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A Compact Novel Tapered U Slot Ultra Wideband Antenna

Qurratul Ain* and Neela Chattoraj

Department of Electronics and Communication, Birla Institute of Technology, Mesra, Ranchi, India

Abstract: This paper presents the design and results of a novel, compact and miniaturized tapered U slot UWB printed monopole microstrip antenna for wireless applications. The planar, small and thin UWB antenna fed by a single 50Ω microstrip line with truncated ground plane is excited by a coaxial SMA connector. The correct feed position is determined for impedance matching. The simulation was done using Ansoft High Frequency Structure Simulator (HFSS) software. The simulated results of impedance bandwidth, radiation patterns and group delay are well supported by measurement. Extensive investigations are also carried out on the same antenna design by varying the dimensions to reduce the overall size of the antenna for miniaturization and the UWB performance parameters are studied. The antennas are fabricated and the measured impedance bandwidths defined by VSWR<2 are 10.34GHz (3.66-14GHz) and 10.60GHz (3.4-14GHz) on FR4 substrate.

Keywords: UWB antennas; printed monopole antennas; group delay; miniaturization; HFSS.

1. Introduction

In the last decade, Ultra-wideband (UWB) has come up as a revolutionary and contemporary wireless technology which has generated a great deal of interest for use in the industry and academia. Ultra- Wideband (UWB) commonly refers to signal or system that either has a large relative bandwidth or a large absolute bandwidth [1]. The rapid progress of UWB as a high data rate wireless communication technology has mainly been spurred on the release of a bandwidth of 7.5 GHz (from 3.1GHz to 10.66GHz) for ultra wideband (UWB) applications by the Federal Communications Commission (FCC), by far the largest spectrum allocation for unlicensed use the FCC has ever granted[2].

As is the case in any conventional wireless communication systems, an antenna also plays a very fundamental role in UWB systems. On the other hand the challenges faced in designing a UWB antenna are many more. A suitable UWB antenna is required to operate over an ultra wide bandwidth as allocated by the US FCC(3.1-10.6GHz).Therefore the return loss for the entire ultra wide band should be below the -10dB point. At the same time it should satisfy performance parameters like omni-directional radiation pattern over the entire frequency range. As the UWB technology is employed mainly for indoor and portable devices the size of the antenna should be considerably small so that it can be easily integrated into various components[3, 4, 5, 6] .

A good candidate for UWB applications are printed monopole antennas (PMAs) due to their compactness, light weight and simple structure. These can be realized easily on the printed circuit boards and can be integrated with other components on PCB. Many kinds of printed

* Corresponding author; e-mail: annie13ahmad@gmail.com

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monopole antennas have been designed and presented in a number of research papers. The PMAs (printed monopole antennas) are very good for UWB technology based cost effective systems [1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12].

The design of a tapered U slot printed monopole microstrip antenna is reported in ultra wideband for wireless applications in this paper. First the planar PCB antenna design is introduced and described. The design steps of the antenna are presented. Also the various design considerations and dimensions are summarized. The UWB antenna is realized on commercially available low cost substrate of FR4 and UWB performance parameters of return loss, radiation pattern, group delay and current distribution are studied. Finally the simulated and measured results are compared. Further investigations are done on the same substrate to increase the compactness of the antenna and in the process realize and fabricate a novel antenna.

2. UWB antenna design

The geometry of the proposed antenna is shown in Figure 1(a) and (b). The development steps of the proposed antenna design are shown as 3D simulation models of the antenna in Figure 2(a), (b), (c), and (d).

Figure 2(a) shows the rectangular radiator and Figure 2(b) illustrates the bevels that have been cut at both the corners of the radiator for better impedance matching especially at higher frequencies. Figure 2(c) and (d) show the final geometry of the proposed antenna.

The planar, very small, thin UWB antenna is etched on a $24 \times 36mm^2$ FR4 epoxy substrate having a relative permittivity of 4.4 and a substrate height of 1.6mm. The operating frequency in the simulations is assumed to be the approximate center frequency of the UWB range at 6.8GHz.

