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Research Article

Compact Single Layer CPW-Fed Antenna with Hexagonal Slot for Ultra Wideband Applications

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Abstract

A new compact single layer ultra-wideband patch antenna is proposed. The antenna operates from 3.05 GHz to 10.9 GHz in the ultra-wide bandwidth range, which is more than the standard, set by FCC. The planar antenna is printed on FR-4 substrate material with a relative permittivity of 4.3 los tangent of 0.025. The structure is simple in design, small in size with total dimensions of 24 mm x 24 mm x 0.9 mm, and easy to fabricate. The measurements of the fabricated design compares well with simulation results. The overall characteristics of the planar antenna show that the design is well suitable for UWB applications. The presented compact antenna demonstrates higher performance compared with similar size recently published designs.

Keywords: *Ultra-Wide band antenna; planar monopole; patch; coplanar waveguide feeding; UWB applications.*

1. Introduction

In the last decade, a huge demand for wireless communications due to the unlimited wireless lifestyle uses. Since the wireless communications services privileges, a continuous rapid growth in the market of wireless systems. Modern wireless systems are attempting to provide a wide range of diverse applications for example data and video to greatest number of mobile users with extreme the highest possible data rates. Nevertheless, these systems are restricted due to the limited resources such as frequency spectrum and power. Consequently, new technologies that are capable to overcome these bounds are necessary (Arslan, *et al*, 2006).

Currently, the ultra-wide bandwidth UWB technology is a potential approach to various wireless communication systems. The past of ultra-wideband is made on the concept of impulse radio since very high data rates have been transmitted using energy pulses instead of a narrowband frequency carrier (Liang, 2006).

In 2002 federal communications commission (FCC) specified a new regulation for the technology of ultra-wide band (UWB) by releasing an unlicensed wide frequency band.it is from 3.1 GHz to 10.6 GHz, which is a bandwidth of 7.5 GHz (FCC, 2002).

Because decreasing the antenna dimensions is one of the Critical issue in wireless communication, some designs features have been sacrificed in order to reduce the size of UWB antennas; thus, it can be inserted inside any UWB device easily (Gautum, *et al*, 2013) (Nouri and Dadashzadeh, 2011). On the other hand, many researchers are keeping the antennas sizes are large in order to keep the structure characteristics excellent such as wider bandwidth, Omni radiation patter, and higher gain values. Therefore, it is a challenging issue to reduce the antenna size while maintaining excellent results and most of the research in this area is focused on improving the structure, by reducing size, lower cost and simplicity, without losing much in the performance. (Yang, *et al*, 2013), (Zaker and Abdipour, 2011), (Sarifi, *et al*, 2011).

Ultra wide band antennas are characterized by several great advantages that make them attractive and fascinating technology over the recent years. They support exceptionally high data rates and capacity while they consume low power (Malay Yadav, 2012). Furthermore, they function over a wide frequency spectrum, which sort them useful for many applications (Oppermann, *et al*, 2004).

Table 1 provides a comparison between this work and some of the recent published designs for UWB applications. It can be observed that this antenna has a higher performance than most of the others, which are close in structure size. In other words, the proposed compact antenna is compatible with larger UWB antennas in terms of gain and operating frequency features.

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Table 1 Comparison of this work with recent published designs in terms of size, gain, and covering entire UWB

Antenna	Size (mm^2)	Gain (dBi)	Standard UWB (3.1-10.6 GHz)
(Shambavi, *et al*, 2012)	49x53	3 to 7	Completely covered
(Fugou Zhu, *et al*, 2013)	36x35	1.7 to 8	Completely covered
(Azim, *et al*, 2013)	22x 24	2 to 4	Completely covered
(Zhu, *et al*, 2012)	26x28.5	-4 to 3	Completely covered
(Srifi, *et al*, 2011)	30x35	-4 to 4	Completely covered
(Wu, *et al*, 2010)	30x35	Not Stated	Completely covered
(Zhu, *et al*, 2012)	38x39	1.73 to 5	Partially covered
This design	24x24	2.7 to 7	Completely covered

Table 2 the structure dimensions in mm of the designed UWB antenna

Parameter	W	L	r	a	L_g
Value (mm)	24	24	7.5	1	7
Parameter	W_g	W_f	s	d	h
Value (mm)	10.5	2.2	2	2	0.9
Parameter	b	C	L_f	g	t
Value (mm)	4	5	9	0.4	1

