An Irregular Ground Oriented Miniaturized Antenna for UWB Industrial Applications

Md Z. Mahmud [1,2], T. Alam [2], M. Samsuzzaman [2], A. Ullah [2], and Mohammad T. Islam [2]

[1] Department of AIS
Jagannath University, Dhaka 1000, Bangladesh
zulfikerm@yahoo.com

[2] Centre of Advanced Electronic and Communication Engineering (PAKET)
Universiti Kebangsaan Malaysia, 43600, Bangi
tauhid13@yahoo.com, samsuzzaman@ukm.edu.my, amanath.ullah@gmail.com, tariqul@ukm.edu.my

Abstract – In this paper, a new small UWB antenna for different UWB industrial applications is presented. The proposed prototype comprises of a simple structure with a modified triangular patch and a sawtooth ground plane. The electrical size of the proposed antenna is 0.15λ× 0.13λ×0.014λ, at lower end frequency. The patch and ground plane is optimized and analyzed. The antenna shows 116% of VSWR<2 impedance bandwidth from 2.8 to 10.5 GHz with a peak gain of 5.6 dBi and 75% of the average radiation efficiency. The proposed design established a nearly omnidirectional radiation characteristic over the operating frequency band. The proposed antenna was successfully simulated, prototyped, and measured. The uniqueness of the proposed antenna is the miniaturization of the antenna for the UWB frequency band, which can be applied for different portable and convenient UWB applications.

Index Terms – Antenna, partial ground plane, UWB, wideband, wireless communication.

I. INTRODUCTION

The demand for a high-performance antenna with wider bandwidth is increasing exponentially due to the rapid growth of the global wireless communication industry. UWB has become a promising technology and area of interest in different industrial applications like short-range communication, ranging and localization, tracking, and data relay satellite (TDRSS), removable media in computers, etc. This is due to some of its striking features like high data rate, small spectral power density, high precision, low cost, robust to multi-path fading, very low interference etc. The Federal Communications Commission (FCC) has assigned 7.5 GHz spectrum from 3.1 to 10.6 GHz for UWB radio applications since February 2002 [1]. Typically, UWB antennas should be electronically small and inexpensive while maintaining desirable wideband performance for different industrial applications. UWB has wide applications in short range and high-speed wireless systems, such as ground penetrating radars, medical an imaging system, high data rate wireless local area networks (WLAN), communication systems for military and short pulse radars for automotive even or robotics [2-5]. Thus, one of the main challenges of designing UWB antennas is to get higher bandwidth, efficiency, and low profile within allocated smaller dimensions.

UWB antenna characteristics can improve by changing the shape of the radiating patch. The patch may be rectangular, circular, heart-shaped, elliptical, etc. The antenna performance also can be improved by manipulating the ground structure [6-12]. In the work of Gokmen et al. [13], a compact size UWB antenna with heart shape using triangular patches with dimensions of 25×26×0.5 mm^3, operating from 4 GHz to 19.1 GHz, is proposed. Liu and Yang [14] presented a hook-shaped UWB antenna operating from 3 GHz to 10.7 GHz with dimensions of 10×10×1.6 mm^3. In the work of Ojaroudi et al. [15], UWB monopole antenna for 3.12 to 11.2 GHz bandwidth with an inverted T-shaped notch in the ground plane is presented with a compact size of 12×18 mm^2. A Tapered-shaped slot antenna [16] with an area of 22×24 mm^2 is presented with operational frequencies from 3 GHz to 11.2 GHz. In another study [17], the antenna is designed with a heart-shaped patch and a defected ground plane. This antenna is proposed and optimized for ultra-wideband applications. To increase the impedance bandwidth and reduce the reflection coefficient, three semi-circular slots were proposed in the ground plane. T. Yang and X. J. Tian [18], proposed a heart-shaped monopole patch and a couple of rectangular ground plane on the same side of a substrate. A standard impedance bandwidth is achieved from 2.1 to 11.5 GHz. Some designs are presented in literature, some of them are large in size, and some of them obtain law gain or low radiation efficiency.

