

On the Design of UWB Circular Fractal Antenna with Notched-Band Characteristics Using W-shape Slot

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Abstract - This paper presents the design of notched-band antenna with CPW - feed. The notched - band has been achieved by using the W-shape slot in ground plane. The antenna has been simulated using a 3D - Electromagnetic simulator. The experimental results of proposed antenna exhibit ultra wideband characteristics from 2.0 - 15.0 GHz except the notched-band frequency from 5.0 - 6.0 GHz. The slot is optimized with respect to width, length and position for a detailed study of notched-band characteristics. It is observed that the centre frequency and bandwidth of notched-band depend on the length and width of slot respectively. The experimental radiation patterns of this antenna are omnidirectional in H-plane and bidirectional in E-plane. This antenna can be useful for UWB system, medical imaging and vehicular radar.

Index Terms- Monopole antenna, Fractal Geometry, UWB antenna, Notch-band, CPW - feed and UWB system

I. INTRODUCTION

With the release of the 3.1 – 10.6 GHz band for ultra-wideband (UWB) operation, a variety of typical UWB applications evolved are indoor/outdoor communication systems, ground penetrating and vehicular radars, wall and through-wall imaging, medical imaging and surveillance. Many future modern UWB communication systems will be utilized to transmit /receive the high data rate with low power consumption at short range communication [1-2]. Therefore, the realization of UWB antennas in planar technologies with small size is the primary requirement. The antenna should have omnidirectional radiation patterns throughout the band. In UWB operating band, the WLAN signal is also present which interferes the UWB signal. To stop the interference by external WLAN signal (5.0 to 6.0 GHz), a band notched filter is required. Using a band notched filter separately along with antenna increases the system size as well as system complexity. To overcome this complexity, many researchers have reported antennas with notched-band characteristics using various shapes of slots in ground plane, feed line and on the radiating patch [3-10]. The most common technique in open literature is a slot loading in the radiation patch [3–5]. This gives poor cross-polarization characteristics because the distribution of surface electricity is changed. Other designing methods

include incorporating a L-shaped slits in the ground plane to achieve notched-band function [6-8]. Beside these methods, another method is to design a resonant circuit on the feed line [9, 10]. The L-shape slot reported in [6-8] is large in size. There is a need to have a compact slot in size. This paper reports the compact W-shape slot in ground to achieve the notched-band characteristic.

Several researchers have also reported the UWB characteristics of antenna using fractal geometry. Fractal geometry is useful for size reduction and good impedance matching throughout the band. Some researchers have reported the UWB fractal antenna with CPW - feed [10-13]. Fractal geometry in monopole antennas with CPW - feed offers the advantages of compactness, UWB characteristics throughout the band, good radiation pattern and low dispersion.

In this article, a new UWB fractal antenna with notched-band characteristics is presented. The notched-band characteristic is achieved by cutting a W-shape slot in ground plane. This antenna is simple, easy to fabricate and integrate with MIC/MMICs devices. The notched-band characteristic is experimentally validated and simulated with respect to various parameters of the slot in the ground plane.

This paper has been divided into six sections. In Section – I, the introductory part of article is discussed. The second section of the paper describes the antenna geometry and slot in ground plane responsible for notched-band characteristics. In Section – III, the approximate design expressions for notched-band frequency is given. The Section – IV concentrates on the parametric analysis of slot dimensions responsible for notched-band characteristics. The section – V discusses the experimental and simulated results of antenna with and without notched-band and in last section the conclusions of the article is given.

II. ANTENNA GEOMETRY

The monopole antenna with CPW - feed is convenient to integrate with MIC/MMICs circuits. The fractal antenna with CPW – feed is advantageous to achieve the UWB characteristic without any additional matching circuitry. This paper proposes a new fractal antenna to achieve UWB characteristics. The geometry of proposed fractal antenna has been constructed inside the circular disc of 30 mm diameter with metallization thickness of 0.1 mm with the centre as origin (0,0). This is called zeroth iteration. The 1st iterative structure has been constructed by creating 10 different triangles. First triangle with side length of 16.63 mm is made inside the circular disc. This triangle is moved along coordinate (-4.5 mm, 2.76 mm). The second triangle of side length 18.72 mm is made and rotated by an angle 40°. This triangle is moved along (-3.5 mm, -2.1 mm) coordinate. The third triangle with side length of 16.64 mm is rotated by 65° and moved along (-0.7 mm, -6.2 mm) coordinate. The fourth triangle with side length of 18.02 mm is rotated by 90° and moved along (3.3 mm, 5.1 mm) coordinate. The fifth triangle with side length of 10.1 mm is rotated by an angle 76° and

