# Bandwidth Enhancement of Slot Antenna Using Fractal Shaped Isosceles for UWB Applications

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***Abstract* –** In this paper, a coplanar waveguide (CPW) fed slot antenna using fractal shaped isosceles trapezoidal corrugations is designed and presented for Ultra-Wideband (UWB) applications. The proposed antenna is formed by a regular hexagonal patch fed through a CPW feed line and radiates amidst a notched wide hexagonal slot. The edge of the wide slot is shaped by a fractal structure that is formed by five trapezoidal notches. The antenna is printed on RO4350B substrate having a compact size of $0.305\lambda_0 \times 0.313\lambda_0 \times 0.012\lambda_0$ at 2.35 GHz. Good agreement is registered between the experimental results of the fabricated prototype and the calculated ones. By using an Agilent 8722ES vector network analyzer, the fabricated prototype confirms that the antenna has an excellent matching impedance over the bandwidth 2.35-10.65 GHz (127%) which covers the entire UWB band. Furthermore, good radiation performances are measured in an anechoic chamber. Consistent radiation patterns with a reasonable peak gain are measured over the entire working bandwidth. Therefore, the designed structure may be worthy considered for different wireless communications systems.

***Index Terms* –** coplanar waveguide (CPW), fractal antenna, isosceles trapezoidal corrugations, slot antenna, ultra-wideband (UWB) antenna.

## I. INTRODUCTION

Over the last few years, the appliance of the Ultra-wideband (UWB) technologies for modern wireless communication systems has received much appreciation owing to their promote features over a wide transmission capacity, such as low power level consuming, low signal disturbances, opportunity of low-cost transceivers, simplicity, and higher data transmission rate [1–3]. UWB systems have attracted enormous preoccupation due to the large bandwidth of 7.5 GHz extending from 3.1 to 10.6 GHz, which was attributed by the FederalCommunications Commission in February 2002 [4]. In today's world, UWB technology has been applied for several applications, such as radar detection, satellite communications, and vehicular communications systems [5]. Recently, enormous attempts have been concentrated on the expansion of UWB microwave components to become more compact and to improve their performances [6]. Typically, printed monopole planar antennas offer the main requirements and considered as excellent devices for UWB applications; dues to the characteristics that are proposed, such as low cost, low profile, compact sizes, possibility of incorporation with other RF devices, larger bandwidth, and consistent radiation patterns with acceptable gains over the considered bandwidths. For these reasons, the development of UWB antennas has spurred academic and industrial research. In recent few

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years, several UWB planar antennas with miscellaneous configurations have been designed. In this respect, various techniques have been used to improve the main requested bandwidth such as the use of large etched slot in the ground plane as in [7]. Another method is to use fractal structures that are also able to diminish the attributed size and to enhance the antenna adaptation as in [8]. Unfortunately, most of the existing antennas in the literature don't cover the entire licensed UWB bandwidth and/or have complex and large configurations. In [9], an octagonal ring shaped antenna was proposed for UWB application. However, the main disadvantage of this antenna is that it doesn't cover the entire licensed UWB range. A bi-directional tapered slot antenna that has a large size of $55 \times 48 \times 1.5$ mm$^3$ has been proposed in [10]. A probe-fed hexagonal UWB antenna with AMC reflector having a complex structure and a bulky size of $100 \times 100 \times 15$ mm$^3$ has been proposed in [11]. A narrow-band Fabry Perot cavity UWB antenna that has a complex structure and a large size of $169 \times 169 \times 38.46$ mm$^3$ has been introduced in [12]. In [13], a narrow band antipodal UWB Vivaldi antenna that has a complex structure and a bulky size of $100 \times 104 \times 1.5$ mm$^3$ has been proposed. A closed loop resonator based compact UWB antenna that has a complex structure and a large size of $100 \times 100 \times 16$ mm$^3$ has been proposed in [14]. A complex geometry that covers only the frequency range of 1.31 – 6.81 GHz has been presented in [15].