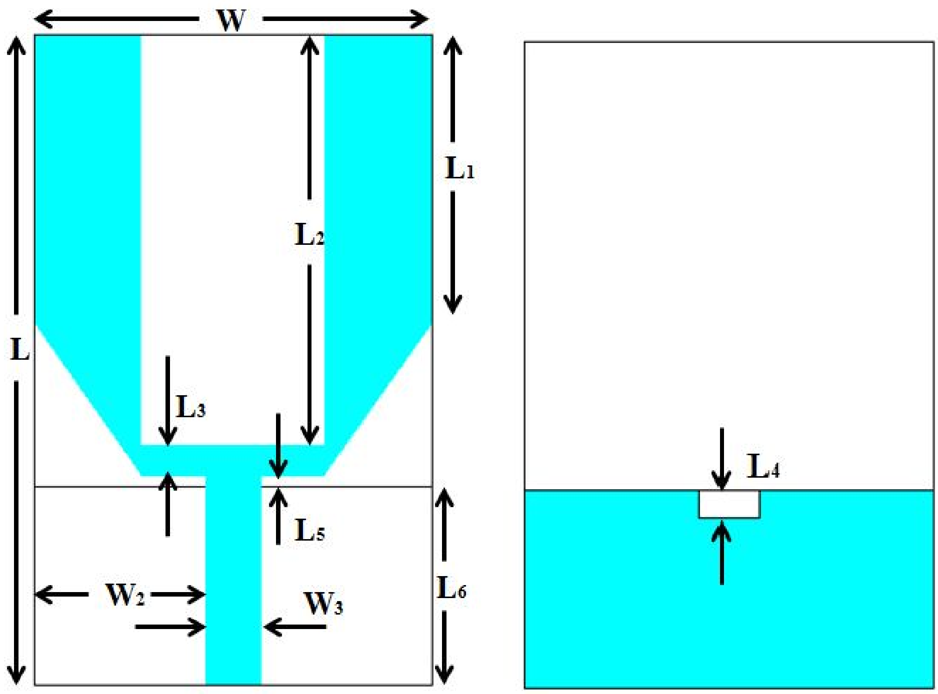


Figure 1. Geometry for the proposed antenna (a) front view; (b) backside view

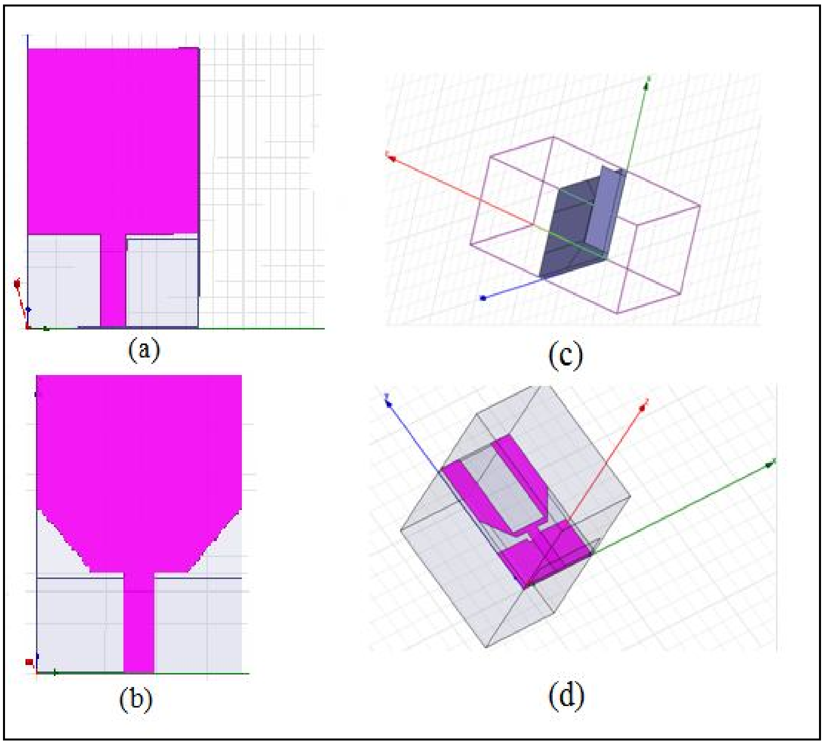
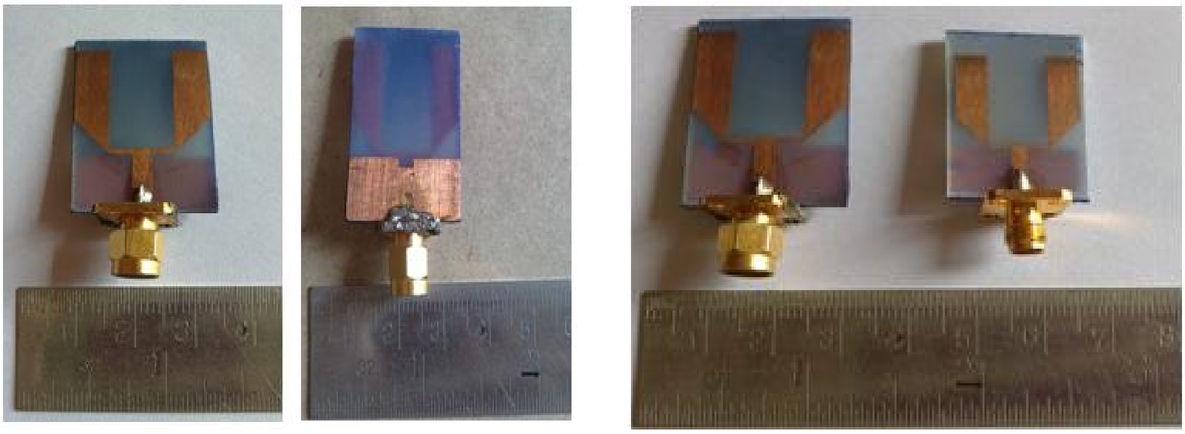


Figure 2. HFSS simulation design of proposed antenna (a) step 1 of antenna design; (b) step 2 of antenna design; (c) final design view; (d) radiator and ground view

Along with the beveling technique used at the lower corners of the radiator for better impedance matching, a notch of size 11x22.7mm^2 is cut out of the radiator to conserve space and create a more compact antenna as shown in Figure 2 and Figure 3.



(a) (b)

Figure 3. Fabricated UWB antenna (a) front & backside view; (b) comparison of original sized and 20% reduced size fabricated antennas

In most of the cases microstrip UWB antennas are fed by microstrip transmission line or by coplanar waveguide (CPW) feeding. In this case lumped port excitation is provided in the simulation which touches the radiator and the partial ground plane as shown in Figure 2. The microstrip transmission line feeding is used for the convenience it provides in fabrication. The antenna is fed using a 50Ω microstrip line whose width is calculated using the well-known microstrip line design equations [13]. The U slot radiating patch and transmission line are connected by tapered edges or bevel slots to obtain better impedance matching.

The partial ground of size 24 x 11.5mm^2 is etched on the opposite side of the substrate. As the distance between the radiator and the ground changes, impedance bandwidth also changes. Thus feed gap is adjusted during the simulations to adjust the impedance matching and finally taken as 0.5mm.

Considering the increasing demand in the UWB communication technology and the need for miniaturized components, the size of the proposed antenna is reduced by 10% and 20% and the antenna performance parameters are analyzed in simulation and then measured. The overall size of the proposed antenna is reduced in steps of 10% and 20% to obtain a more compact antenna.

The simulations are carried out and it is seen from the results that the size of the antenna can be further reduced without compromising the performance parameters. The dimension parameters of the proposed antenna are given in Table 1. Also the parameters considered for the 10% reduced and 20% reduced sizes are given in Table 1.

Figure 3(a) and Figure 2(b) show the snapshot of comparison in sizes of fabricated antennas with initial set of dimensions and 20% reduced set of dimensions .

Table 1. Detailed parameters for the proposed UWB antenna in different sizes

Serial No.	Dimension parameters			
	Symbols used	*Original size (mm)*	*10% reduced size (mm)*	*20% reduced size (mm)*
1	L	36	32.4	28.8
2	L_1	16	14.4	12.8
3	L_2	22.7	20.43	18.16
4	L_3	1.3	1.17	1.04
5	L_4	1.5	1.35	1.2
6	L_5	0.5	0.45	0.4
7	L_6	11.5	10.35	9.2
8	W	24	21.6	19.2
9	W_1	6.5	5.85	5.2
10	W_2	10.25	9.225	8.2
11	W_3	3.5	3.15	2.8

3. Results and discussion

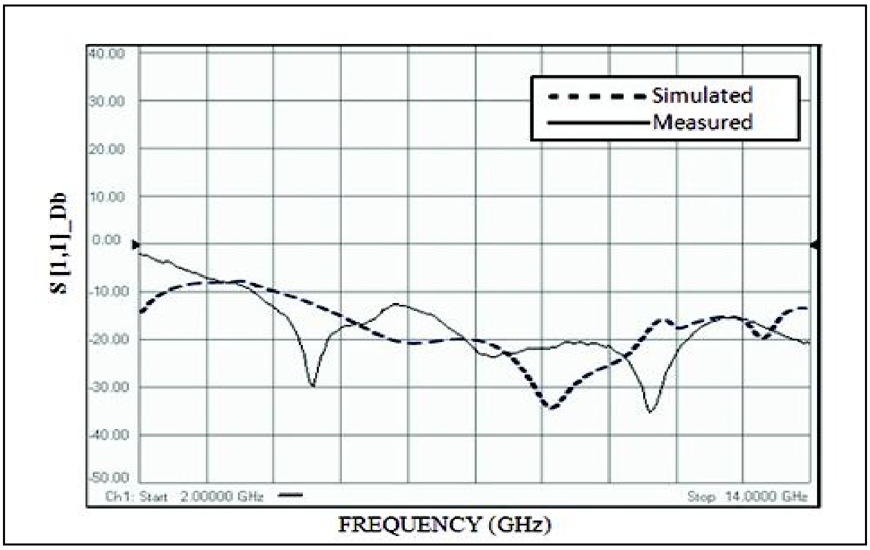
Simulations have been carried out with the Ansoft HFSS to determine the UWB antenna's performance parameters of impedance bandwidth (VSWR<2), radiation patterns and group delay. Also the current distributions are simulated and the antenna behaviour is studied.