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In this work, a new and ultra-small ($13\times16mm^2$) UWB antenna with enhanced impedance bandwidth is presented. The main objective of the work is to reduce the dimensions of the antenna and increase the bandwidth to make it applicable for portable and convenient UWB applications. This antenna consists of a sawtooth orientation ground plane on the back side of the substrate with a rectangular shape and a patch with the modified triangular shape. The inner parts of the patch are partially etched away to increase the bandwidth especially for covering the lower end of the UWB frequency spectrum. By using the triangular patch and defected ground plane, wide input impedance matching is achieved over the entire 2.9 to 10.5 GHz band with relatively stable omnidirectional radiation patterns. Simulated results of different frequencies for VSWR, gain, efficiency, radiation pattern, Surface Current distribution are presented along with the measured results. The simulation is performed by Computer Simulation Technology (CST) Microwave studio.

II. ANTENNA DESIGN

The geometric layout of the proposed UWB antenna is depicted in Fig. 1. The dimension of the antenna is 13×16 mm^2 of 1.6 mm thickness. Substrate Flame Retardant (FR4) is used with a dielectric constant of 4.3 and loss tangent is 0.025. FR4 is commonly used in the industry because of its low cost and convenient to make from one-layer to multi-layer PCBs. The proposed antenna is composed of a partial radiating patch on one side and ground plane on the opposite side of the substrate. The orientation of the ground plane and shape of the patch has a strong effect on the impedance matching. Therefore, by properly selecting ground orientation and patch shape, good impedance bandwidth and radiation characteristics are achieved. A triangular shape patch is developed on the front side of the antenna. In the middle of the patch, a triangular pattern is etched away. This is mainly done for covering larger bandwidth especially to cover lower frequencies. A microstrip feed line of 1 mm width and 5 mm long is printed on top of the substrate. The gap from patch to end of the substrate in left and the right side is not same. It is much larger on the left side (G) than the right side (g), as shown in Fig. 1. The ground plane of the antenna is a rectangular shape. The height of the ground plane is 4 mm and width is the same as antenna width. The ground consists of a sawtooth configuration on the upper side by etching a number of triangles from a partial rectangular ground plane to improve the performance at higher frequencies. Without this irregularity, discontinuities appear in the operational bandwidth shown in Fig. 3. The proposed prototype use microstrip feed using 50 Ω SMA connectors located at the edge of the lower part of the antenna. At this point, the electromagnetic energy, which is in the form of voltage and current waves, is split into two parts. One flows along the strip line while the other continues through the edge that acts as an open transmission line. The overall size of the antenna is $W\times L$ mm^2 and the ground plane has an area of $W\times L_g$ mm^2. In Table 1 details of the optimized design, parameter are summarized.

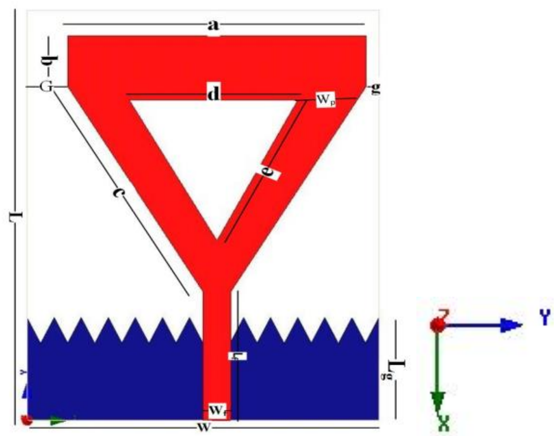


Fig. 1. The geometric layout of the proposed antenna (all dimensions are in mm).

Table 1: Optimized dimension of antenna prototype

Para.	Value (mm)	Para.	Value (mm)	Para.	Value (mm)
W	13	L	16	L_g	4
W_f	1	a	11	b	2
W_p	3.1	G	1.5	g	0.5
c	9.43	d	6.25	e	6.26

The uniqueness of the proposed antenna is its size. The comparison of the proposed antenna with a few recently proposed antennas [6-10] is presented in Table 2. The size of the antenna is significantly reduced in the proposed design.