moved along (5.79 mm, 8.75 mm) coordinate. The sixth triangle with side length of 16.64 mm is rotated by an angle 90° and moved along (-0.7 mm, 5.7 mm) coordinate. The seventh triangle with side length of 18.02 mm is rotated by an angle 110° and moved along (3.7 mm, -5.2 mm) coordinated. The eighth triangle with side length of 10.1 mm is rotated by an angle 106° and moved along (6.15 mm, -8.4 mm) coordinate. Similarly, ninth & tenth triangles each of side length of 7.348 mm are rotated by an angle 100° and are moved along (9.15 mm, -7.75 mm) and (9 mm, 7.8mm) coordinate respectively. After placing these triangles, the geometry is obtained as shown in Figure 1 (a). Then these triangles are united and subtracted from the circular disc of 30 mm diameter. Now, one more circular disc with diameter of 23.4 mm and metallization thickness of 0.1 mm is made with centre at -3.3 mm as shown in Figure 1(b). Then this circular disc is subtracted as shown in Figure 1(c). This geometry is fed by CPW - feed. This is called 1st iteration as shown in Figure 1(d).

In 2nd iteration, geometry of 1st iterative structure is scaled down by a factor of 0.79, copied in a circle of 23.4 mm diameter with centre at (0,-3.3mm) and subtracted. We get the geometry similar to first iterative geometry but smaller in size. This geometry is made to intersect with the original circle near the feed line. This is called second iteration. In 3rd iteration, the second iterative fractal geometry is copied and scaled down with factor of 0.8. This geometry is copied in the circle of 18.72 mm diameter with centre (0, -5.64mm). This copied geometry is made to intersect at the original circle near feed line. In 4th iteration, the third iterative fractal geometry is copied and scaled down by factor of 0.495. This geometry is copied in circle of 9.2664 mm with centre at (0, -10.3668 mm) and subtracted from circular disc. This geometry is made to intersect with the original circle near feed line in similar manner as earlier. This is the final proposed fractal antenna with optimized dimensions as shown in Figure 2a.

The W-shape slot is created in the ground plane on both sides of the feed line as shown in Figure 2a. The dimensions of the W-shape slot are shown in Figure 2b separately to have the clarity in dimensional. The W-shape slot is made 2.516 mm away from ground edge at feed side. The total angle of the W-shape slot has been taken as 75 degree. One side of the W-shape slot cuts the upper edge of ground plane. Another side of W-shape slot is at 0.516 mm below the upper edge of ground plane. The total length of the slot cut in ground plane is 9.0 mm.

