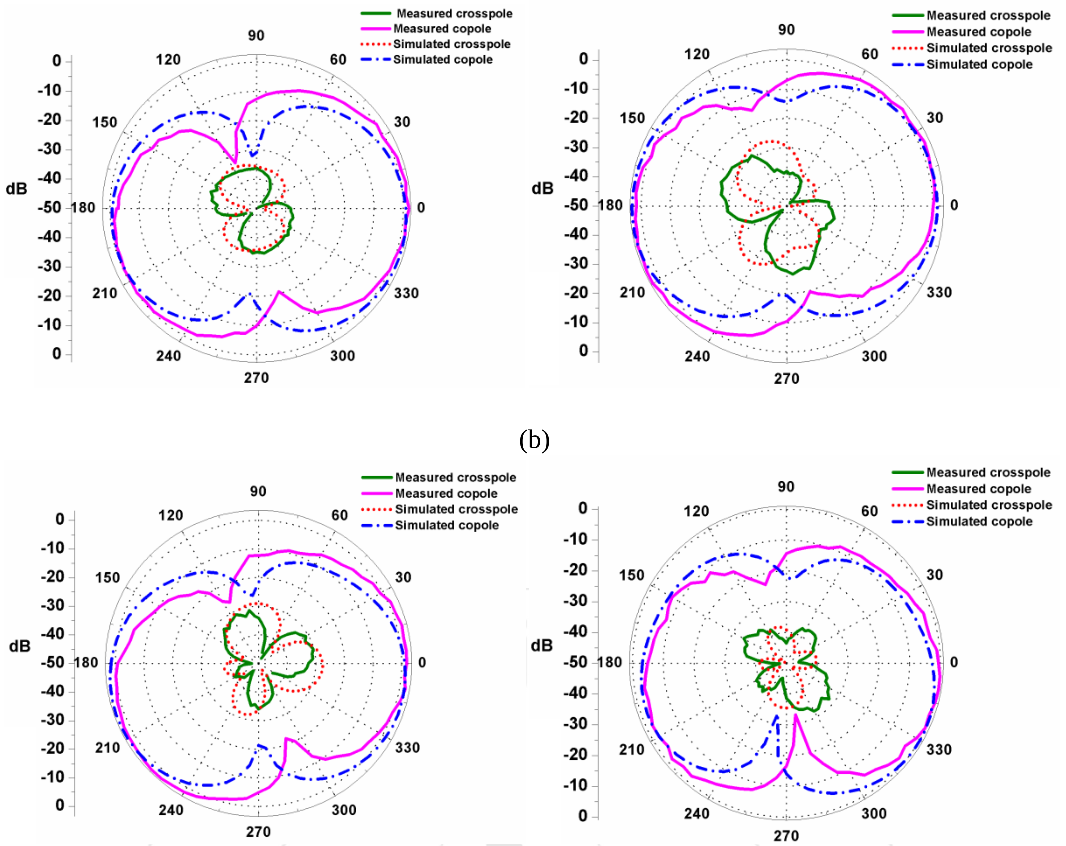


Figure 9: Electric field distribution of the proposed antenna at notched frequency of 5.5GHz

Fig. 10 represents the simulated as well as measured normalised H-plane (xz) and E-plane (yz) radiation characteristics of the antenna at three different resonant frequencies of 4.5GHz, 7.2GHz and 12.5GHz respectively. It is observed that the presented S-shaped DRA provides consistency of the eight shape omni-directional patterns in the E-plane, whereas H-plane shows the omni-directional patterns with low cross polarization level. Moreover, it is seen that the radiation characteristics is mostly omni-directional over the entire frequency band but due to the asymmetrical S-shaped structure, slight distortion is observed.