Table 2: Comparisons of the proposed antenna with existing antenna dimension

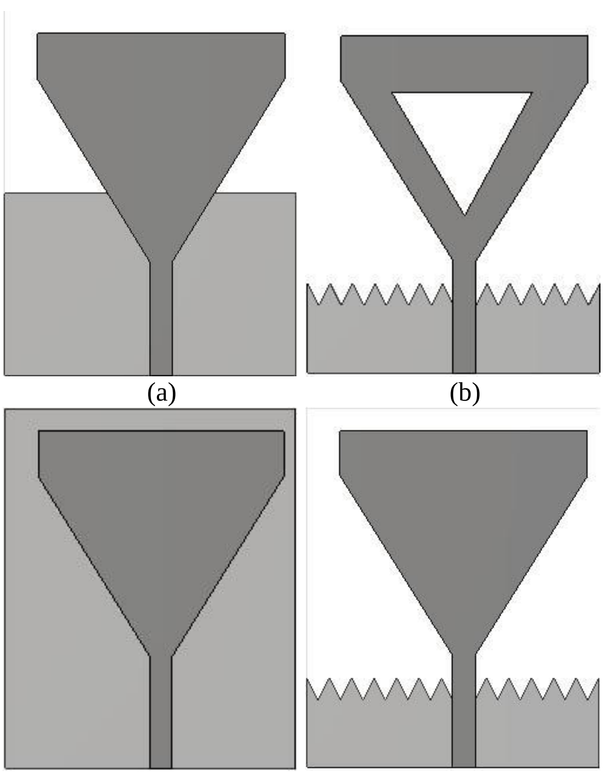
Existing Work	Antenna Configuration	Size Decreases (Proposed/ Literature)
[6] Sharma and Shrivastava	Fractal elliptical	97%
[7] Shaalan and Ramadan	Hexagonal monopole	76%
[8] Yang et al.	CPW-fed planar	69%
[9] Liu et al.	Circular-ring	71%
[13] Isik and Topaloglu	Heart shape triangular patch	68%

III. PARAMETRIC STUDY

For investigating the effect of different parameters on antenna performance, some crucial antenna parameters were studied. At a time, a single parameter is changed while others remained unchanged. All the parameters were studied using a CST microwave studio.

A. Effect of ground and patch structure

In order to optimize the patch and ground plane, the proposed design was compared to five other structures as shown in Fig. 2. Their comparative antenna performance in terms of reflection co-efficient S_{11} are shown in Fig. 3. It is evident that the proposed antenna layout achieves much better performance than the other configurations. When full substrate used as a ground, as shown in Fig. 2 (c), no reasonable operating frequency was found. When half of the substrate was used as a ground, as illustrated in Fig. 2 (a), the almost same result was recorded. In other cases, like without the middle triangle, without sawtooth orientation of the ground and without both, there has some band under -10dB but not contiguous. Some parts go higher than -10 dB, hence they do not cover the entire UWB bandwidth. Same parametric study for gain is depicted in Fig. 4. For the gain, it is seen that the proposed layout achieves better gain than other configurations.



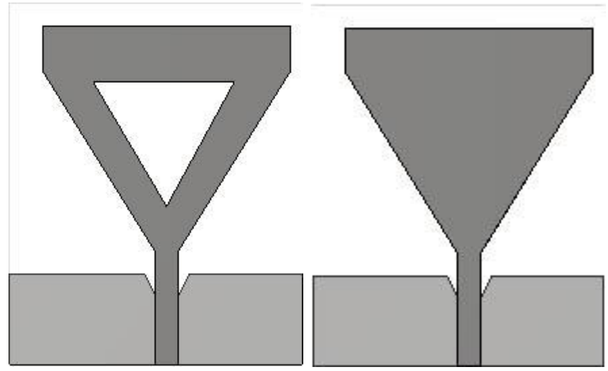


Fig. 2. Different geometric layout: (a) with half ground plane, (b) proposed, (c) full ground, (d) without middle triangle, (e) without saw-tooth ground orientation, and (f) without both saw-tooth ground orientation and middle triangle.

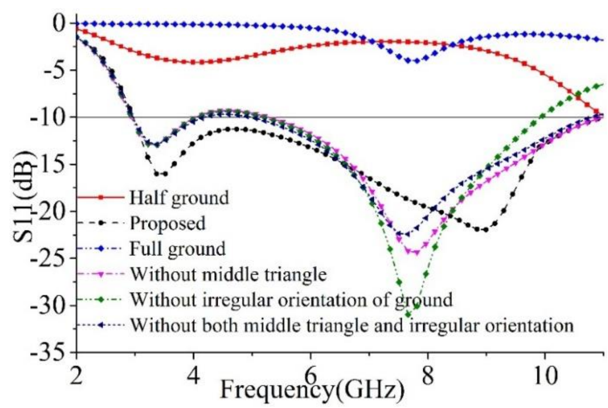


Fig. 3. Simulated reflection coefficient (S_{11}) for a different structure of ground plane and patch.

