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V-Shaped Monopole Antenna with Chichena Itzia Inspired Defected Ground Structure for UWB Applications

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Abstract: Due to rapid growth in wireless communication technology, higher bandwidth requirement for advance telecommunication systems, capable of operating on two or higher bands with higher channel capacities and minimum distortion losses is desired. In this paper, a compact Ultra-Wideband (UWB) V-shaped monopole antenna is presented. UWB response is achieved by modifying the ground plane with Chichen Itzia inspired rectangular staircase shape. The proposed V-shaped is designed by incorporating a rectangle, and an inverted isosceles triangle using FR4 substrate. The size of the antenna is 25 mm×26 mm×1.6 mm. The proposed V-shaped monopole antenna produces bandwidth response of 3 GHz Industrial, Scientific, and Medical (ISM), Worldwide Interoperability for Microwave Access (WiMAX), (IEEE 802.11/HIPERLAN band, 5G sub 6 GHz) which with an additional square cut amplified the bandwidth response up to 8 GHz ranging from 3.1 GHz to 10.6 GHz attaining UWB defined by Federal Communications Commission (FCC) with a maximum gain of 3.83 dB. The antenna is designed in Ansys HFSS. Results for key performance parameters of the antenna are presented. The measured results are in good agreement with the simulated results. Due to flat gain, uniform group delay, omni directional radiation pattern characteristics and well-matched impedance, the proposed antenna is suitable for WiMAX, ISM and heterogeneous wireless systems.

Keywords: V-shape, monopole, gain, staircase, ultra-wideband, omni-directional, defected ground structure.

1 Introduction

The progressing of antenna in communication technology has seen an exponential growth over past two decades as wireless communication has much advantageous features in commercial applications [Abdullah, Kiani and Iqbal (2019); Altaf, Alsunaidi and Arvas (2017); Abdullah, Kiani, Abdulrazak et al. (2019); Liu, An and Zhang (2018)]. Ultra-

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wideband (UWB) antennas have become crucial need for higher data rates applications as most advance systems require more than a single frequency band. Unlike narrow band traditional antennas, UWB antennas offer higher data rates and channel capacity over a bandwidth [Iqbal, Smida, Mallat et al. (2019); Srivastava and Mohan (2015); Venkatachalam and Govindasamy (2019); Lu, Huang, Chattha et al. (2011); Pervez, Abbas, Muhammad et al. (2016)]. Their immunity to multipath propagation over narrow band antennas gives them upper edge in commercial products [He, Xie, Xie et al. (2019); Muhammad, Abbas and Li (2017); Chou, Liao, Chen et al. (2019)]. An UWB antenna technology covers the operating range of 3.1-10.6 GHz including applications for indoor and handheld devices according to standard protocol and spectrum of Federal Communications Commission (FCC) [Saeidi, Ismail, Wen et al. (2019)]. The compact antenna design for the portable devices is one of the critical concerns in the UWB system design [Khaleel, Al-Rizzo, Rucker et al. (2012); Rahman, Ko and Park (2017)]. The printed antenna lowers the volume of the UWB antenna by substituting the three dimensional planar antenna, thus it becomes easy to integrate it in the Printed Circuit Boards (PCB) and Radio Frequency (RF) circuits [Ali, Subhash and Biradar (2018); Jeong and Hwang (2010); Novak, Miranda and Volakis (2018)]. To achieve the higher data rate communication in the presence of existing wireless communication standards is the principal goal of UWB. The use of UWB signals in microwave imaging [Islam, Islam, Samsuzzaman et al. (2015); Moosazadeh, Kharkovsky, Case et al. (2016)], healthcare applications [Bharadwaj, Swaisaenyakorn, Parini et al. (2017); Foroutan and Nikolova (2019)], printed circuits [Andre, Rack, Nyssens et al. (2019)], and automated applications [Alsath and Kanagasabai (2015)] along with wireless communication needs suitable antennas between the UWB transceivers and the propagating medium as transducer. The UWB compact omni directional antenna designing with persistent gain and least group delay is one of the key tasks in antenna technology. Broadband planar monopole antennas have acknowledged substantial consideration owing to their noteworthy merits of larger impedance bandwidth, adequate radiation properties with easy fabrication. Cruz et al. [Cruz, Serres, de Oliveira et al. (2019)] have presented a UWB printed monopole antenna for high voltage insulation process. The design of monopole antenna is inspired from bio leaf model with overall dimensions of 37,944 mm^2. The partial discharging is sensed by good average mean effective gain of 3.6 decibels. Kumar et al. [Kumar, Krishna and Kushwaha (2013)] have found that the quasi triangular slots are etched in circular disc to obtain UWB response with nearly omni directional patterns. Slots in antennas if adjusted parametrically can result in multiple resonances over the frequency and band notch characteristics. A Tri-band notch characteristic is reported [Bakariya, Dwari and Sarkar (2015)] with half wavelength ring and circular slots on resonating patch covering UWB range up to 12 GHz. Resonances of antennas can be controlled using electronic components such as varactor diodes. Hua et al. [Hua, Lu and Liu (2016)] have achieved a UWB response using varactor diodes with stable radiation patterns and higher peak gain of 5.5 decibels.