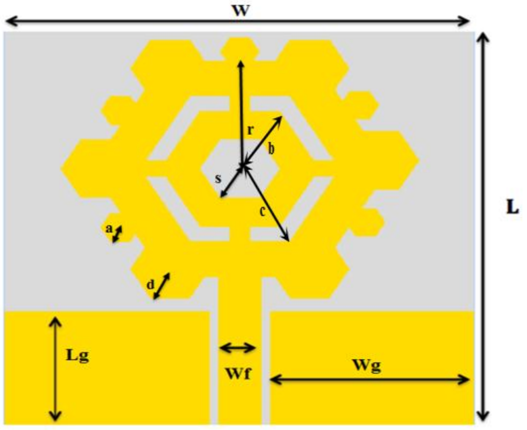


Fig.1 top view scheme of the UWB antenna labeled with the structure parameters

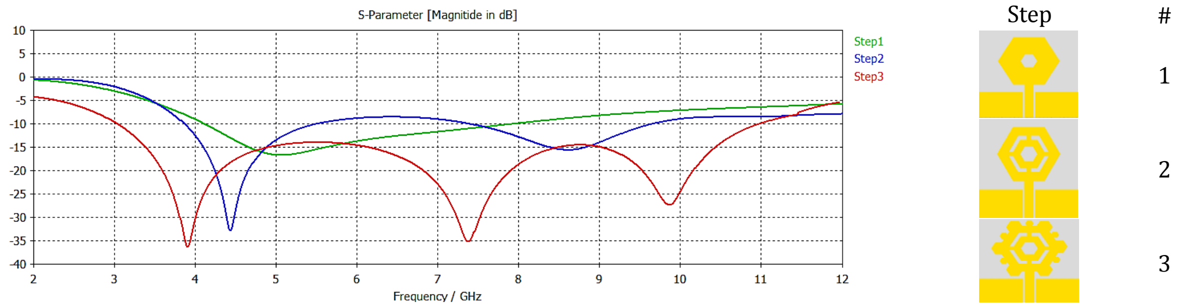


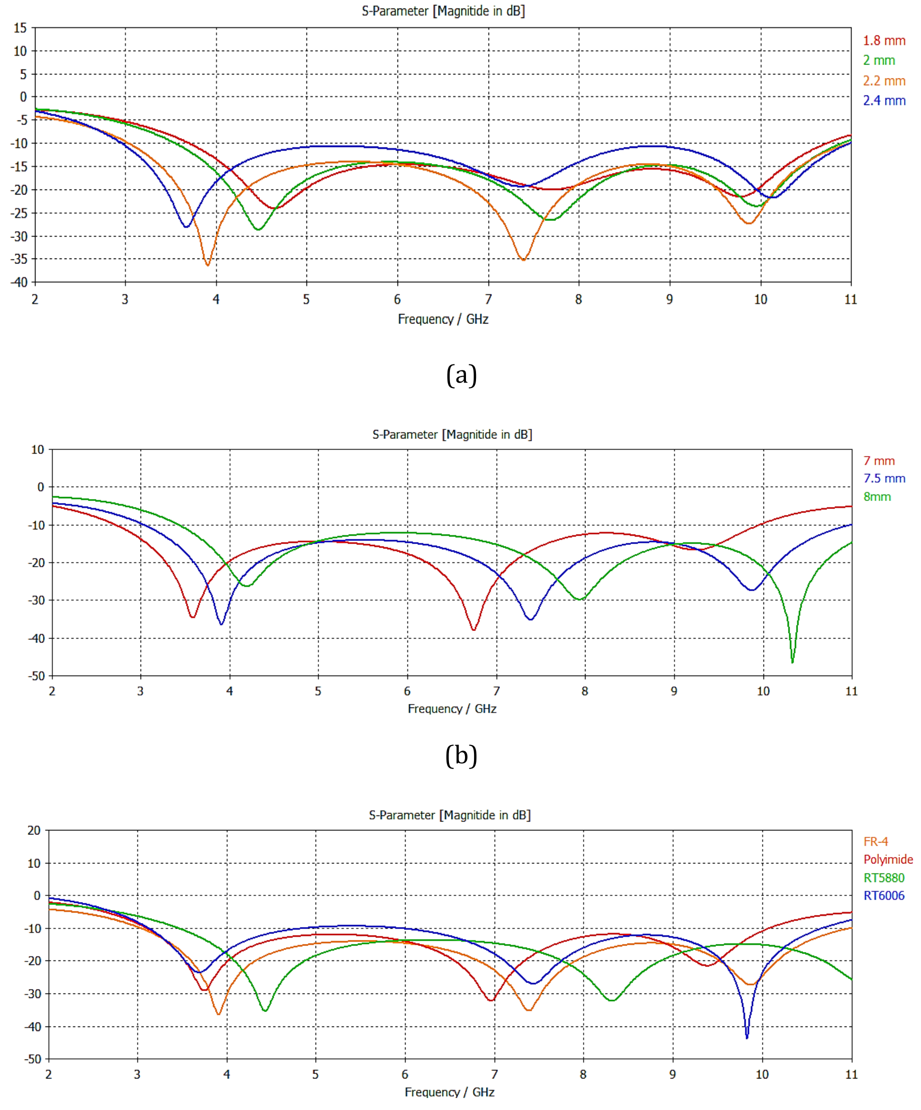
Fig.2 The effects on the operating frequency (a) for three major designing steps (b) of the proposed antenna