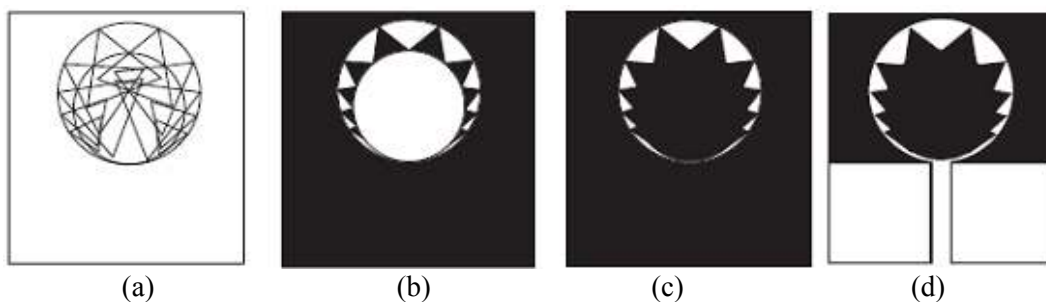


Fig. 1. Basic Geometry of the proposed antenna

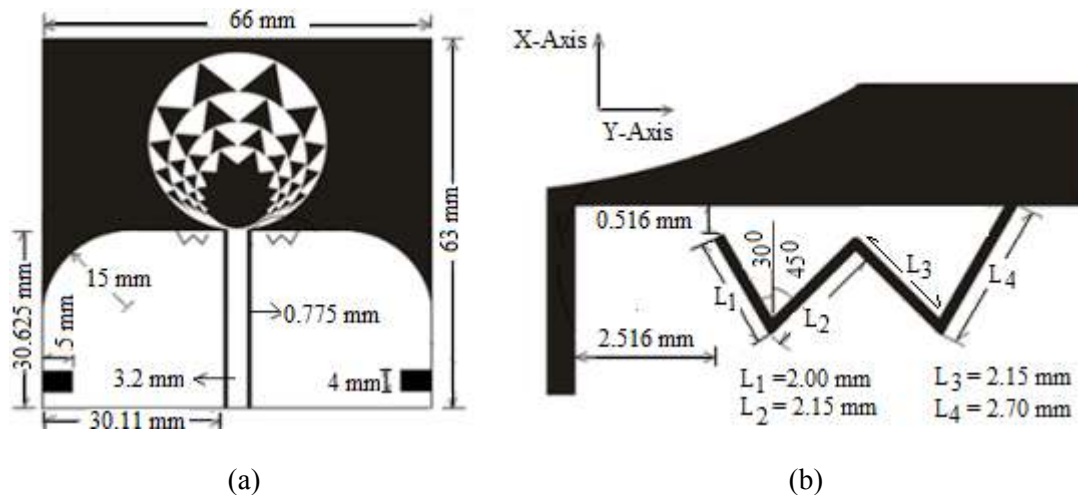


Fig. 2 a) Proposed fractal antenna with optimized dimensions, b) Slot dimensions

III. DESIGN EXPRESSIONS

The notched – band has been created by cutting the slots in the ground plane. A W- shape slot is chosen to be the slot cut on both sides of the ground plane with its dimensions optimized systematically on HFSS simulation software. The optimized dimensions are slot width $w = 0.21$ mm and length of the slot $L = 9.0$ mm. These dimensions provide exact notched-band characteristics from 5.0 GHz to 6.0 GHz. The formulation for the calculation of notched-band centre frequency (f_{notch}) can be as follows:

$$V_p = f_{notch} \times \lambda = \frac{c}{(\epsilon_{eff})^{1/2}} \quad (1)$$

Where V_p = phase velocity

$$\epsilon_{eff} = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2} \times \left(1 + \frac{4b}{w}\right)$$

ϵ_r = relative permittivity of the substrate

b = thickness of the substrate

w = width of the notch

ϵ_{eff} = effective permittivity of the substrate

The total length of the slot is equal to $L_{notch} = L_1 + L_2 + L_3 + L_4$, where $L_1 = 2.0$ mm, $L_2 = 2.15$ mm, $L_3 = 2.15$ mm and $L_4 = 2.70$ mm. Therefore, total length is $L = 9.0$ mm. Since the slot is cut through the ground at upper edge at one end and other end in the ground plane. We consider it is to be open circuited at one end and short circuited at the other. The resultant length of slot is equal to $\lambda/4$ at notched center frequency. So, length of the slot i.e. $L_{notch} = \lambda/4$. This can be substituted in equation (1);

$$f_{notch} = \frac{c}{4} \times L_{notch} \times (\epsilon_{eff})^{1/2} \quad (2)$$

This expression can be used for calculating the rough slot length of slot in ground plane. This estimated length is optimized using 3D - Electromagnetic software. This antenna with notched-band characteristic has been designed on FR4 substrate of dielectric constant $\epsilon_r = 4.3$ and thickness of substrate $h = 1.53$ mm.

IV. PARAMETRIC STUDY OF SLOT

The parametric study of slot in ground for creating the notched-band characteristic has been carried out using HFSS software. The W-shape slot width, length and its position are the critical parameters to achieve the required notched - band characteristics. This is because, current distribution is stronger at notched-band centre frequency 5.5 GHz. The current distribution on the W-shape slot antenna is shown at frequencies 3.5 GHz and 5.5 GHz in Figure 3. It is seen that the current density is stronger around slot at frequency 5.5 GHz i.e. at band-notched centre frequency. The current density is negligible at other than the notched - band frequency i.e. at 3.5 GHz as shown in Figure 3. Due to stronger current density at frequency 5.5 GHz around W-shape slot, the W- shape slot length, width and position affect the notched - band characteristics. The proposed antenna has been optimized for the notched - band from 5.0 – 6.0 GHz. The proposed antenna with optimized dimension is shown in Figure 2.