In this paper, we present a V-shaped monopole antenna with defected ground structure of spiral shape staircase. Furthermore, the analysis of proposed simulated model is presented with measured results of fabricated version. The proposed antenna is designed with five basic shapes of rectangle with additional V-shaped cut in order to attain the higher bandwidth response with acceptable gain and omni directional radiation pattern.

The measured and simulated results show that the proposed antenna is well designed and is suitable candidate for UWB application systems.

The rest of this paper is sequenced as follows. In Section II, the geometry of the proposed antenna, equivalent circuit model and its parametric modeling is presented. Section III describes the fabricated results of the proposed antenna with simulated version and comparison with others work, follows by the Conclusion in Section IV.

2 Antenna design

Substrate selection can be vital consideration in antenna design process [Kiani, Mahmood, Altaf et al. (2018); Kiani, Mahmood and Altaf (2018)]. The Proposed V-shaped monopole antenna (Fig. 1) is designed on the low lossy FR4 substrate, having relative permittivity and thickness of 4.4 and 1.6 mm, correspondingly. On ground plane and front face of monopole antenna the copper sheet with thickness of 0.035 mm is used. The V-shaped cut is introduced in order to produce higher bandwidth response and stable radiation patterns with enhanced performance parameters. The antenna is fed by 50-ohm transmission line having thickness of 3 mm. The overall volume of the proposed V-shaped antenna is 25 mm×26 mm×1.6 mm. In order to introduce UWB response, the ground plane of the monopole antenna is shaped into the arrangement of spiral staircase at "Chichen Itzia" Defected Ground Structure (DGS). The proposed antenna is shown in Fig. 1, whose parameters are set as: CW=9.2 mm, GL=16.5 mm, SL=2 mm, SW=2 mm, SCH=4.1 mm, SCW=4 mm, H=2 mm, and DST=1.1 mm.

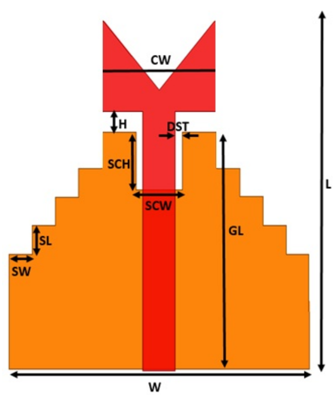
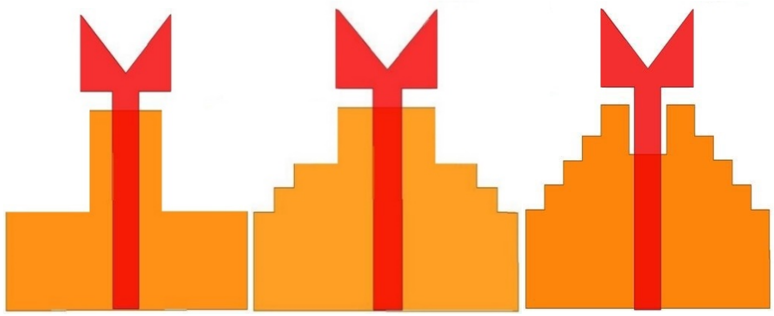