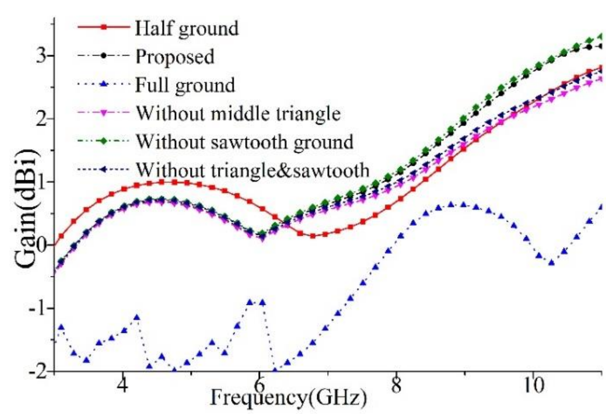


Fig. 4. A simulated gain for a different structure of ground plane and patch.

B. Effect of substrate material

A good selection of substrate will yield superior performance of the antenna. The effect of substrate materials on impedance matching for different dielectric substrates are presented in Fig. 5. The analysis would help to investigate the effects of the different substrate materials on impedance bandwidth. The chosen substrate materials are FR4 (ε_r = 4.3, tanδ = 0.025), Rogers RT 5870 (ε_r = 2.33, tanδ = 0.012), Rogers RT 6010 (ε_r = 10.2, tanδ = 0.0023) and Glass-PTFE (ε_r = 2.33, tanδ = 0.0009). It can be clearly observed from the figure that proposed FR4 composite substrate offers wider bandwidth and lower reflection coefficient for the proposed prototype. Due to good electrical performance, very nice dimensional stability and ideal dielectric constant, FR4 composite materials offer better performance compared to some common substrate materials.

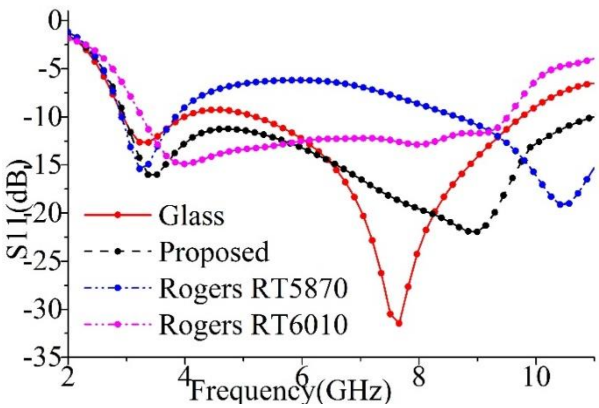
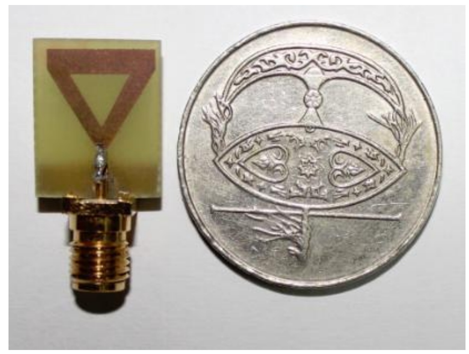


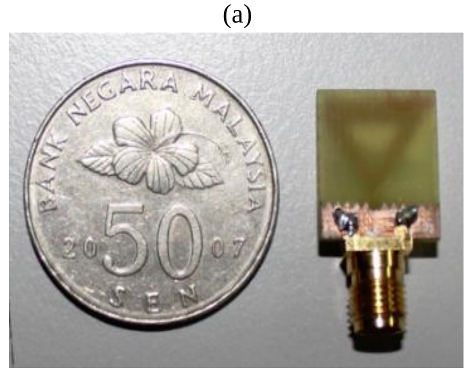
Fig. 5. Simulated reflection coefficient (S_{11}) for different substrate materials