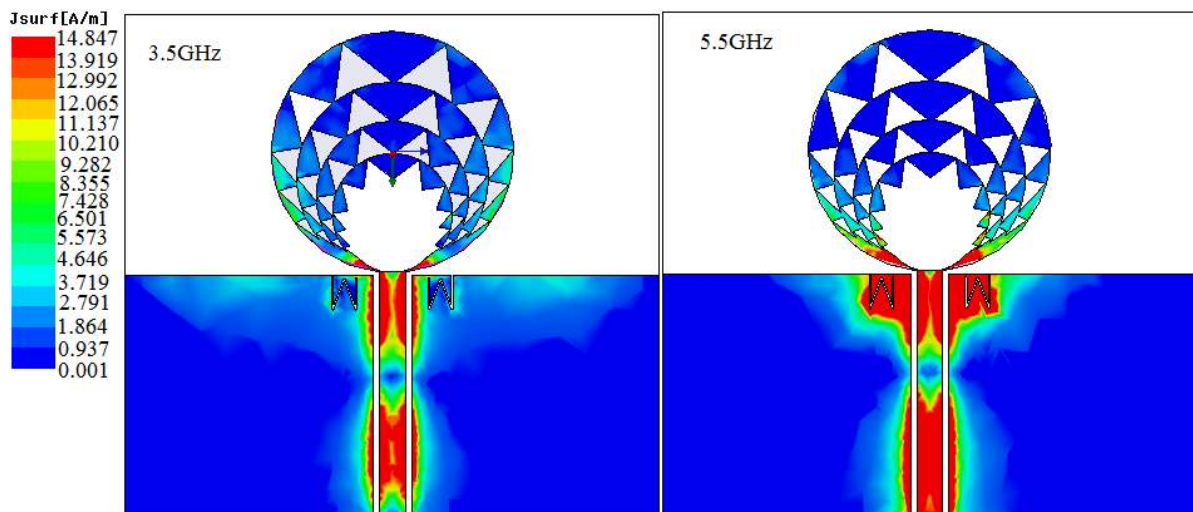


Fig. 3. Current distribution on proposed antenna at 3.5 GHz and 5.5 GHz

A. Effect of W - Shape Slot Length

The proposed antenna has been simulated with respect to various lengths of W - shape slot. The total length of slot L is varied with a step of 0.5 mm. The simulated results of various slot length are shown in Figure 4. It is observed from the simulated results as the total length of the slot increases the centre frequency of the notched - band shifted towards lower frequency side. It is also observed, as the

length of W - shape slot increases, the band width of notched - band remains unaffected. The centre frequency of notched-band is observed at 5.6 GHz for 9.0 mm slot length, 5.3 GHz for 9.5 mm slot length, 5.1 GHz for 10.0 mm slot length, and 4.5 GHz for 11.0 mm slot length respectively.

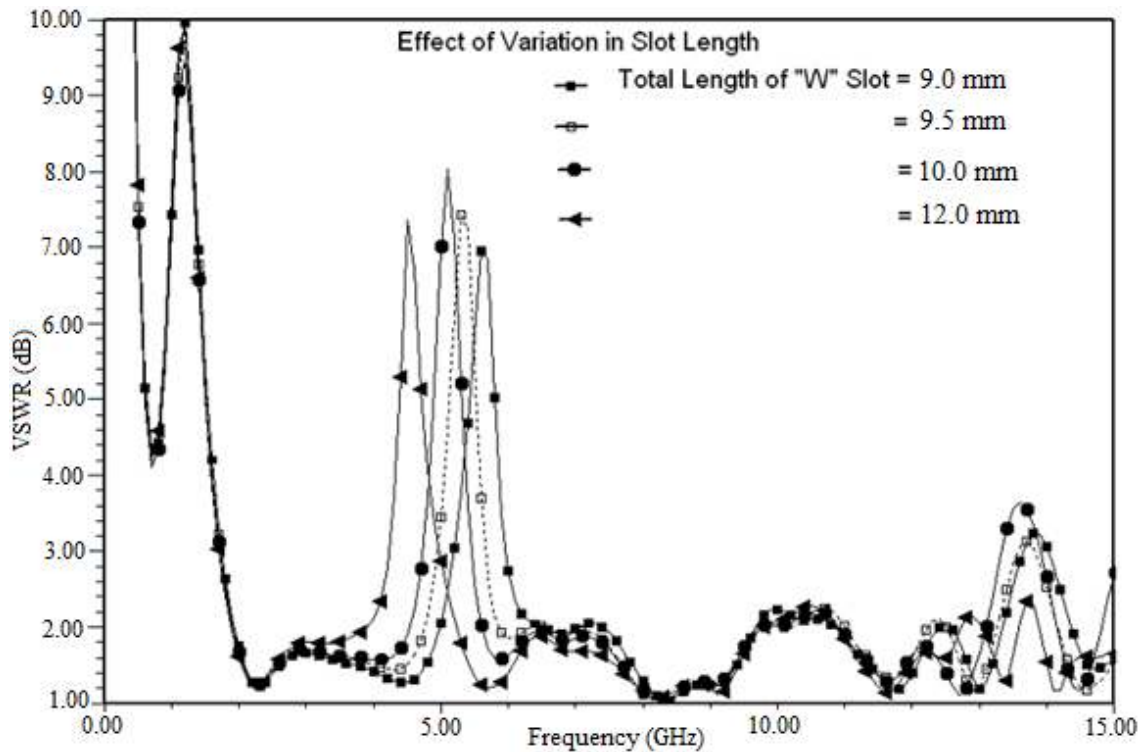


Fig. 4. Simulated results of proposed antenna with respect to various length of slot

B. Effect of W - Shape Slot Width

The proposed antenna has also been simulated with respect to various width of the W – shape slot. The length of the slot $L = 9.0$ mm and other optimized parameters are kept constant. The simulated results of various values of slot width i.e. 0.16 mm, 0.21 mm, 0.31 mm and 0.46 mm are shown in Figure 5. It is observed for the narrow slot width, that the notched-band bandwidth is narrow. As the slot width increases, the notched bandwidth also increases. It is because the wide slot offers a low impedance and narrow slot offers the high impedance at notched-band frequency. The simulated notched-band bandwidth at VSWR 2 for 0.16 mm, 0.21 mm, 0.31 mm, 0.46 mm slots width is around 0.72 GHz, 0.95 GHz, 1.05 GHz and 1.25 GHz respectively.