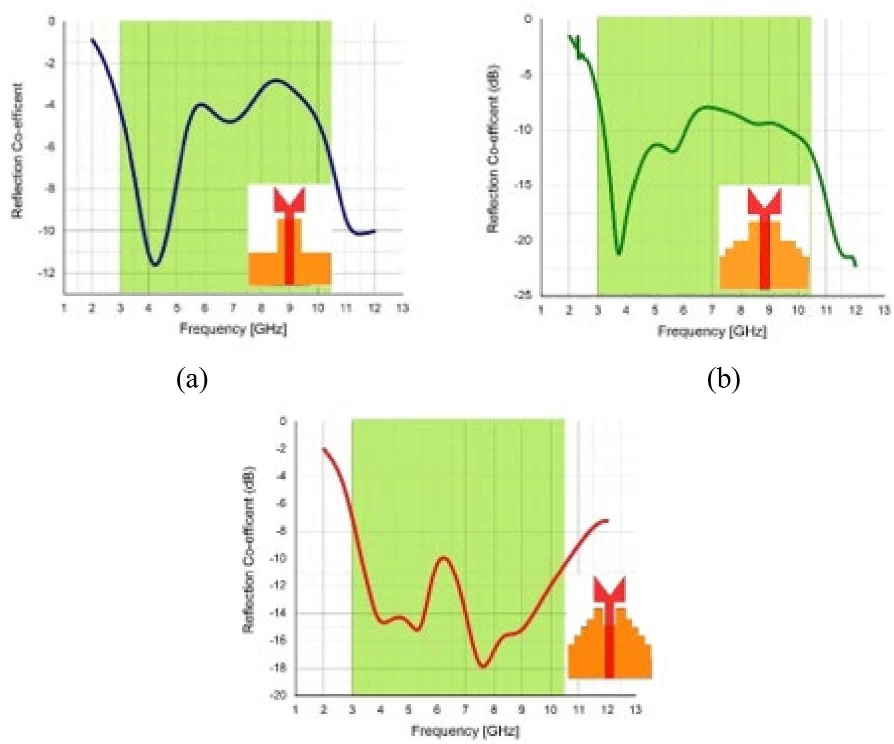
Figure 1: Proposed monopole antenna

The evolution of UWB V-shaped monopole antenna is shown in Figs. 2(a)-2(c). At first, the proposed antenna is introduced with simple ground plane with one third removed top as shown in Fig. 2(a). The one third removed ground plane produced the bandwidth response of approximately 1 GHz ranging from upper band of 4.8 GHz and lower band of 3.85 GHz as shown in Fig. 3(a). The monopole design is then introduced with staircase shape over a ground height of one third. This staircase arrangement of DGS produces two higher bandwidth responses; the first response of bandwidth i.e., 3 GHz ranging from 3.1 to 6.1 GHz (Fig. 3(b)) and second bandwidth response, ranging from 9.5 GHz and above (Fig. 3(c)). Figs. 4(a) and 4(b) show the Equivalent Circuit model of the proposed antenna and its impedance response. It is obligatory to develop equivalent circuit model of antenna for UWB receivers and transmitters [Iqbal, Smida, Alazemi et al. (2020); Iqbal, Alazemi and Mallat (2019); Iqbal, Bouazizi, Kundu et al. (2019); Iqbal, Saraereh, Bouazizi et al. (2018); Zebiri, Sayad, Elfergani et al. (2019)]. Antenna impedance should be matched with circuit model. As UWB antenna is composed of number of frequencies resonation, keeping that in mind the circuit model is derived from which well-matched impedance is achieved. Tab. 1, shows the RLC values of equivalent circuit model. The equivalent circuit model input impedance response both real and imaginary are well matched with EM model.