IV. RESULTS AND DISCUSSION

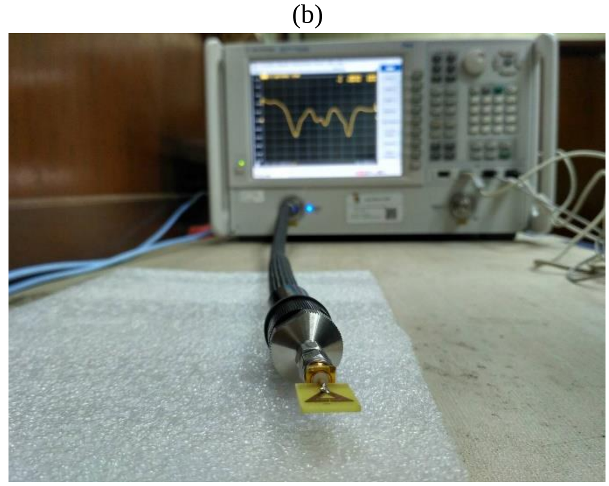
The photograph of the antenna prototyped for experimental verification is shown in Fig. 6. For measurement, the Agilent E8362C vector network analyzer (VNA) shown in Fig. 6 (b) and Satimo near field anechoic chamber (UKM StarLab) shown in Fig. 8 (b) is used. The simulated and experimental Voltage Standing Wave Ratio (VSWR) against the frequency of the proposed antenna are illustrated in Fig. 7. The measured bandwidth for VSWR ≤ 2 ranges from 2.8 GHz to 10.5 GHz and in the simulation from 2.9 GHz to 10.5 GHz. In both cases, it exhibits wideband performance. The measured and simulated results show a good agreement. The minor discrepancies between simulated and measured results can be attributed to imperfect fabrication and the coaxial cable used during measurement. The cable is not considered in the simulation. The size of the proposed antenna is smallest among recently published antenna but it achieves a wide bandwidth. The proposed antenna cover the UWB band (3.1-10.6). A smart average gain of 4.2 dBi presented in Fig. 8. The peak gain is 5.6 dBi at 8.6 GHz. In Fig. 9, the simulated and measured radiation efficiencies of the proposed antenna are presented. The maximum radiation efficiency is achieved at 8.2 GHz of 89% and an average of 75% over the bandwidth. At lower frequency, the efficiency is lower than the average. It is so due to the copper losses of the proposed structure at starting. After a certain level, the losses are minimized and higher order current mode is excited than the efficiency is increased. It also may cause due to the dielectric losses.



(a)



(b)



(c)

Fig. 6. Photographs of the fabricated antenna: (a) top layer, (b) bottom layer, and (c) VNA measurement setup.

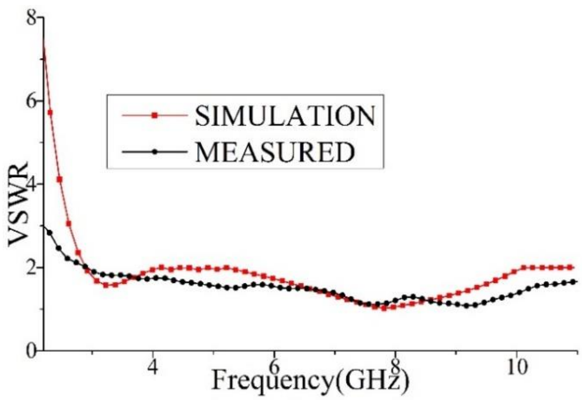
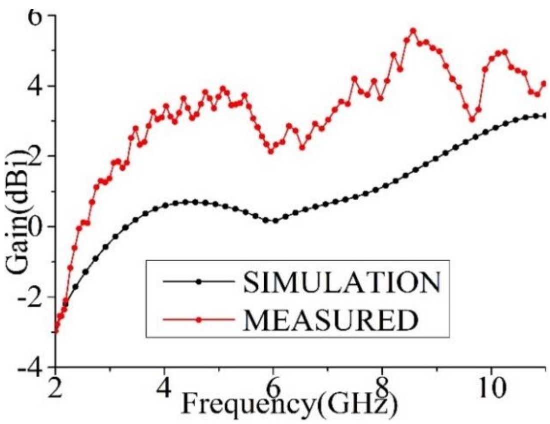
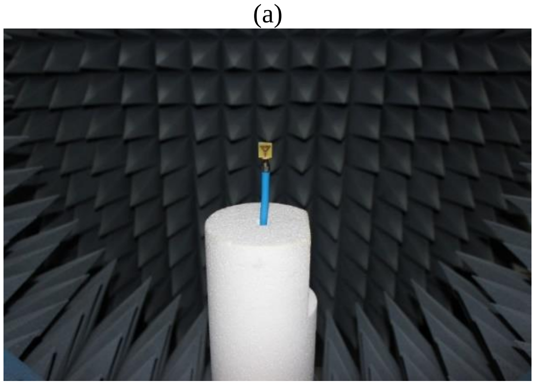


Fig. 7. Simulated and measured VSWR of the proposed antenna.