2. Antenna structure

The structure of the designed antenna is displayed in figure 1 and it is labeled with the dimensions. Coplanar waveguide (CPW) is the used feeding technique as revealed in figure 1 with 50 ohms characteristics impedance. Generally, CPW feeding technique is more favorable than many other feeding methods such as microstrip line or coaxial. This is because it makes the antenna more suitable for most of compact wireless devices due to easiness in fabrication, and applicability to single layer structures (Deepti Das Krishna, 2010). Besides, CPW method produces mutual coupling between the structure and the adjacent lines that may enhance the radiation (Zhu, *et al*, 2009). The presented patch is a kind in the category of printed planar antennas, which are very attractive in ultra-wideband UWB systems due to the excellent virtues of light in weight, low cost, and easy in fabrication (Deepti Das Krishna, 2010).

Figure 1 shows the designed antenna labeled with parameters and they are given in table 2. The proposed antenna, which is made of copper material, is printed on a substrate of FR4 material with relative permittivity of ε_r =4.3 and los tangent of 0.025. The substrate has a thickness of 0.9 mm, length of 24 mm, and 24 mm width. The designed feeding microstrip line is 2.2 mm wide and 9 mm long. It is connected to the radiating elements, which are composed of one main hexagonal element partially containing six small hexagonal elements with radius of 2 mm and other five smaller hexagonal radiators with radius of 1 mm for each of them. The main radiator has a radius of 7.5 mm, which has a small hexagonal slot at the center as revealed in figure 1. These radiating elements are placed precisely in the accurate position due to the sensitivity of the design.

The proposed planar antenna has been developed and designed in three main steps as illustrated in figure 2 and various adjustments have been tried in between. It can be noticed from step 2 that the slots in the main radiator increase the impedance matching between the feeding line and radiator, which leads to wide bandwidth. Step 3 at which six radiating elements have been placed at the edges of the main radiator and additional smaller five elements. All the radiating parts have the hexagonal shape. At this step, the operating frequency becomes wider and covers the entire UWB. Many iterations of the design widths and heights have been studied in order to optimize the simulation results. The designed patch antenna parameters after optimization are displayed in table 1. The next section presents the simulations results and the experimental measurements with detailed discussions.



(a)

(b)

(c)

Fig.3 Parametric and material studies on the proposed antenna: (a) feeding line width (w_f), (b) main hexagonal radiator size, and (c) different substrate materials.