(a) (b) (c)

Figure 2: Proposed antenna evolution (a) Geometry-1 (b) Geometry-2 (c) Geometry-3



(a) (b)

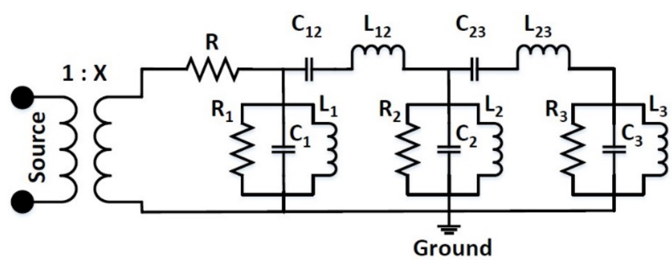
(c)

Figure 3: Reflection coefficient (a) Geometry-1 (b) Geometry-2 (c) Geometry-3

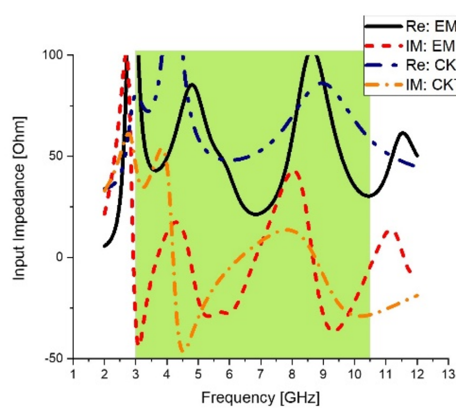
The proposed design of monopole antenna is parametrically adjusted by introducing the stairs (rectangular cuts) in the ground plane from bottom to top, as shown in Fig. 2(c). The proposed antenna is familiarized with a V-shaped cut which further helps to achieve complete UWB response. The simulated bandwidth response of proposed antenna is shown in Fig. 3(c).

Table 1: Equivalent circuit model RLC values

Component	Value	Component	Value	Component	Value
R1	1.96 kO	R2	72.4 O	R3	107.9 O
C1	1.16 pF	C2	1.45 pF	C3	0.88 pF
L1	1.04 nH	L2	0.66 nH	L3	1.38 nH
C12	1.22 pF	C23	1.02 pF	R	25 O
L12	0.68 nH	L23	0.86	nH X	1.14



(a)



(b)

Figure 4: (a) EM circuit model (b) Input impedance response of EM and equivalent circuit model

2.1 Parametric study

The proposed antenna design is parametrically adjusted in terms of number of stairs introduced in the ground plane and rectangular cut parameter i.e., SCH and SCW. The rectangular cut introduced in the middle of top staircase is observed with different values of 1 mm apart. The shift in reflection coefficient values with different values of square cut is shown in Fig. 5.

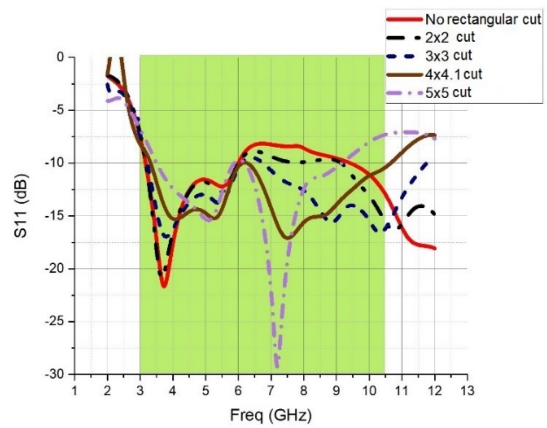


Figure 5: Reflection coefficient with different values of rectangular cut in the middle of top staircase