(a)



(b)

(c)

Figure 10: Simulated and measured far-field radiation patterns; E-plane (*yz*) and right H-plane (*xz*) at (a) 4.5GHz (b) 7.2GHz and (c) 12.5GHz

Fig. 11 represents the measured gain and radiation efficiency of the DRA. It is seen that the proposed antenna achieves more than 90% efficiency within the whole band. From the measured results, it is seen that the overall gain appears more than 3dBi over the entire operating band. Furthermore, it is also identified that the gain and radiation efficiency have drastically decreased across the notch band at 5.5GHz.

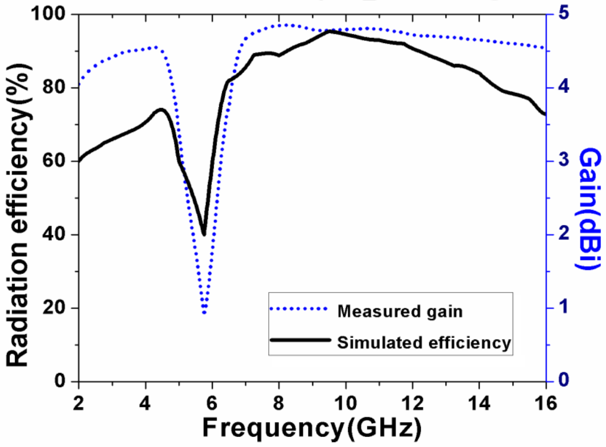


Figure 11: Simulated radiation efficiency and measured gain of the proposed antenna

Table I represents the comparison of the proposed DRA with other related antennas. It is noticed that in ref [7, 9], the size of the antenna is larger with impedance bandwidth lower than the proposed antenna. Similarly, after comparing the size and impedance bandwidth of ref [10] and ref [19], it is observed that the proposed UWB DRA is compact in size and achieves impedance bandwidth of 135 % (3.1-15.75GHz) which creates novelty.

Table 1: A comparison of the proposed antenna with other related references

References	Size (mm^2)	S_{11} bandwidth
[7]	50×44	3.1-10.6 GHz
[9]	18×36	3.14-10.9GHz
[10]	15×33	3.1-10.6GHz
[19]	100×100	5.6-11.5GHz
Proposed Antenna	11×23	3.1-15.75GHz

5. Conclusions

A novel compact S shaped UWB DRA with band notch characteristic is presented. The proposed antenna consists of an inserted S shaped DR excited by modified U shaped microstrip feedline, a partial rectangular slotted ground plane etched at the back side of the dielectric substrate and an inverted T shaped parasitic strip to achieve wideband characteristics which covers the UWB band from 3.1GHz to 15.75GHz along with band notch characteristics for WLAN band (5.15GHz-5.825GHz). Moreover, the measured and simulated results of the compact S shaped DR verifies their predicted performance characteristics including Omni directional radiation patterns, band notch characteristics at 5.5GHz for WLAN band, high radiation efficiency of more than 90% and nearly constant gain which is more than 3.5dBi over the desired frequency band. Hence this antenna can be considered to be a potential candidate for modern wireless communication systems.

6. Acknowledgement

This work has been supported by ‘UGC BSR Start Up Grant No. F.30-376/2017 (BSR)’.

References

[1] E. G. Lim, Z. Wang, C.-U. Lei, Y. Wang, and K. Man, “Ultra wideband antennas—Past and present, ” *IAENG Int. J. Comput. Sci.*, vol. 37, pp. 304–314, 2010.

[2] L. Jianxin, C. C. Chiau, X. Chen, and C. G. Parini, “Study of a printed circular disc monopole antenna for UWB systems, ” *IEEE Transactions on Antennas and Propagation*., vol. 53, no. 11, pp. 3500–3504, Nov. 2005.

[3] L Z. N. Chen, T. S. P. See, and X. Qing, “Small printed ultra wideband antenna with reduced ground plane effect,” *IEEE Transactions on Antennas* and *Propagation*, vol. 55, no. 2, pp. 383–388, Feb. 2007.