3. Simulation Results and Analysis

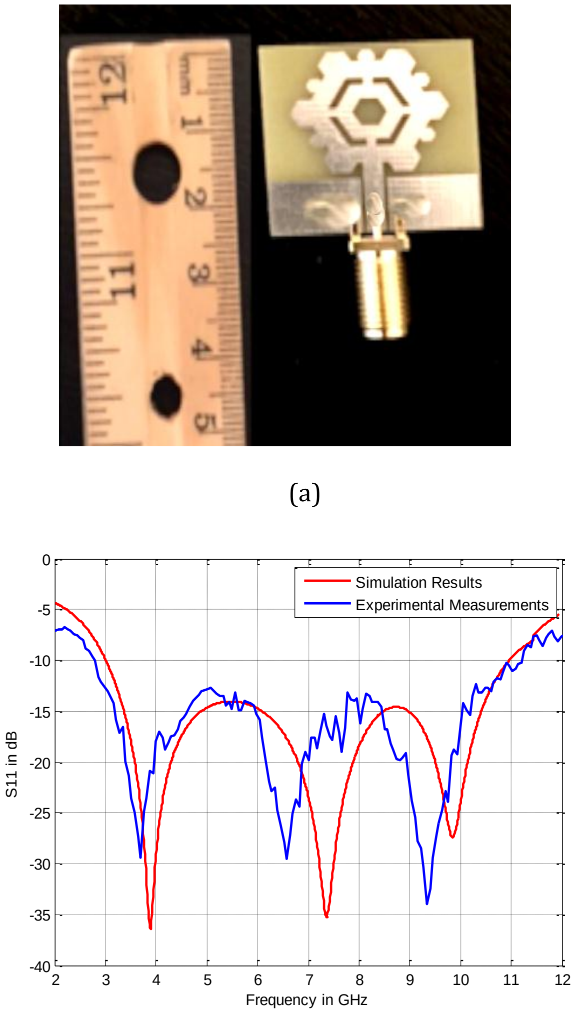
The proposed compact antenna has been designed and simulated using industry standard simulation code. The antenna performance demonstrates that it has an ultra wide band frequency (from 3.05 GHz to more than 10.9 GHz), which covers the complete UWB set by FCC. Typically, a microstrip antenna has one resonant frequency; thus, its bandwidth is not ultra wide band. Then, having many overlapped resonant frequencies can result into an ultra wide band. The majority of the designed ultra wide band antennas are based on this concept (Kang, *et al*, 2012). Therefore, the operating frequency has three resonant frequencies, which are 3.9 GHz, 7.4 GHz, and 9.9 GHz. The wide operating frequency is due to the good impedance matching over its wide bandwidth. The excellent impedance matching translates to high antenna efficiency and power transfer (Hans schantz, 2005).

As part of the design analysis, the structure parameters have been studied and optimized. Figure 2 (a) displays the reflection coefficient $|S_{11}|$ plots in dB for different feeding line width (w_f) values, which are 1.8, 2, 2.2, and 2.4 mm. It is clear that as the feeding line width decreases such as 2 mm or less, the impedance matching of the antenna declines. Consequently, the drawback in the reflection coefficient values will reduce the ultra wide bandwidth based on -10 dB standard. So, a feeding line width of 2.2 mm is the most appropriate for this design. Additionally, the proposed antenna has been investigated with different radiuses of the main hexagonal radiator. The radiuses are 7 mm, 7.5 mm, and 8 mm and the simulation $|S_{11}|$ plots are shown in figure 3 (b). The plots illustrate some likeness between the three iterations in terms of number of resonant frequencies. Yet, the simulation results of $|S_{11}|$ for r=7.5 mm provides the most wide bandwidth that cover the complete UWB set by FCC. Also, from figure 3 (c), it has been distinctly observed that using FR4 material with ε_r =4.3 for this design as a substrate provides the optimum simulation results. In addition, FR-4 is easily found with low cost in fabrication market compared to many other materials. The reflection coefficient and operating frequency for several substrate materials such as FR4 ($\varepsilon r = 4.3$), duroid RT 6006 ($\varepsilon r = 6.15$), and duroid RT 5880 ($\varepsilon r = 2.2$) have been simulated and studied as illustrated in the previous figure.

3. Fabrication and measurements

It should be noted that all the tables must be firstly drawn in Excel and after that they should be placed in your article. The heading of the table should be above the table. An example is given as under.

Federal Communication Commission (FCC) has regulated the maximum boundary of power emission for UWB communication systems devices and it is set to be -41.3 dBm/MHz (FCC, 2002). The limit is set to be very small to stop UWB applications from causing interference to other wireless systems.



(a)

(b)

Fig.4 (a) A prototype of the presented planar antenna and (b) Simulated and experimentally measured reflection coefficient in dB as a function of frequency in GHz

This antenna, due to its high gain values, is able to reach the EIRP value with low input power. Consequently, the high gain levels can make the battery life longer which is an significant improvement for wireless communication systems. Figure 5 presents the normalized to the peak value radiation pattern of the proposed antenna for the three resonant frequencies, which are 3.94 GHz, 7.41 GHz, and 9.9 GHz. It shows the radiation pattern of the E plane (elevation plane) and H plane (azimuth plane) in polar forms. During the operating bandwidth, the radiation pattern of H plane is clearly omni-directional pattern and the E plane is almost in bidirectional shape with minor distortion at the third resonant frequency. Therefor, the proposed patch antenna is suitable for ultra wideband applications since the monopole antenna has omnidirectional radiation, which means that it is independent of placement orientation. Furthermore, the simulated and measured antenna gain are plotted in figure 6 over its bandwidth, and it reveals that the design high gain values with average about 5 dB.