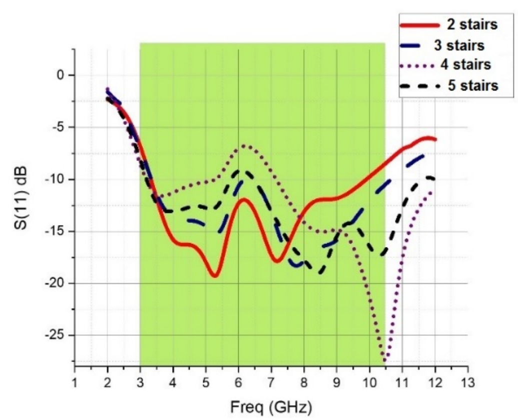
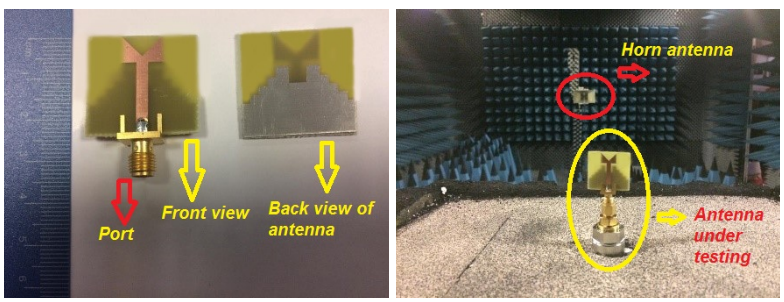


Figure 6: Reflection coefficient with different number of stairs in the ground plane

At no rectangular cut, the antenna shows dual bandwidth response with first response i.e., ranging from 3.1 to 6 GHz, and second response from 9.5 GHz and above which remain nearly unchanged at minute cut of 2 mm×2 mm size. The rectangular cut of size, 4 mm×4.1 mm produces higher desired ultra-bandwidth response however the rectangular cut of 3 mm×3 mm size, is missing the bandwidth of 1 GHz from lower band of 6 GHz and higher band of 7 GHz frequency. As the value of the rectangular cut is increased further (5 mm×5 mm), the bandwidth response shows a sudden decline and provides a frequency bandwidth from 3.3 GHz to 9.2 GHz. The rectangular stairs addition to the ground plane with respect to V-shaped monopole antenna is observed and adjusted for achieving high bandwidth. At first the two stairs are introduced which yield a bandwidth of nearly 7 GHz with lower and higher range of frequency from 3.1 GHz to 10 GHz approximately. After increasing the number of stairs to three, the bandwidth response of proposed monopole antenna shifts the higher range with increase of 1 GHz from that of previous one. Further increase in the number of stairs (four), show bandwidth behavior changing from UWB to dual band response as shown in Fig. 6. At exact including five rectangular stairs in the ground plane, the reflection coefficient behavior further exited down to narrow band.

3 Results and discussion

The proposed antenna is designed in Ansys HFSS 14, as well as fabricated and tested. The measured and simulated results show that the antenna is well assembled and designed. Fig. 7, shows the fabricated model of the proposed V-shaped antenna. The proposed antenna is tested in the anechoic chamber for results validation. Fig. 8, shows the reflection coefficient and bandwidth response of the antenna i.e., simulated and measured. The measured results depict good resemblance with the simulated one.



(a) (b)

Figure 7: (a) Fabricated prototype of antenna (b) Antenna for testing in anechoic chamber