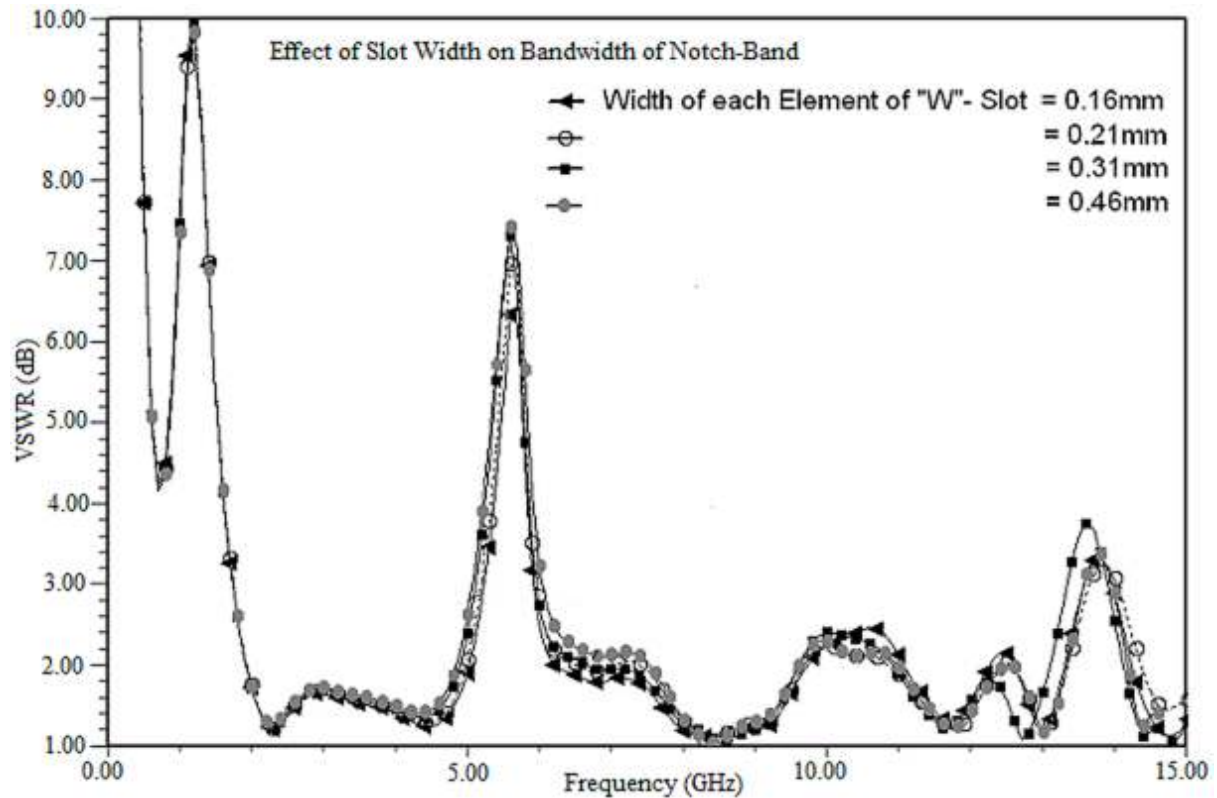


Fig. 5. Simulated results of proposed antenna with respect to various width of slot

C. Effect of Position of Slot

The proposed antenna is also been simulated for various positions of slot. The original position of the slot is 2.516 mm from ground edge at feed side. The proposed antenna has been simulated for the position of slot i.e. 0.516 mm, 2.516 mm, 3.516 mm, 4.516 mm 6.516 mm and 8.516 mm away from feed side with respect to its original position. As the position of the W – shape slot is shifted away from the feed side, the VSWR at the notched-band reduces. This is because the current density reduces around the slot as it is shifted away from feed side. The simulated VSWR with respect to original position of slot 0.516 mm, 2.516 mm, 3.516 mm, 4.516 mm and 6.516 mm are 10.0345, 8.1526, 6.0679, 4.7352, 3.4131 and 3.0928 respectively. These simulated results are shown in Figure 6. It is also observed, as the W-shape slot is shifted away from the feed side, the notched bandwidth also decreases. The simulated notched-band bandwidth is observed around 1.25 GHz for 0.516 mm slot position, 1.05 GHz for 2.516 mm slot position, 0.95 GHz for 3.516 mm slot position, 0.85 GHz for 4.516 mm slot position, 0.7 GHz for 6.516 mm slot position, and 0.6 GHz for 8.516 mm slot position.