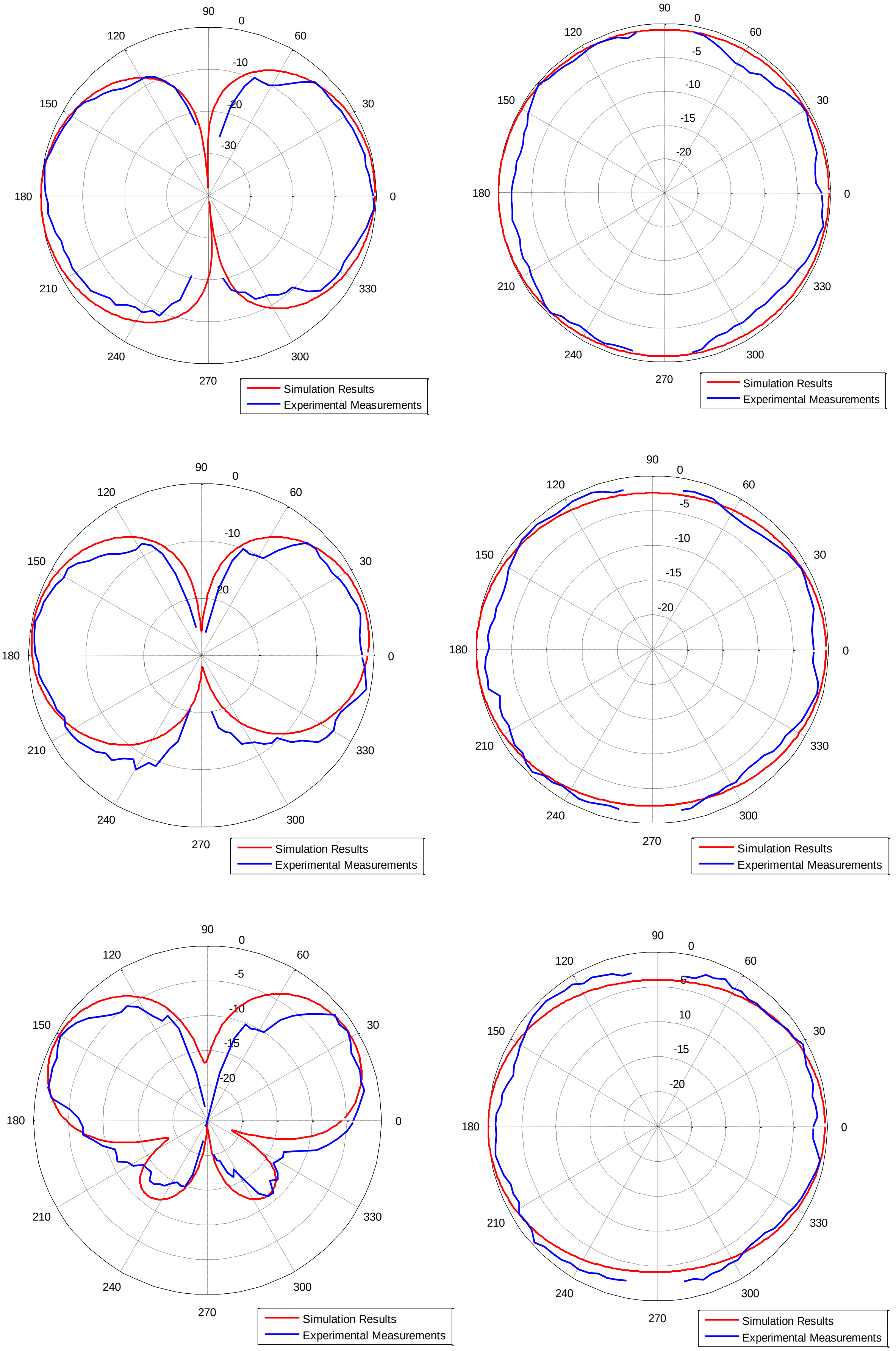


Fig.5 Normalized radiation pattern for E (a) and H (b) planes in polar form at 3.94 GHz, 7.41 GHz, and 9.9 GHz for both simulation results and experimental measurements