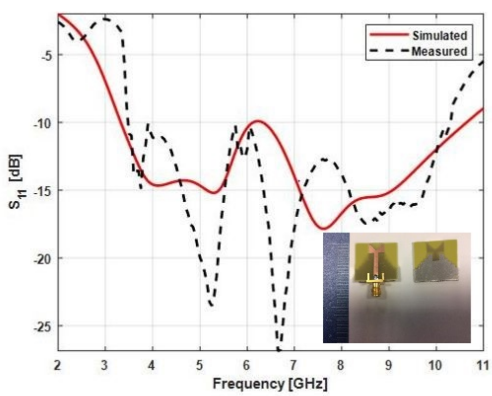
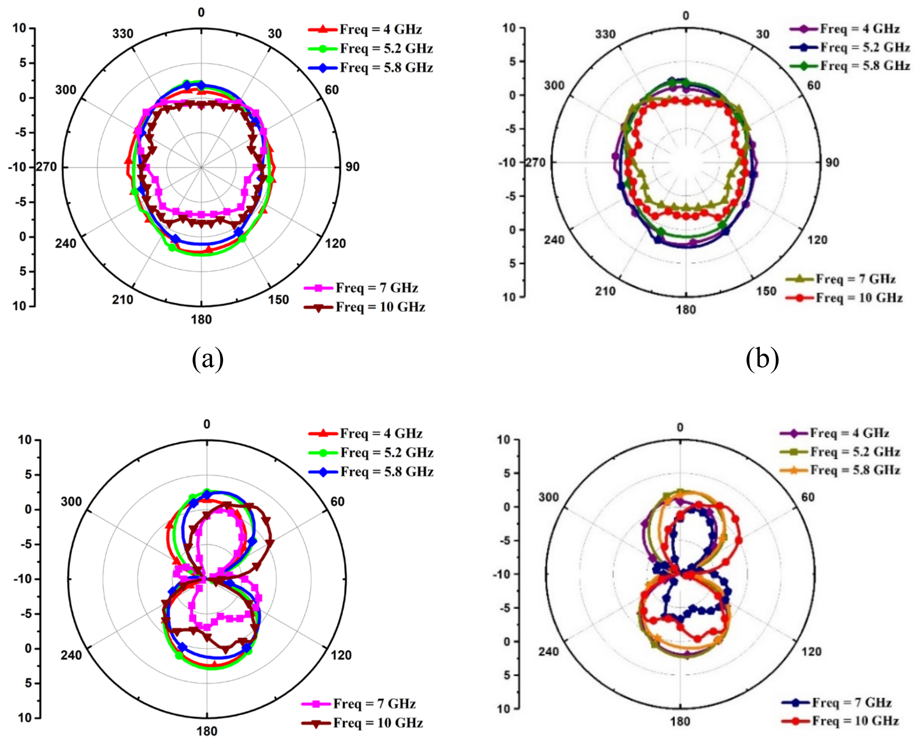


Figure 8: Simulated and measured reflection coefficient comparison

The radiation patterns of proposed V-shaped antenna are shown in Fig. 9. The simulated and measured polar radiation patterns at the frequency of 10.0 GHz, 7.0 GHz, 5.8 GHz, 5.2 GHz and 4.0 GHz in the YZ-Plane or H-Plane are shown in Figs. 9(a) and 9(b), respectively. Figs. 9(c) and 9(d), show the simulated and measured XZ-Plane or E-Plane polar radiation patterns at the above-mentioned frequencies. The E-plane patterns show the similar response like a bowtie and dipole antenna radiation pattern, while the H-Plane patterns at the desired frequencies show the omni directional radiation pattern, making them suitable for sensor applications.



(a) (b)

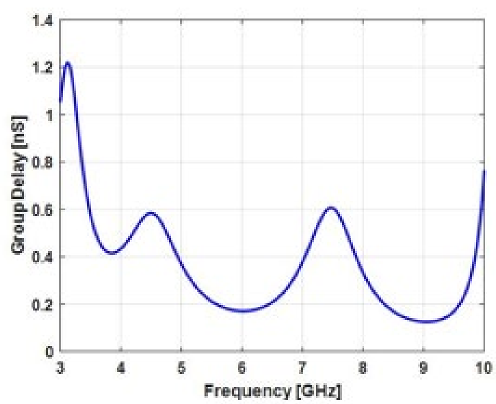
(c) (d)

Figure 9: (a) Simulated YZ or H plane radiation pattern (b) Measured YZ or H plane radiation pattern (c) Simulated XZ or E plane radiation pattern (d) Measured XZ or E plane radiation pattern