(a)



(b)

Fig. 8. (a) Simulated and measured gain of the proposed antenna, and (b) Satimo measurement setup.

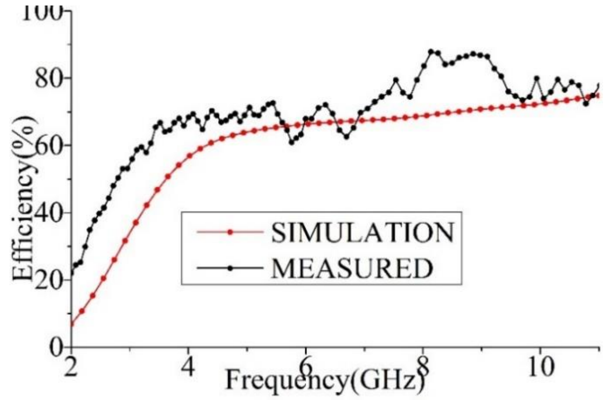
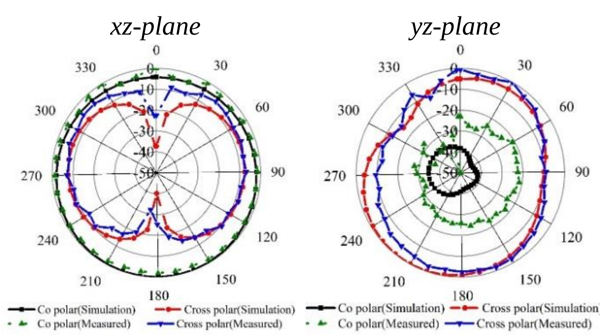


Fig. 9. Simulated and measured efficiency of the proposed antenna.

Measured and simulated radiation pattern, including the cross-polarization and co-polarization of the fabricated antenna for two resonant frequencies 3.25 GHz and 7.8 GHz in both *xz-plane(φ=0)* and *yz-plane(φ=90)*, are shown in Fig. 10. It is seen that, over the desired bandwidth, the proposed antenna exhibits stable radiation pattern characteristics. At lower frequency (3.25 GHz) the radiation pattern is omnidirectional in *xz-plane*. The value of co-polarization is significantly higher than cross-polarization. With the increase of frequency to 7.8 GHz, the cross-polarization increases slightly. At higher frequency in the Fig. 10 (b) in both *xz* and *yz plane* multiple nulls are observed in the radiation pattern as the surface currents are not distributed evenly. This indicates that the radiating element is excited with higher order modes, which typically results in more directional radiation patterns.