[4] Al-Husseini, M., L. Safatly, A. Ramadan, A. El-Hajj, K. Y. Kabalan, and C. G. Christodoulou, “Reconfigurable Filter antennas for pulse adaptation in UWB cognitive radio systems, " *Progress In Electromagnetics Research B*, Vol. 37, 327-342, 2012.

[5] Wei Tong, and Z. R. Hu, “A CWP fed circular monopole antenna for ultra wideband wireless communications”, *IEEE Antennas and propagation Society International Symposium* vol. 3A, pp.528-531, 2005.

[6] X. S. Fang and K. W. Leung, “Designs of Single, Dual Wideband Dielectric Resonator Antenna” *IEEE Transactions on Antennas and Propagation*, Vol.59, No.6, pp. 2409-2414. 2011.

[7] M. Y. Abou Shahine, M. Al-Husseini, K. Y. Kabalan, and A. El-Hajj, “An Ultra-wideband Dielectric Resonator Antenna with Reconfigurable Band Rejection”, *PIERS Proceedings*, Moscow, Russia, August 19-23, pp.534-537, 2012.

[8] T.A. Denidni Z. Weng, “Hybrid UltraWideband Dielectric Resonator Antenna and Band Notch Designs”, *IET Microwaves, Antennas & Propagation*, Vol 5, pp 450-458, 2011.

[9] M. Abedian, S. K. A. Rahim, and M. Khalily, “Two-Segments Compact Dielectric Resonator Antenna for UWB Applications”, *IEEE Antennas and Wireless Propagation Letters*, Vol.11, pp.1533-1536, 2012.

[10] Kenny Seungwoo Ryu and Ahmed A. Kishk, “UWB Dielectric Resonator Antenna Having Consistent Omnidirectional Pattern and Low Cross-Polarization Characteristics”, *IEEE Transactions on Antennas and Propagation*, Vol.59, No.4, 2011.

[11] Thomas Hansen, Frank Hofmannand Robert Bosch GmbH; “Automotive Multi and Broadband Monopole Antenna for GSM, WLAN and UWB Applications”, *IEEE International conference on Ultra Wideband*, vol.2, pp.219-222, 2008.

[12] Bappadittya Roy, Ankan Bhattacharya, A.K. Bhattacharjee, S.K.Chowdhury, “An UWB Monopole Antenna for WLAN and WiMAX Applications”, *9th International conference on Industrial and Information systems*, pp:1-3, 2014.

[13] W.-S. Lee, D.-Z. Kim, K.-J. Kim, and J.-W. Yu, “Wideband planar monopole antennas with dual band-notched characteristics,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 6, pp. 2800–2806, Jun. 2006.

[14] A. Nouri , 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.

[15] M. S. Ellis, Z. Zhao, J. Wu, Z. Nie, and Q.-H. Liu, “A novel miniature band-notched wing-shaped monopole ultra wideband antenna,” *IEEE Antennas Wireless Propagation Letter*, vol. 12, pp. 1614–1617, 2013.

[16] J.Wang, Y. Yin, X. Liu and T.Wang, “Trapezoid UWB antenna with dual band-notched characteristics for WiMAX/WLAN bands,” *Electronics. Letters*, vol. 49, no. 11, pp. 685–686, May 23, 2013.

[17] Ki-Hak Kim and Seong-Ook Park, “Analysis of the Small Band-Rejected Antenna with the Parasitic Strip for UWB”, *IEEE Transactions on Antennas and Propagation*, Vol.54, pp.1688-1692, 2006.

[18] A. M. Abbosh and M. E. Bialkowski, “Design of UWB Planar Band-Notched Antenna Using Parasitic Elements”, IEEE Transactions on Antennas and Propagation, Vol.57, pp.796-799, 2009.

[19] Kui-Sheng Feng, Na Li, Si-Jia Li, Xiang Yu Cao, Jun Gao, Tong Li, “Modified Ultra Wideband Hybrid Monopole Dielectric Resonator Antenna”, 2017 Sixth Asia-Pacific Conference on Antennas and Propagation (APCAP), 26th July, 2018, China.