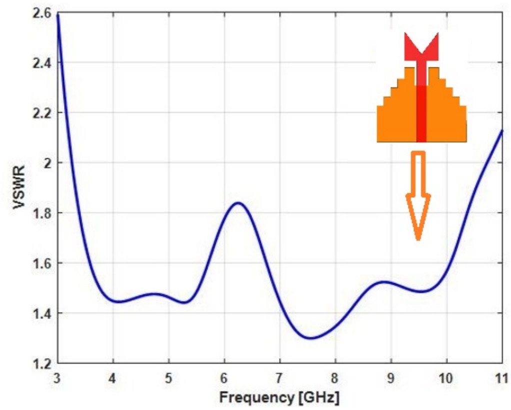
Table 2: Comparison of the proposed design with the literature designs

Reference	Antenna Size (L×W) mm	Bandwidth (GHz)	Peak Gain (dB)
[Parchin, Basherlou, Abd-Alhameed et al. (2019)]	40×28	Dual Band (2.2-2.6) and (5.3-5.6)	4.00
[Cruz, Serres, de Oliveira et al. (2019)]	314×121	UWB (3.40-8.0)	4.01

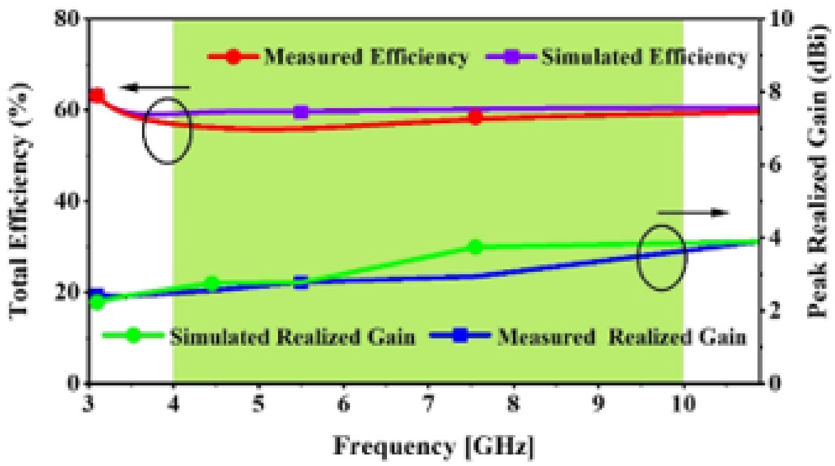
[Kumar, Krishna and Kushwaha (2013)]	50×35	UWB (4.00-12.0)	5.80
[Bakariya, Dwari and Sarkar (2015)]	31×21	UWB (3.00-15.0)	2.50
[Hua, Lu and Liu (2016)]	42×30	UWB (2.80-11.9)	5.50
[Zhao, Huang and Jiang (2019)]	18×16	Wide band (5.0-11.0)	1.60
[Zhang, Zhong, Zhou et al. (2019)]	17×22	UWB (2.90-1.04)	2.00
[Li, Zhang, Yin et al. (2016)]	34×18	Tri-Band (2.41-2.70, 3.32-3.72, 5.39-5.74)	4.79
[Hussain, Sharawi and Shamim (2018)]	120×160	WB (1.77-2.51)	3.20
[Mathur and Dwari (2018)]	36×36	UWB (3.10-10.6)	4.00
[Kubacki, Czyzewski and Laskowski (2018)]	27×31	UWB (4.00-13.5)	4.50
[Amin, Saleem, Shabbir et al. (2019)]	40×40	UWB (3.10-10.6)	4.00
Proposed Work	25×26	UWB (3.10-10.9)	3.83



(a)



(b)