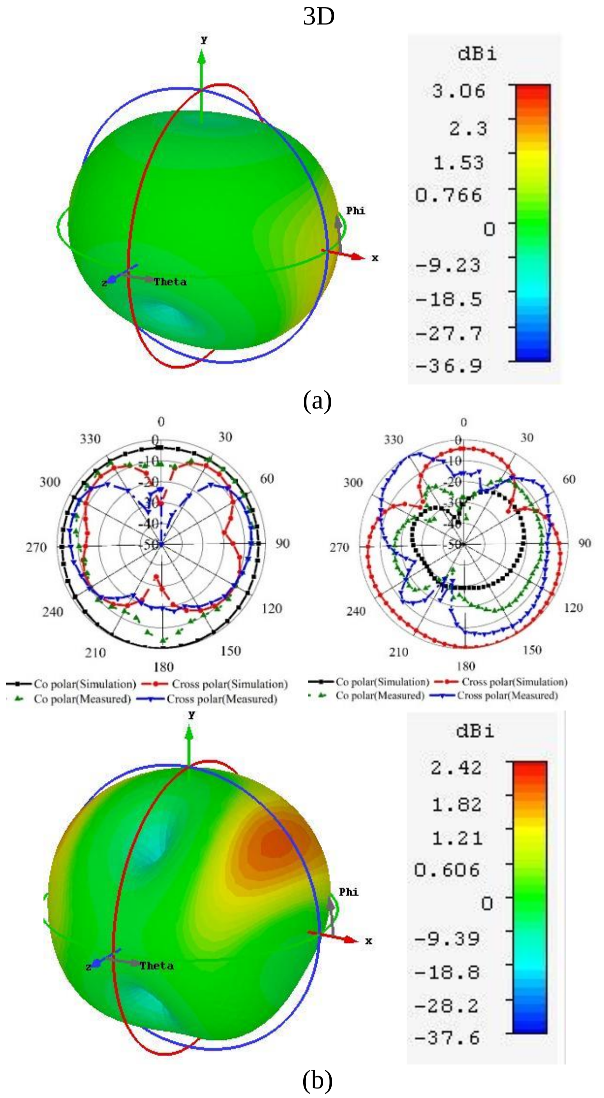


Fig. 10. Measured radiation pattern at different frequencies: (a) 3.25 GHz and (b) 7.8 GHz.

The surface current distribution of proposed defected ground plane antenna is shown in Fig. 11 at 3.2 and 7.8 GHz. The main current conducting area is on the patch and around the middle triangle. The sawtooth on the ground plane change the current path and creates higher order current modes. For this change of ground plane, a remarkable change in the antenna characteristics is found.

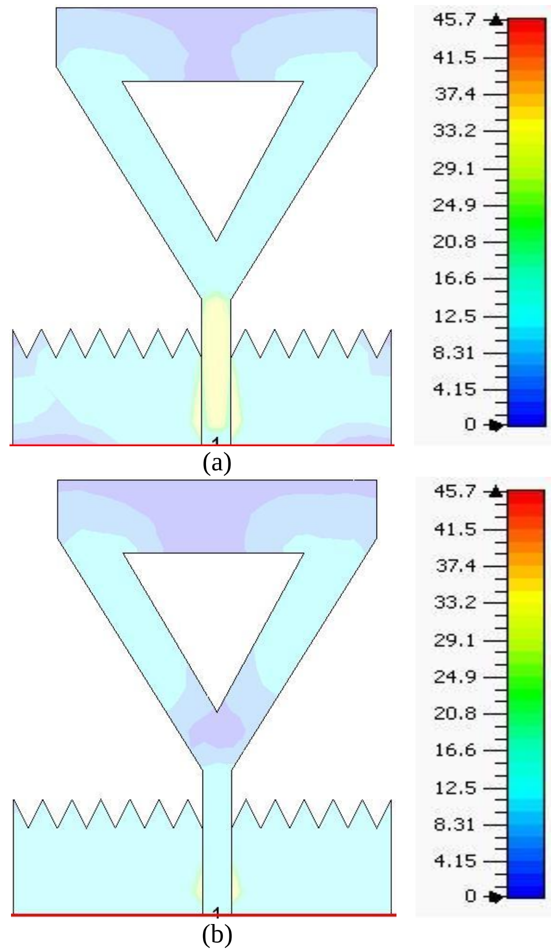


Fig. 11. Current distribution of proposed antenna: (a) 3.2 GHz and (b) 7.8 GHz.

The proposed antenna and the existing antennas (literature review) were studied to ensure an impartial comparison in Table 3, where all reference antennas cover ultra-wideband spectrum. The performances parameters, such as size, applications, less than -10-dB bandwidth, dielectric constant, gain and fractional bandwidth are presented. The proposed antenna is the smallest among all the antenna studied with fair bandwidth and gain. Therefore, the proposed prototype can offer good compact characteristics for different UWB applications.