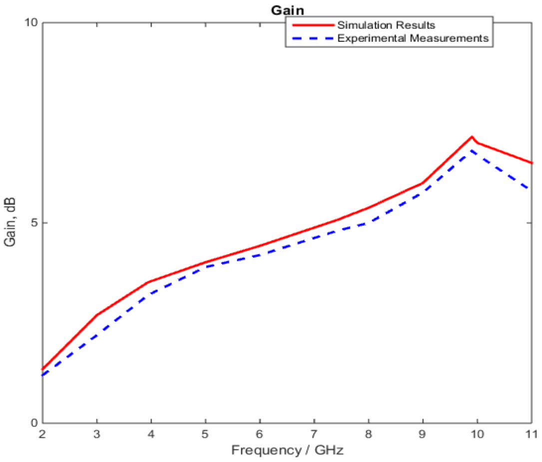


Fig.6 The simulated and measured antenna gain in dB over the frequency in GHz showing high values

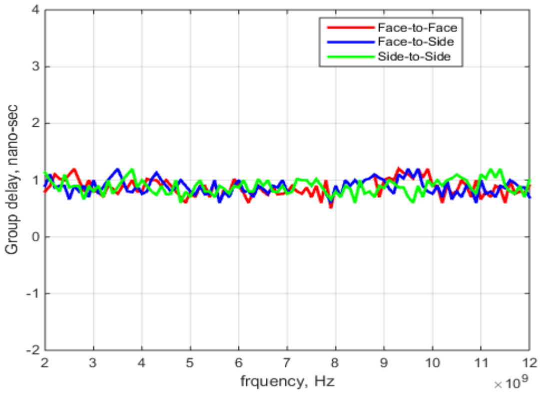


Fig.7 The measured group delay of the designed patch antenna in three situations: face-to-face, face to side, and side-to-side alignments.

Group delay is calculated in order to verify that no distortion occurred to the transmitted signal. It can be calculated from the phase of S21 where two identical antennas are placed face-to-face, face to side, and side to side with separation distance of 250 mm. The two antennas are placed inside anechoic chamber in order to prevent multipath reflections from any scatterer. The relationship between the group delays and the phase of S21 is shown below (Gabriela, 2010):

$$\tau = \frac{-d\phi(w)}{\mathrm{dw}} \qquad (1)$$

A linear phase gives a constant group delay while the deviations of the phase means variations in the group delay time. The average transit time through two antennas or ports systems is characterized by the average group delay (Agilnet, 2005). Therefore, an excellent UWB antenna should have almost stable group delay over the operating frequency. Fast variations or spikes in the group delay signal could produce a distortion in the transmitted signal which might lead to inter-symbol interference (ISI). Usually, group delay in the range of few nanoseconds or less and small variations are very common and acceptable.

The group delay of this designed antenna has been calculated using the previous equation from the phase of the S21. For all the three situations, which are side-to-side, face-to-side, and face-to-face, the antenna has almost stable delay time with an average of 1 nanosecond during the entire UWB. Figure 7 demonstrates the measured group delay as a function of frequency in the three orientations.

Conclusions

In conclusion, a new single layer design of an ultra wideband (UWB) antenna has been designed, simulated and experimentally measured. The antenna is simple in structure, very compact size, not complicated in fabrication, and low in cost. Also, the design results demonstrate high performance in terms of impedance matching, gain values, and Omni directional radiation pattern. Furthermore, the proposed antenna has a very wide bandwidth from 3.05 GHz to 10.9 GHz, which covers the entire UWB set by FCC for such applications. In addition, proposed antenna is compatible in performance with larger size previously published UWB antennas. Thus, this design is appropriate for ultra wideband applications.

References

Arslan, H.; Chen, Z. & Benedetto, M. (2006), Ultra Wideband Wireless Communication, John Wiley & Sons, Inc., 0471715212, New Jersey.

J. Liang (2006), Antenna Study and Design for Ultra Wideband Communication Applications, PhD Thesis, University of London, United Kingdom.

Federal Communication Commission (2002), First Report and Order, Revision of Part15 of the Commission's Rules Regarding Ultra-Wideband Transmission System, FCC 02 48.