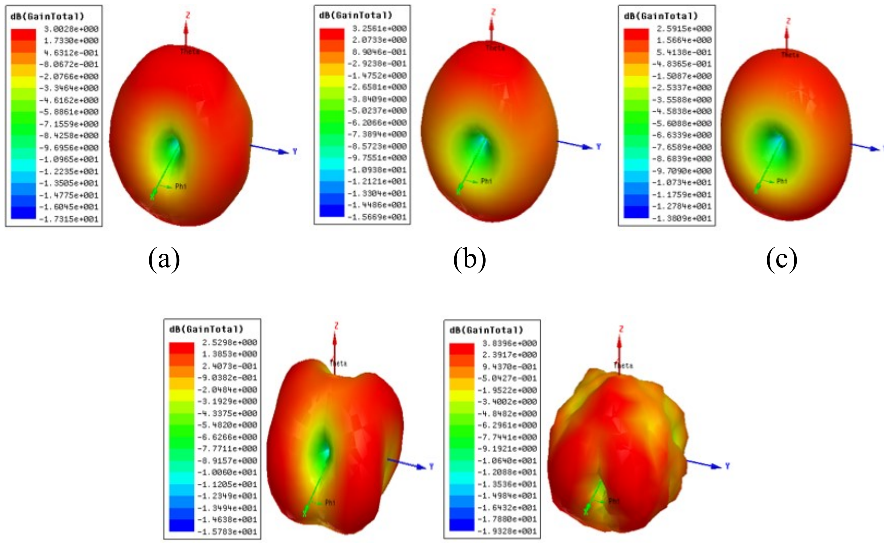


(c)

Figure 10: (a) Group delay of proposed monopole antenna (b) VSWR graph (c) Simulated and measured efficiency with peak gain of the proposed antenna

Group delay is used to measure the alteration of signals in antenna design. For simulating group delay with distance of 30 cm apart; the proposed V-shaped antenna is placed and tested. The flat group delay makes this antenna suitable for many useful applications. The VSWR graph over the entire bandwidth shows minimum VSWR value as depicted in Fig. 10b, and over selected frequencies of 10.0, 7.0, 5.8, 5.2 and 4.0 GHz; the value of VSWR is observed in the range of 1.2 and 1.6 which shows that proposed antenna holds well matched impedance. The simulated and measured graph of efficiency with peak gain is presented in Fig. 10(c), which show that the antenna measured, and simulated results are nearly alike.

Fig. 11, depicts the 3D radiation patterns of the proposed V-Shaped monopole antenna. The omnidirectional radiation pattern (Fig. 11) is observed at the desired frequencies i.e., 5.8, 5.2 and 4.0 GHz with a peak gain of 3.00, 3.25 and 2.59 dB, respectively. The 3D radiation pattern at the frequency band of 7 and 10 GHz (Figs. 11(d) and 11(e)) is nearly omnidirectional in the H-plane with some deformation in donut shape pattern with a peak



(a) (b) (c)

(d) (e)

Figure 11: 3D gain patterns of the designed Antenna at the desired frequencies of (a) 5.8 GHz (b) 5.2 GHz (c) 4.0 GHz (d) 7.0 GHz (e) 10.0 GHz

gain of 2.52 and 3.83 dB, respectively. It is seen that the gain of proposed antenna is nearly uniform over the entire UWB range. The performance comparison of proposed V-shaped monopole antenna with previous published literature is given in Tab. 2.

4 Conclusion

In this paper, a novel and compact V-shaped monopole antenna for UWB application is presented. The V-shaped antenna is consisted by a rectangular cut in the middle of a top staircase and staircase defected ground structure, which produce ultra-wideband response of almost 8 GHz. The proposed antenna is simulated using the HFSS software and as well as fabricated with testing in the anechoic chamber. The simulated and fabricated model results show a good resemblance with stable gain ranging from 2.52 dB to 3.83 dB. The proposed antenna shows a nearly omnidirectional radiation patterns in the H-Plane, while the E-Plane radiation patterns are observed alike bowtie and dipole antenna. The simulated and measured results agreement makes proposed antenna suitable for WiMAX, ISM, microwave imaging, Ultra-wideband applications and heterogeneous wireless systems.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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