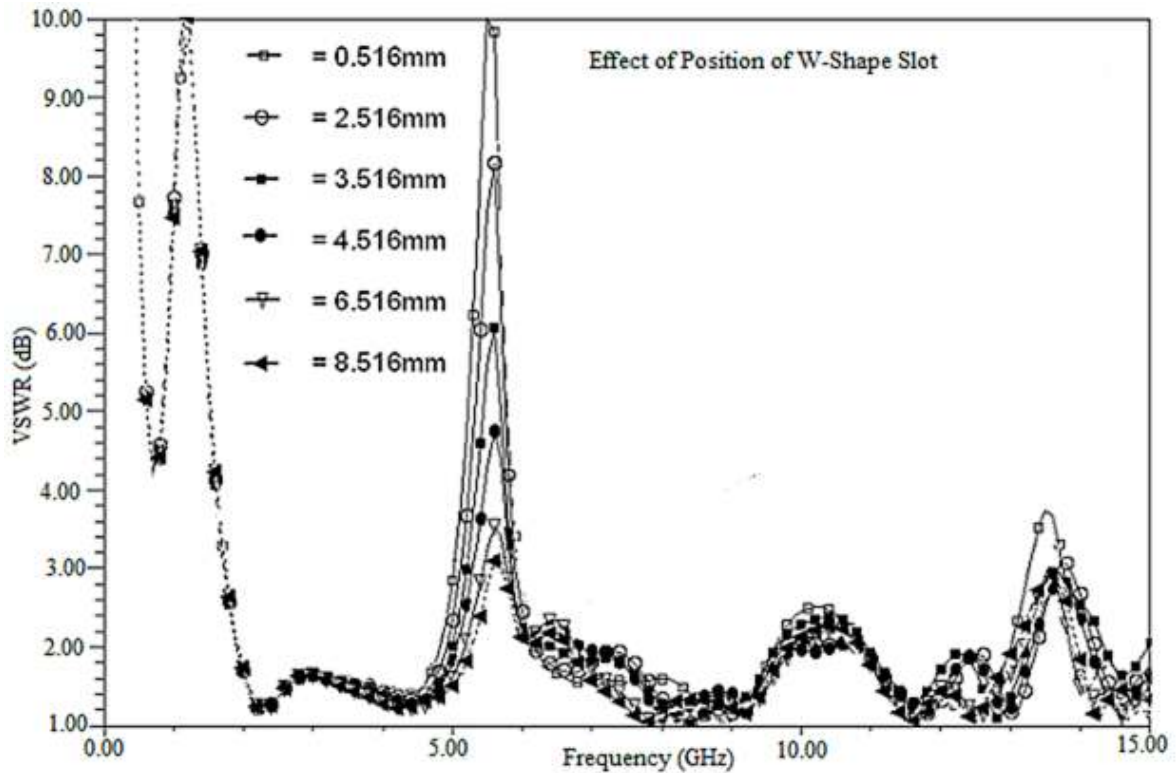


Fig. 6. Simulated results of proposed antenna with respect to various position of slot

V. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed fractal antenna has been fabricated with and without W - shape slot with optimized dimensions. The W - shape slot in ground plane is optimized to create the notched-band with dimensions 9.0 mm slot length, 0.21 mm slot width and 2.516 mm slot position from feed side. The VSWR is improved without notched-band by optimizing the curvature of ground plane with 15 mm radius and by putting two slot of 4 mm x 5 mm in ground plane at both side. The other optimized dimensions are feed width 3.2 mm, gap between ground and feed 0.775 mm, gap between patch and ground 0.5 mm. The both fractal antennas with and without notched-band are fabricated and tested using R & S ZVA40 vector network analyzer. The experimental results acquired from vector network analyzer exhibit the UWB characteristics. The measured results of the proposed antennas with and without notched-band are compared as shown in Figure 7. It is observed that antenna offers the UWB characteristic from 2.0 GHz to 15.0 GHz except the notched-band frequency 5.0 to 6.0 GHz. This bandwidth of proposed antenna is beyond the FCC defined band.