3.1. Impedance bandwidth

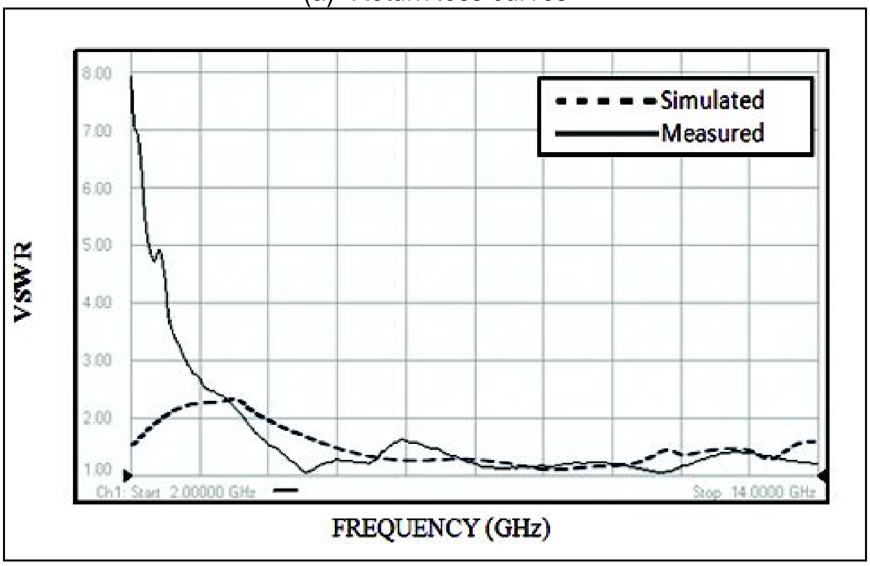
Figure 4 and Figure 5 show the variations of the measured and simulated return loss for the proposed UWB antenna with original and 20% reduced set of dimensions respectively. The measurements were done using vector network analyser (VNA, PNA N5230A, Agilent

Technologies) as shown in Figure 6.

The simulation results show that the proposed antenna with original size achieves an impedance bandwidth (VSWR<2) from 4.1-14GHz and the measured result for the original set of dimensions has an impedance bandwidth of 3.66-14GHz. The return loss curves and the VSWR curves for the simulated and measured results for the 20% reduced set of dimensions are as shown Figure 5(a) and (b). Further miniaturization of the antenna by 10% and 20% of the original size were carried out with good conformity to the UWB performance parameters considered. It is observed that the simulated results obtained for antenna realized on FR4 with 10% size reduction and with 20% size reduction have bandwidths of 4.3-14GHz and 4.1-14GHz respectively as shown in Figure 7.

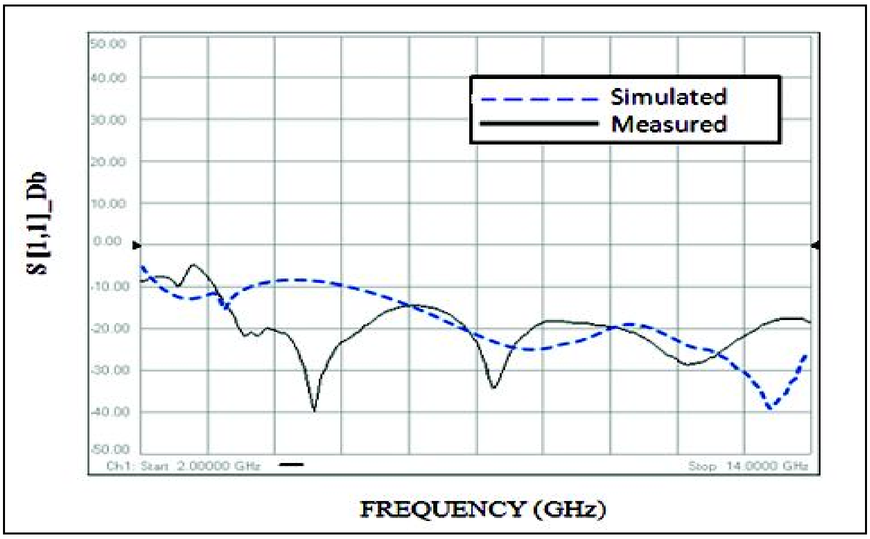


(a) Return loss curves

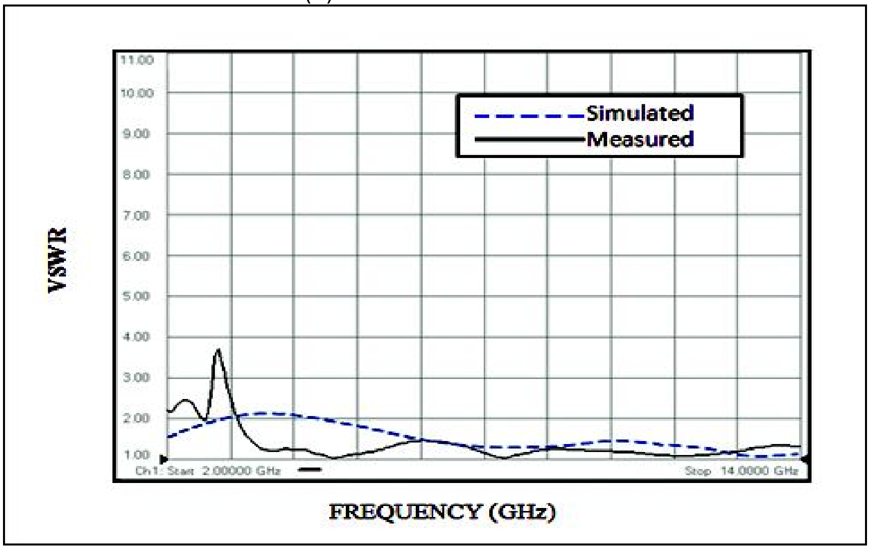


(b) VSWR curves

Figure 4. Comparision of simulated and measured results of proposed antenna with original dimensions



(a) Return loss curves



(b) VSWR curves

Figure 5. Comparision of simulated and measured results of proposed antenna with 20% reduced set of dimensions