A. Gautam, S. Yadav, and B. Kanaujia (2013), A CPW Fed Compact UWB Microstrip Antenna, IEEE Antennas and Wireless Propagation Letters, vol.12, pp. 151 – 154.

A. Nouri and G. Dadashzadeh (2011), A Compact UWB Band-Notched Printed Monopole Antenna With Defected Ground Structure, IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 1178-1181.

X. Yang, L. Liu, S. Cheung, and Y. Sun (2013), A Simple UWB Monopole Antenna using Half-elliptical Radiator, IEEE International Workshop on Antenna Technology, pp. 145-149.

R. Zaker and A. Abdipour (2011), Bandwidth enhancement and miniaturizationof fork-shaped monopole antenna, IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 697–700.

M. Sarifi, S. Podilchak, M. Essaaidi, and Y. Antar (2011), Compact Disc Monopole Antennas for Current and Future Ultra wideband (UWB) Applications, IEEE Transactions on Antennas and Propagatio, vol. 59, no. 12, pp. 4470-4480.

Malay Yadav (2012), Coplanar Waveguide Fed UWB Antenna with Dual Band Notch Characteristics," Master Thesis, Thapar University.

I. Oppermann, M. Hamalainen and J. Iinatti (2004), UWB Theory and Applications" John Wiley & Sons.

K. Shambavi And Zachariah C. Alex (2012), Design Of Printed Dipole Antenna For Ultra Wideband Applications, Microwave And Optical Technology Letters / Vol. 54, No. 3.

Fuguo Zhu, Steven Gao, Anthony T. S. Ho, Chan H. See, Raed A. Abd-Alhameed, Jianzhou Li, And Jiadong Xu (2013), Compact-Size Linearly Tapered Slot Antenna For Portable Ultra-Wideband Imaging Systems, International Journal Of RF And Microwave Computer-Aided Engineering/Vol. 23, No. 3.

Rezaul Azim, A. Toaha Mobashsher, And M. Tariqul Islam (2013), Ultra-Wideband Slot Antenna With Notched Band For World Interoperability For Microwave Access, International Journal Of Communication Science And Engineering Vol:7 No:7.

F. Zhu, S. Gao, A.T.S. Ho, C.H. See, R.A. Abd-Alhameed, J.Li, and J. Xu (2012), Design And Analysis Of Planar Ultra-Wideband Antenna With Dual Band-Notched Function, Prog Electromagn Res 127, 523–536.

Mohamed Nabil Srifi, Symon K. Podilchak, Mohamed Essaaidi, And Yahia M. M. Antar (2011), Compact Disc Monopole Antennas For Current And Future Ultrawideband (UWB) Applications, IEEE Transactions On Antennas And Propagation, Vol. 59, No. 12.

Wu, S and J. (2010), Study Of An Ultra-Wideband Monopole Antenna With A Band-Notched Open-Looped Resonator," IEEE Trans. Antennas Propag., Vol. 58, No. 6, 1890,1897.

F. Zhu, S. Gao, A.T.S. Ho, R.A. Abd-Alhameed, C.H. See, J.Z. Li, And J.D. Xu (2012), Miniaturized Tapered Slot Antenna With Signal Rejection In 5–6 Ghz Band Using A Balun, IEEE AntennasWireless Propag Lett 11, 507–510.

Deepti Das Krishna (2010), Investigations On Broadband Planar Monopole And Slot Radiators And Their Suitability For UWB Applications," PhD Thesis, Cochin University Of Science And Technology Cochin-682022, India.

X. Zhu, Y. Li, S. Yong, and Z. Zhuang (2009), A novel defnition and measurement method of group delay and its application,_ IEEE Trans. Instrum. Meas., vol. 58, no. 1, pp.229_233.

C.-H. Kang, S.-J.Wu, and J.-H. Tarng (2012), A novel folded UWB antenna for wireless body area network, IEEE Trans. Antennas Propag., vol. 60, no. 2, pp. 1139–1142.

Hans Schantz, The Art and Science of Ultrawideband Antennas, Artech House, Boston, Mass, USA.

Gabriela Quintero Diaz De Leon (2010), Analysis and Design of Ultra-Wideband Antennas in the Spectral and Temporal Domains, PhD Thesis, Ecole Polytechnique Federale De Lausanne.

Understanding the Fundamental Principles of Vector Network Analysis (2005), Application Note 1287-1 Ed., Agilnet Technologies.