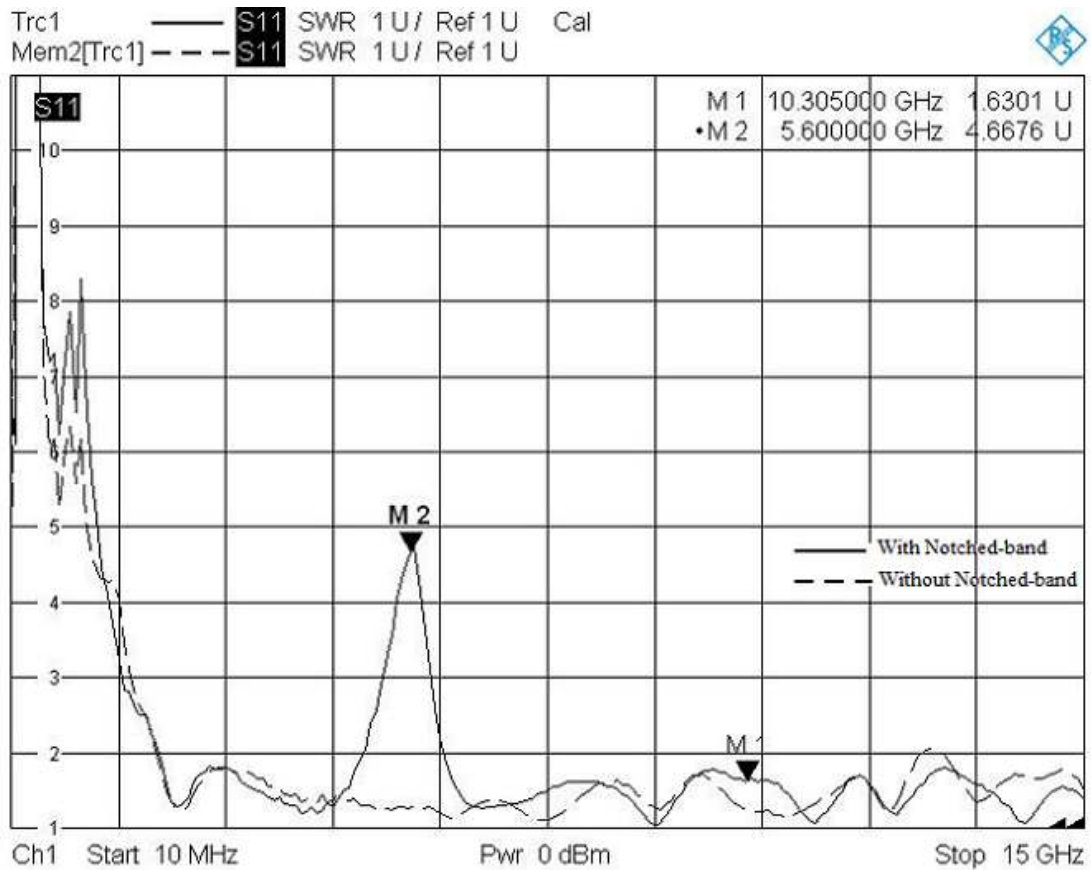


Fig. 7. Experimental VSWR of Proposed fractal antenna with and without notch

The radiation patterns of proposed antenna have been measured in the anechoic chamber at selective frequencies. The H-plane radiation patterns of this UWB antenna are measured at 3.0 GHz, 5.0 GHz, 6.15 GHz and 9.975 GHz as shown in Figure 8. Similarly, the E-plane radiation patterns of this UWB fractal antenna are measured at 6.25 GHz and 8.175 GHz as shown in Figure 9. The nature of the radiation patterns are omni-directional in H-plane and bidirectional in E-plane. It is also observed, as the frequency increases, the radiation patterns slightly varies which may be due to edge reflection, fractal geometry and high loss tangent of substrate.

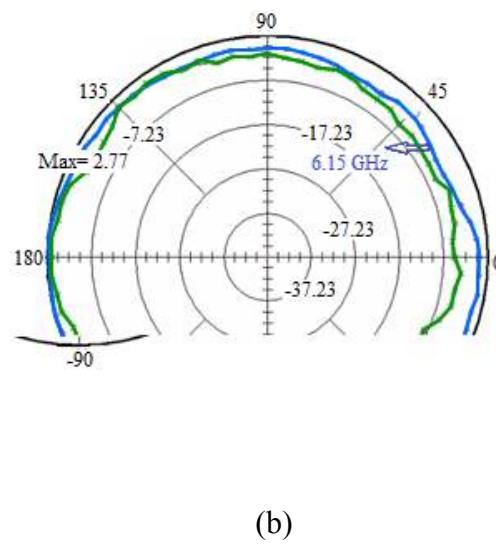
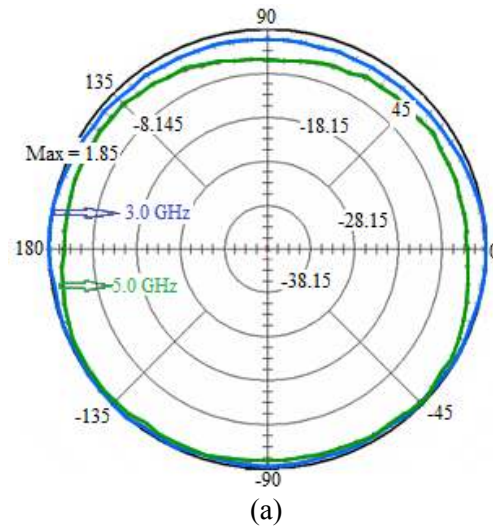


Fig. 8. Experimental H-plane radiation patterns measured at 3.0 GHz, 5.0 GHz, 6.15 GHz and 9.975 GHz

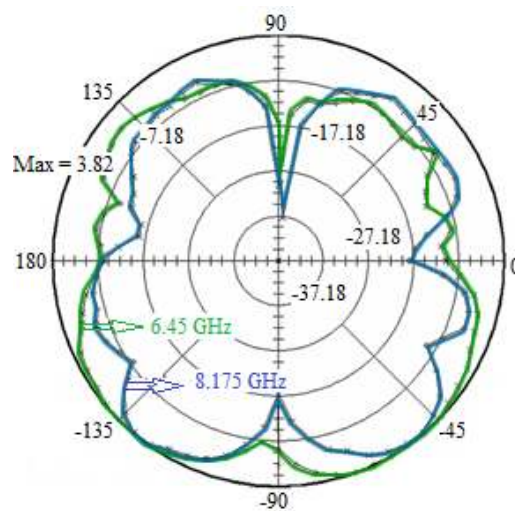


Fig. 9. Experimental E-plane radiation patterns measured at 6.45 and 8.175 GHz

The gain and radiation efficiency of the proposed antenna have also been calculated and tabulated in table 1. It is revealed from tabulated results that the gain and radiation efficiency drop drastically at notched-band frequency. This indicates that external signal like WLAN will not interfere in the operating band of this antenna. It is also observed at higher frequency that the radiation efficiency reduces which may be because of loss tangent of FR4 substrate.