Figure 6. Snapshot of the measuring instrument

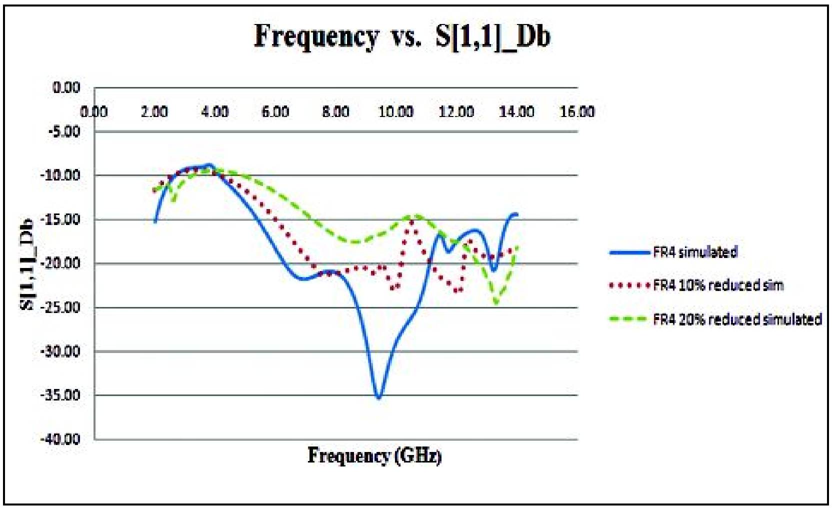


Figure 7. Comparison of simulated return loss results of UWB antenna in different sizes

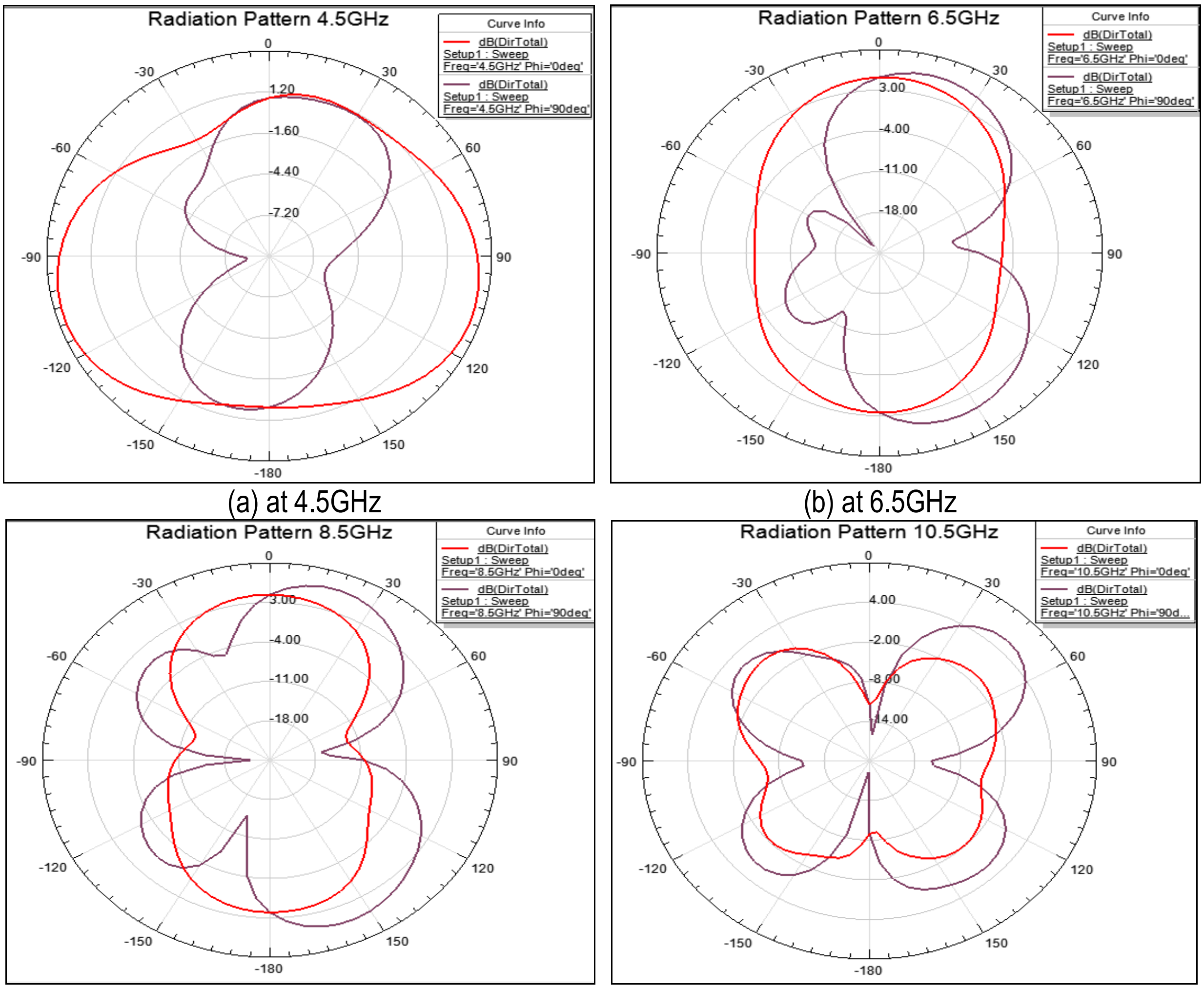
The antenna size is reduced in two steps i.e. with size reduction of 10 and 20%. Comparison of simulated return loss curves for the proposed design of antenna with different size reductions shown in Figure 7 shows that the design works well in the entire frequency range of operation and bandwidth remains stable and does not reduce. Thus a novel and compact antenna is realized. The range of the fabricated 20% reduced antenna on FR4 substrate was found to be from 3.4GHz-14GHz. It is seen from comparing the Figures 4 and 5 that the bandwidth of the proposed antenna with 20% reduced dimensions improves and remains stable over the entire operating frequency range. Thus the antenna is miniaturized successfully without compromising the performance parameters and this type of antenna can easily be integrated into system circuits for a compact design and fabricated at a very low manufacturing cost.

Some differences in the simulated and measured results are seen. One of the reasons is that measurement is done in a non-controlled environment. Another reason for degradation of antenna performance parameters is, that the antenna is fed by a microstrip line so, misalignment occurs because etching is required on both sides of the dielectric substrate. This can be removed by trying CPW feed method and creating a planar pattern on one side of dielectric. Losses occur due to soldering of SMA connector and also the RF cable used for measurements.

3.2. Radiation patterns

Figure 8 shows the simulated radiation patterns of the proposed antenna with original set of dimensions at 4.5, 6.5, 8.5 and 10.5GHz whereas Figure 9 shows the same for 20% reduced set of dimensions. As is seen from Figures 8 and 9 the radiation patterns of the antennas with initial set of dimensions and reduced dimensions are almost omni-directional in H plane and monopole like in E plane, especially at lower frequencies**.**

It is clear that reduction in the size of the antenna does not affect the radiation patterns much and the overall radiation patterns do not deteriorate with the 20% size reduction in size. However the radiation patterns deteriorate in high frequency because the equivalent work area is different in the wide operation frequency. Due to serious unequal phase of distribution and larger magnitude high order modes at high frequencies side lobes appear.