Table 3: Bandwidth, dielectric constant, fractional bandwidth and gain comparison

Reference	Application	Size (mm^2)	BW (GHz) or VSWR<2dB	ε	FBW (%)	Gain
[13]	UWB	25×26	4-19.1	3.5	100%	3 dBi
[14]	UWB	80×40	3-10.7	4.4	112%	4.5 dBi
[15]	UWB	12×18	3.12-12.73	4.4	120%	--------
[16]	UWB	22×24	3-11.2	4.6	115.5%	4 dBi
[17]	UWB	48×40	2.7-26	4.08	162%	<4 dBi
[18]	UWB & RFID	30×35	2.1-11.5	4.4	110%	<6dBi
Proposed	UWB	13×16	2.8-10.5	4.3	116%	>4.5dBi

V. CONCLUSION

A sawtooth partial ground oriented antenna with an extremely small size of 13×16 mm^2 monopole antenna is proposed for UWB applications. The simulated and measured results comply with the UWB requirements, which is VSWR<2 impedance bandwidth of 116% with stable omnidirectional radiation pattern and 75% of average radiation efficiency over the operating bandwidth. The proposed design is compact in size and can be integrated into limited space around microwave circuitry with low manufacturing cost. The experimental results show that the proposed antenna could be a suitable candidate for industrial UWB Applications.

ACKNOWLEDGMENTS

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Md. Zulfiker Mahmud is an Assistant Professor of AIS Department in Jagannath University Bangladesh. He received the B.Sc. and M.Sc. degree in Computer Science and Engineering from Islamic University Kushtia, Bangladesh. Currently he is working as a Ph.D. student in the Universiti Kebangsaan Malaysia (UKM), Malaysia. He is currently a Graduate Research Assistant at the Department of Electrical, Electronic and Systems Engineering, UKM, Malaysia. He has authored or co-authored approximately 25 referred journals and conference papers. His research interests include the microwave imaging, antenna design, satellite antennas, satellite communication and wireless communication.

Touhidul Alam is a post graduate student at the Department of Electrical, Electronic and Systems Engineering of the Universiti Kebangsaan Malaysia (UKM). He received B.Sc. in Electrical & Electronic Engineering (EEE) from International Islamic University Chittagong (IIUC) in 2012 and Master of Space Science from Universiti Kebangsaan Malaysia, 2015. From May 2012 to till now, he is working as an Assistant Professor at International Islamic University Chittagong (IIUC). His publications include over 16 research journal papers, nearly 12 conference papers, and two book chapters on various topics related to antennas, microwaves and electromagnetic radiation analysis. His research interests include the antenna, RF, electromagnetic field and propagation, electromagnetic radiation, metamaterial applications and electromagnetic compatibility and microwave imaging.

Md. Samsuzzaman was born in Jhenaidah, Bangladesh in 1982. He received his B.Sc. and M.Sc. degrees in Computer Science and Engineering from the Islamic University Kushtia, Bangladesh in 2005 and 2007, respectively, and the Ph.D. degree from the Universiti Kebangsaan Malaysia, Malaysia 2015. From February 2008 to February 2011, he worked as a Lecturer at the Patuakhali Science and Technology University (PSTU), Bangladesh. From February 2011 to 2015, he worked as an Assistant Professor at the same university. He is now as an Associate Professor at the same university. Samsuzzaman is a Post-Doctoral Fellow of Universiti Kebangsaan Malaysia. He is the author and co-author of about 80 research journal articles, nearly 20 conference articles, and a few book chapters on various topics related to antennas, microwaves and electromagnetic radiation analysis with one inventory patents filed. His Google scholar citation is 546 and H-index is 13. His research interests include the communication antenna design, satellite antennas, and microwave imaging.

Md. Amanath Ullah received B.Sc. in Electrical & Electronic Engineering (EEE) from International Islamic University Chittagong (IIUC) in 2015. Currently, he is pursuing M.Sc. in Electrical, Electronic and Systems Engineering at Universiti Kebangsaan Malaysia (UKM). From September 2016 to till now. His research interests include antenna and propagation, 3D antenna applications, microwave imaging and embedded systems.

Mohammad Tariqul Islam is a Professor at the Department of Electrical, Electronic and Systems Engineering of the Universiti Kebangsaan Malaysia (UKM). He is currently the Group Leader of the Radio Astronomy Informatics Group at UKM. He is the author of over 300 research journal articles, nearly 165 conference articles, and a few book chapters on various topics related to antennas, microwaves and electromagnetic radiation analysis with 11 inventory patents filed. Thus far, his publications have been cited 1990 times and his H-index is 25 (Source: Scopus). He is now handling many research projects from the Malaysian Ministry of Science, Technology and Innovation and Ministry of Education, and some international research grants from Japan. His research interests include communication antenna design, radio astronomy antennas, satellite antennas, and electromagnetic radiation analysis.