Table 1: Gain and Radiation Efficiency of the proposed antenna

Frequency (GHz)	Gain (dB)	Efficiency (%)
2.0	1.0	94
3.5	2.45	96
5.5	-5.5	71
7.0	4.05	95
9.0	4.8	94.5

VI. CONCLUSIONS

The new proposed fractal antenna has been designed and experimentally validated. The antenna exhibits UWB characteristics beyond the FCC recommended band (3.1-10.6 GHz). The notched - band from 5.0 GHz to 6.0 GHz is achieved using W-shape slot in ground plane. The effects on the notched - band characteristic have been studied with respect to length, width and position of slot. The length and width of slot affect the centre frequency and bandwidth of notched - band respectively. Measured radiation pattern of the proposed antenna is omni-directional in H-plane and bidirectional in E-plane. The gain and radiation efficiency of this antenna fall down drastically at notched-band centre frequency. This antenna is conformal, lightweight, small in size, low cost and easy to integrate with MIC/MMICs devices. Such type of antenna can be used for UWB system, Microwave medical imaging, vehicular radar and precision positioning.

ACKNOWLEDGEMENT

Authors are grateful to the Vice Chancellor, Pro-Vice Chancellor, Dean (Acad) of Defence Institute of Advanced Technology (Deemed University), Pune, India for permitting to publish this work. Author is also thankful to the colleague of the Department of Electronics Engg. for timely support and cooperation.

REFERENCES

- [1] FCC, Federal Communication Revision of part 15 of the Commission's Rules Regarding Ultra - Wideband Transmission System, FCC, First Report and order FCC, 02, V48, 2002.
- [2] L. Yang and G. B. Giamalkis, "Ultra wide band Communications," IEEE signal processing Magazine, Nov. 2004, pp. 26-28.
- [3] X.-R. Yan, S.-S. Zhong, and G.-Y. Wang, "The band-notch function for a compact coplanar waveguide-fed super-wideband printed monopole," Microwave Opt Technol. Lett. 49, 2007, 2769-2771.
- [4] T. P. Vuong, A. Ghiotto, Y. Duroc, and S. Tedjini, "Design and characteristics of a small U-slotted planar for IR - UWB," Microwave Opt Technol. Lett. 49 (2007), 1727-1731.
- [5] J. Kim, C. S. Cho, and J. W. Lee, "5.2 GHz notched ultra-wideband antenna using slot-type SRR," Electron Lett. 42 (2006), 366-367.

- [6] S. Ho, J.-W. Baik, and Y.-S. Kim, "A coplanar fed monopole ultra-wideband antenna having band-notched frequency function by two folded-striplines," *Microwave and Optical Technology Lett.* 49 (2007), 2747–2750.
- [7] C.-Y.-D. Sim, W.-T. Chung, and C.-H. Lee, "An octagonal UWB monopole antenna with 5 GHz band-notch function," *Microwave and Optical Technology Lett.* 51 (2009), 74–78.
- [8] J.-B. Jiang, Y. Song, and Z.-H. Yan, "Band-notch UWB printed antenna with an inverted-L-slotted ground," *Microwave and Optical Technology Lett.* 51 (2009), 260–263.
- [9] Y. Ding, G. Wang, and J.-G. Liang, "Compact band-notched ultra wideband printed antenna," *Microwave and Optical Technology Lett.* 49 (2007), 2686–2689.
- [10] S.-W. Qu, J.-L. Li, and Q. Xue, "A band-notched ultra wide-band printed monopole antenna," *IEEE Antennas Wireless Propag. Lett.* 5 (2006), pp. 495–498.
- [11] Raj Kumar et.al. "On the design of inscribed triangle non-concentric circular fractal antenna," *Microwave and Optical Technology Letters*, Vol.52, No. 12, Dec. 2010, 2696-2699.
- [12] Raj Kumar et.al., "On the design of wheel shape Fractal antenna," *Microwave and Optical Technology Letters*, Vol.53, No.1, pp.155-159, January 2011.
- [13] M. Ding, R.H. Jin, J.P. Geng, and Q. Wu, "Design of a CPW-fed ultra-wideband fractal antenna," *Microwave Opt. Technol Lett.* 49 (2007), 173–176.