(a) at 4.5GHz (b) at 6.5GHz

(c) at 8.5GHz (d) at 10.5GHz

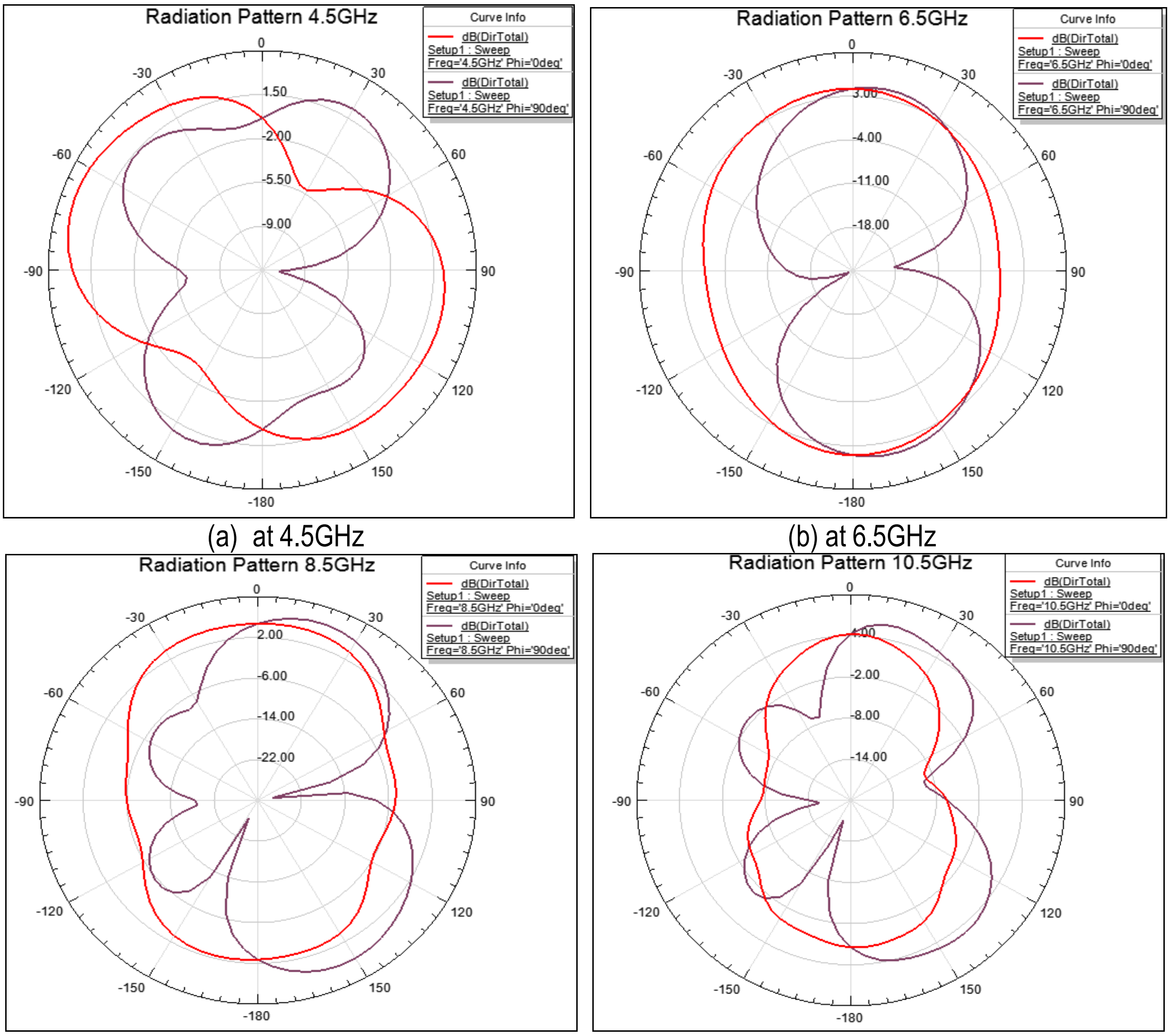
Figure 8. Simulated radiation patterns for original dimensions of the proposed UWB antenna (a) at 4.5 GHz; (b) at 6.5GHz; (c) at 8.5GHz; (d) at 10.5GHz

The radiation patterns were measured using C-band (4-8GHz) and X-band (8-12.4GHz) Microwave benches (Vidyut Yantra Udyog) in uncontrolled environment and the snapshot of the measurement setup is shown in Figure 10. The directivity of an planar microstrip antenna is given as follows: $D = \dfrac{\frac{r}{2\eta_0}\left(|E_\theta|^2 + |E_\varphi|^2\right)}{\frac{P_r}{4\pi}}$

where P_r is the radiated power $\eta_0 = 120\pi$ and E_θ and E_Φ are the radiated fields.

During the measurement the proposed UWB antenna is kept as the receiving antenna on a rotating pedestal to measure the received power which is in microwatts(μw) at different angle (θ) values.

Thus the radiation pattern is plotted by using the different calculated power points with respect to theta(θ).



(a) at 4.5GHz (b) at 6.5GHz

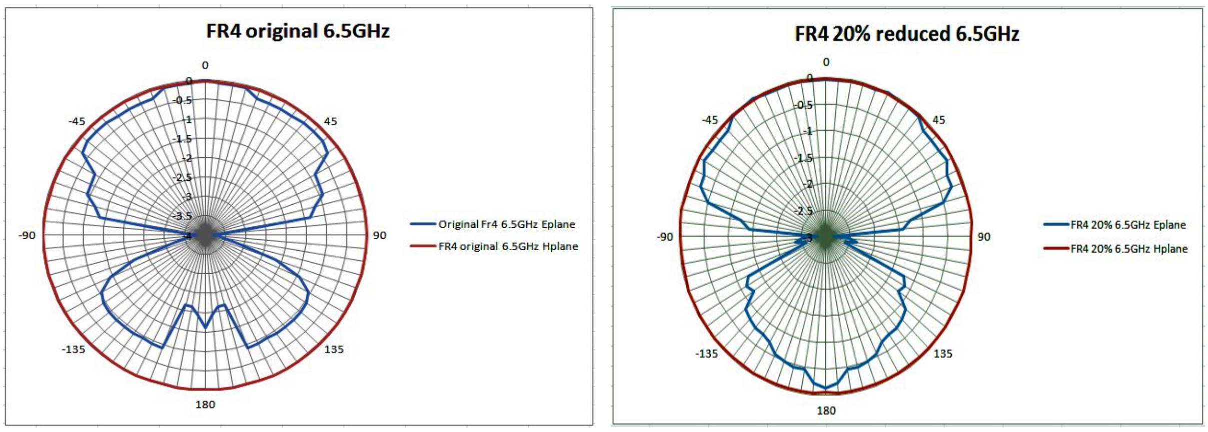
(c) at 8.5GHz (d) at 10.5GHz

Figure 9. Simulated radiation patterns for 20% reduced dimensions of the proposed UWB antenna (a) at 4.5 GHz; (b) at 6.5GHz; (c) at 8.5GHz; (d) at 10.5GHz

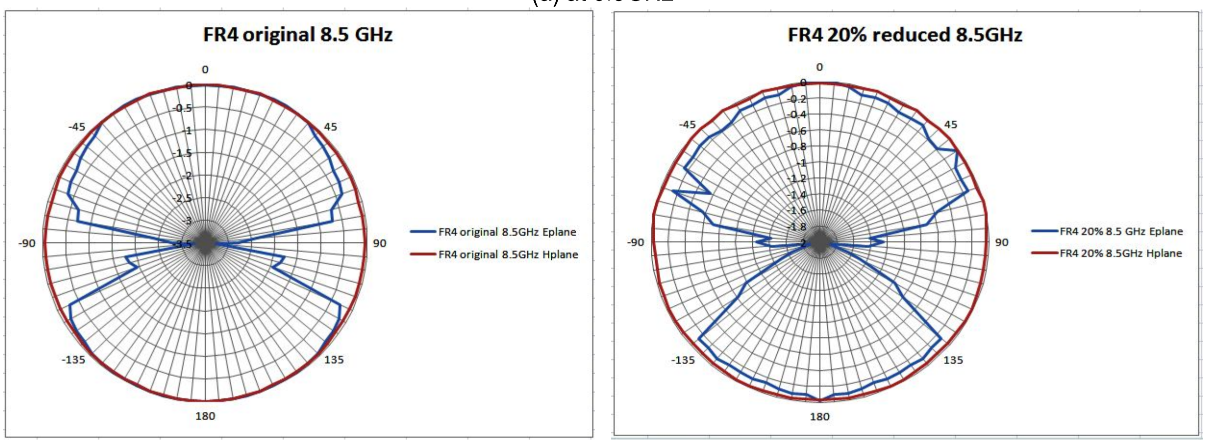
Figure 10. Snapshot of radiation measurement setup

The measured far field radiation patterns of the proposed antenna for the original set of dimensions and its 20% reduced size at 6.5, 8.5, 10.5GHz are plotted in Figure 11.

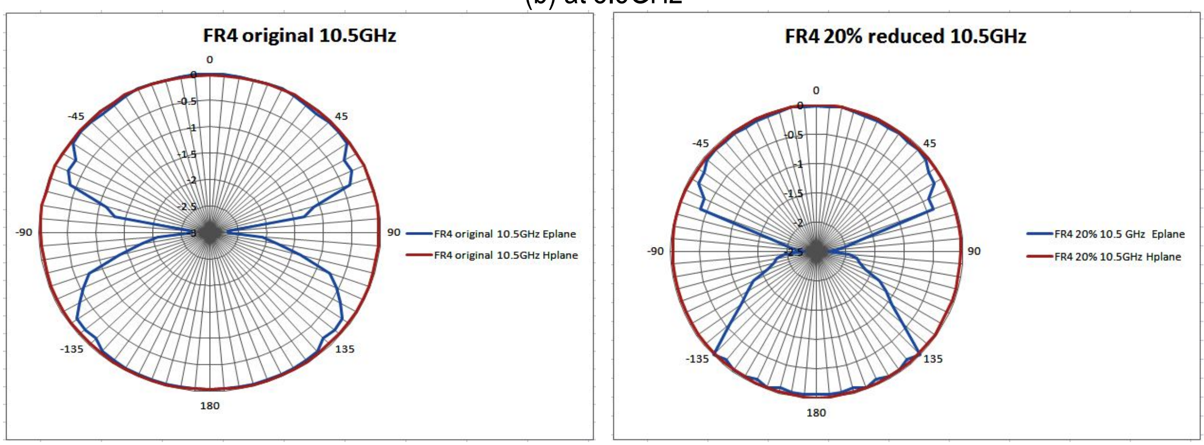
It is clearly observed that the radiation patterns obtained show omni-directional characteristics. Some discrepancy appears in the measured radiation patterns as seen in Figure 11 due to uncontrolled measurement environment and due to errors in substrate and joining of SMA connector.



(a) at 6.5GHz



(b) at 8.5GHz

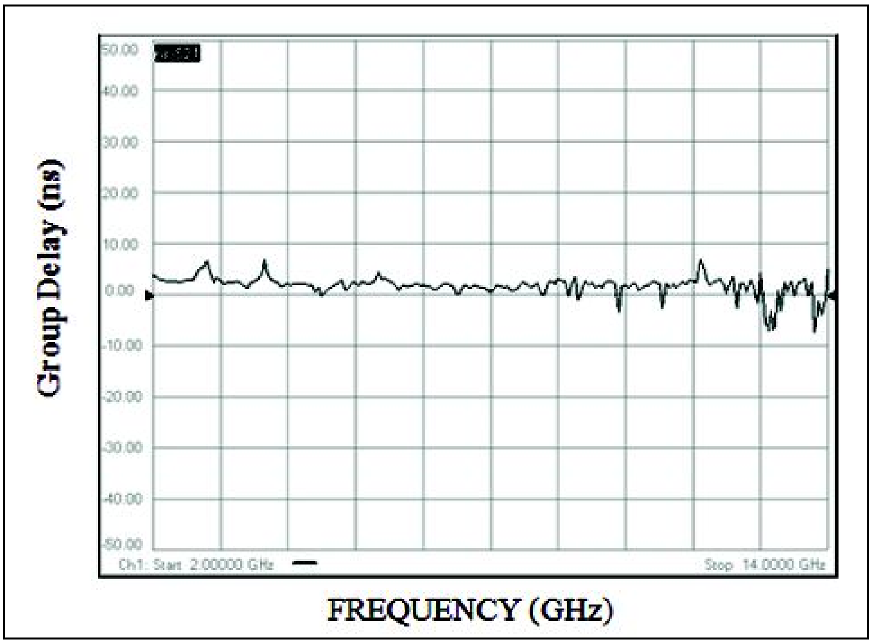


(c) at 10.5GHz

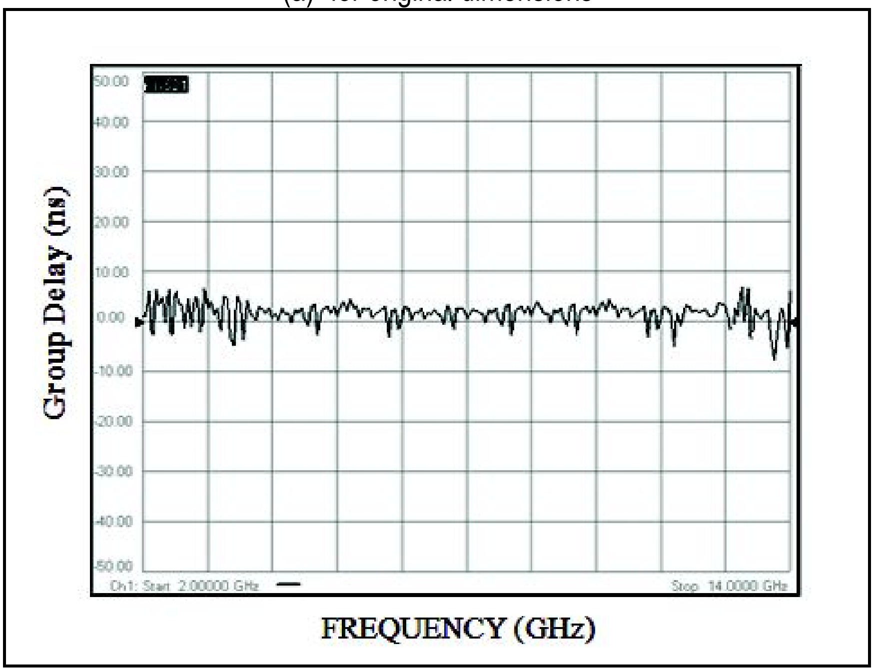
Figure 11. Measured radiation patterns of the proposed UWB antenna with original and 20% reduced dimensions (a) at 6.5GHz; (b) at 8.5GHz; (c) at 10.5GHz

3.3. Group delay characteristics

The group delay is an important parameter in UWB antenna design. The measurement setup for the group delay consists of two identical antennas that are placed 30 cm apart and oriented face to face with each other in a non-controlled environment. From the measured results the antenna group delays are approximately constant within the frequency band of interest as shown in Figure 12.



(a) for original dimensions



(b) for 20% reduced dimensions

Figure 12. Measured group delay for fabricated UWB antenna (a) for original dimensions; (b) for 20% reduced dimensions

3.4. Current distribution

The current distribution is evaluated to help understand the performance of the antenna better. The comparison of simulated current distributions of the initial antenna geometry before cutting the region of low current density and after the notch cut as shown in Figure 2(b) and (d), at 4.5GHz, 6.5GHz, 8.5GHz and 10.5GHz respectively are shown in Figure 13. It is seen that the current is mainly concentrated on the bottom of the patch with very low density toward and above the center and along the edges of the patch except the top edge, for all frequencies. Thus it is concluded that the region of low current density on the patch is not that important in the performance of the antenna. Therefore a notch of size 22.7(L_2)x11mm^2 and therefore cut out as seen in the final antenna geometry (Figure 2(d)). It is observed that the current distributions of the antenna geometry after the center notch cut are similar to the ones as before the cut. As a result of this notch cut, the size of the antenna is reduced and has a lighter weight, which is very attractive for the freedom it presents in designing of the antenna. Another benefit of the notch cut is that it results in less conductor losses. Figure 14 shows the surface current distributions on the antenna with 20% reduced set of dimensions at 4.5GHz, 6.5GHz, 8.5GHz and 10.5GHz respectively with the notch cut present. In this case also it is seen that the electric currents are mainly concentrated around the feeding strip at all frequencies with very low current density above the centre. Thus a more compact and light weight antenna is realized.

4. Conclusion

A new small UWB antenna has been designed, simulated, measured and fabricated. The simulation results obtained by Ansoft HFSS software show good agreement with the measured results. The antenna provides excellent performance in the entire operational bandwidth. It is clearly seen that the plotted radiation patterns of E-plane are monopole like and H-plane radiation patterns show almost omni-directional characteristics which is a requirement for a UWB antenna. Group delay which is more meaningful parameter to show good time domain characteristic in UWB antenna is also investigated and the variations obtained are also good and within the acceptable limit. Group delay variations obtained are also good and within the acceptable limit. To miniaturize UWB antenna, tapering and truncated ground plains are used. The current distribution is evaluated to help understand the performance of the antenna better. It is seen from the measured results that very large bandwidths are obtained and hence these antennas can be used in wireless communication systems. Also because of their low cost, light weight and easy design these printed monople antennas are very attractive for UWB communication systems and applications.

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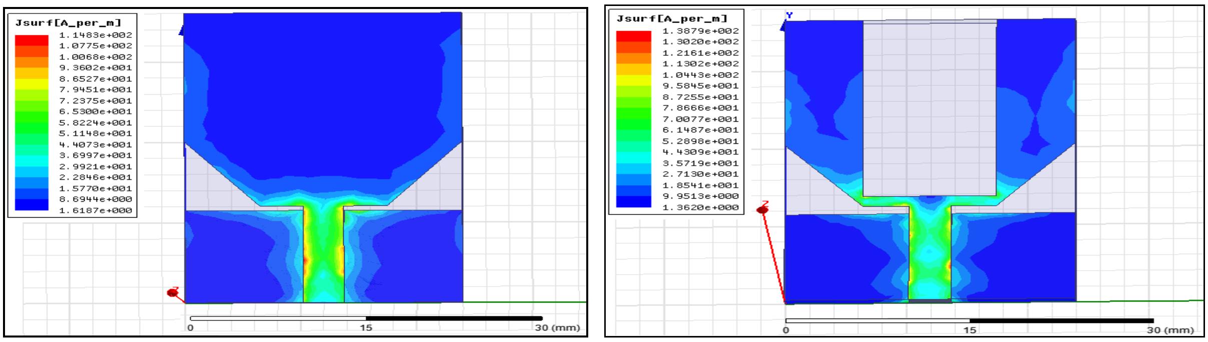
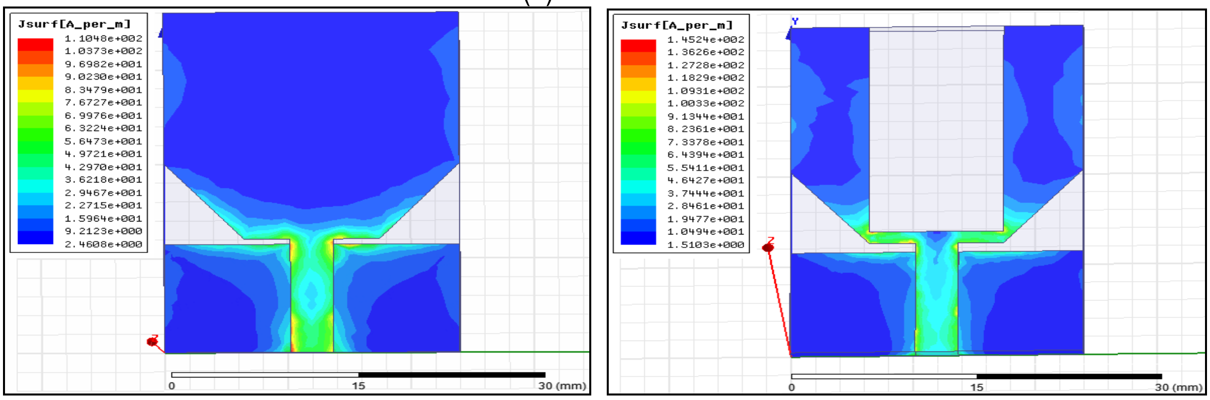
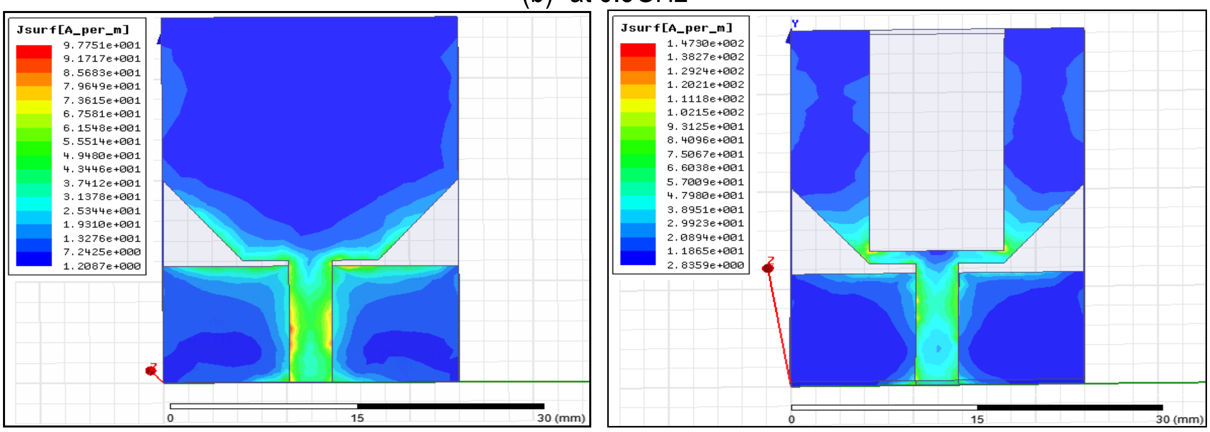
The authors would like to acknowledge and thank the support of Birla Institute of Technology (Mesra) for providing the facility and equipment for this work.



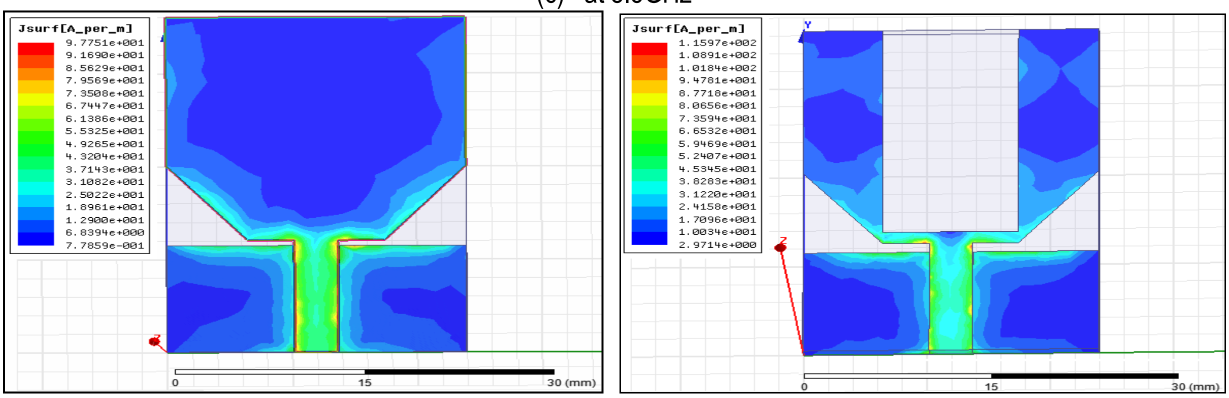
(a) at 4.5GHz



(b) at 6.5GHz



(c) at 8.5GHz



(d) at 10.5GHz

Figure 13. Surface current distribution for the proposed antenna with initial dimensions to show that current is distributed at edges

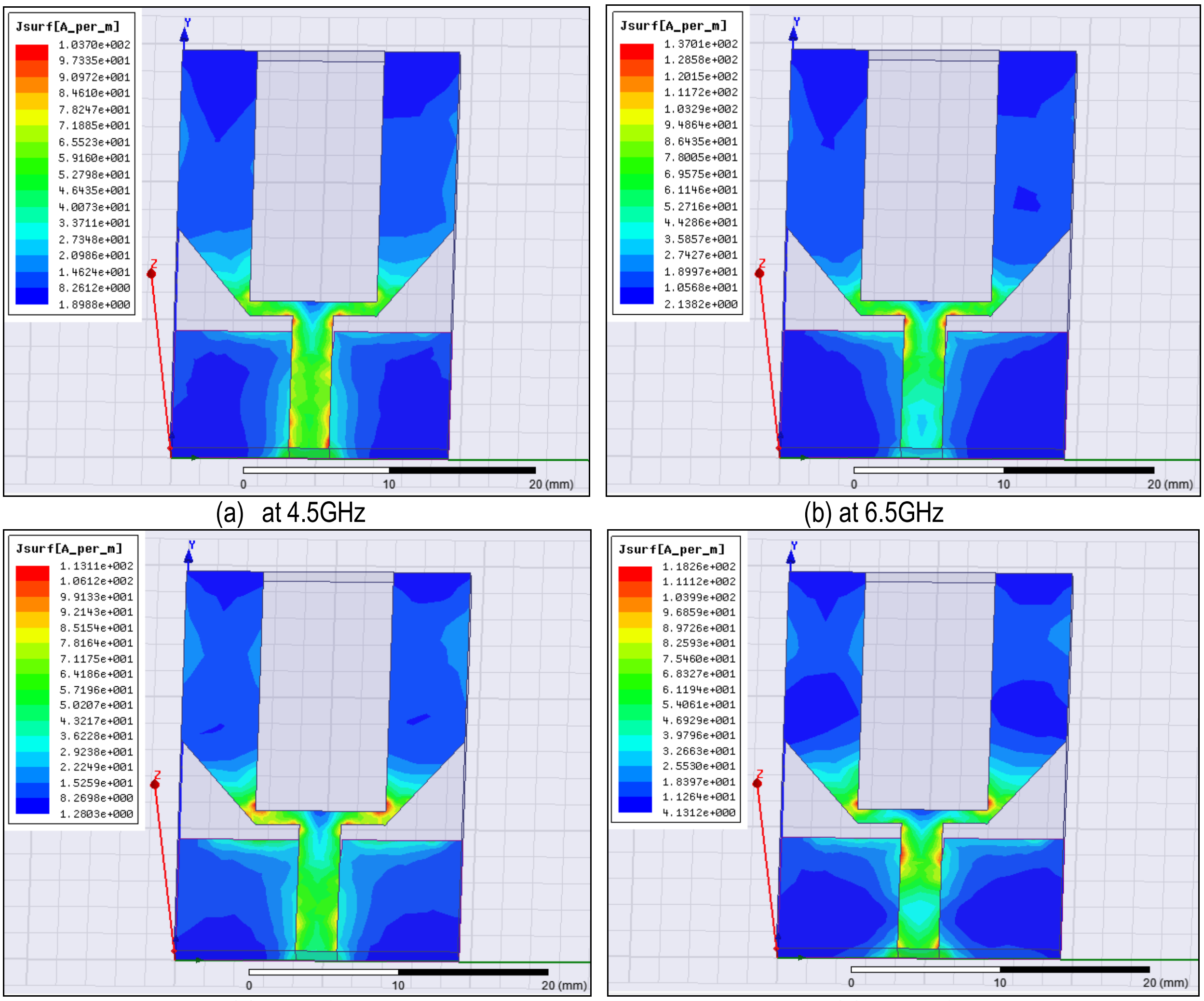

(a) at 4.5GHz (b) at 6.5GHz
(c) at 8.5GHz (d) at 10.5GHz

Figure 14. Surface current distribution for the proposed antenna with 20% reduced dimensions

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