## II. ANTENNA CONFIGURATION AND DESIGN

The geometrical configuration of the proposed wide hexagonal slot fractal antenna is presented in Fig. 1. It is designed using RO4320B substrate having a relative permittivity $\varepsilon_r$= 3.66, a thickness of 1.524 mm and a loss tangent of 0.004. The proposed CPW-fed UWB slot antenna is basically composed of a wide-hexagonal-slot antenna and a parasitic hexagonal patch fed by a CPW. Thus, there are two radiating elements: the wide-hexagonal-slot and the hexagonal patch which acts as a tuning stub. Moreover, five trapezoidal slots are inserted symmetrically on the perimeter of the wide-hexagonal-slot antenna to improve the impedance characteristics. The hexagonal patch antenna has been designed by relating the areas of a circular patch with the one of the hexagonal patch structure. As given in [16], the side length $B$ of a hexagonal patch can be calculated using the equation

$$B \approx 1.1\, r_e, \tag{1}$$

where $r_e$ is the equivalent radius of a comparable circular patch given by the formula

$$r_e = \sqrt{r^2 - \frac{2hr}{\pi\varepsilon_r}\left(ln\frac{\pi r}{2h} + 1.7726\right)}\ , \tag{2}$$

where $\varepsilon$ is the dielectric constant of the substrate, $c$ is the speed of light in free space, $h$ is the thickness of the substrate, and $r$ is the radius of a comparable circular patch. The resonant frequency $f_r$ of the hexagonal patch can be calculated using the formula (3).

$$f_r \approx \frac{Y_{mn}c}{2\pi r_e\sqrt{\varepsilon_r}}, \tag{3}$$

where $Y_{mn}$ is the m$^{th}$ zero of the derivative of the Bessel function of order n. The values of $Y_{mn}$are given in Table 1.

Table 1: Values of $Y_{mn}$

| Modes | $Y_{mn}$ |
|---|---|
| TM01 | 0 |
| TM11 | 1.841 |
| TM21 | 3.054 |
| TM02 | 3.832 |
| TM31 | 4.201 |
| TM41 | 5.317 |
| TM51 | 6.415 |

The edge of the proposed wide slot is constituted by a fractal structure that is formed by notching a succession of five regular isosceles trapezoidal from the middle of the ribs constituting the hexagonal slot that having a length of A = 16.2 mm. The isosceles trapezoidal notches have three identical ribs of length $h_1$= 3.2 mm and one lengthy rib of length $h_2$= 6.4 mm.

The radiating element is lodged inside a ground plane having the same outer dimensions of the substrate of $0.305\lambda_0 \times 0.313\lambda_0$ at 2.35 GHz. The patch consists of a regular hexagon with a length of B = 10.5 mm and is fed by a CPW with an input impedance of value 50 Ω. The strip width $W_f$ and the gap g between the feed line and the ground plane have of values 2.9 mm and

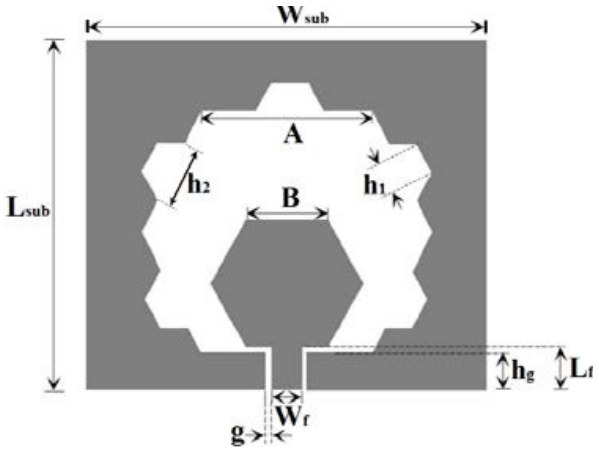


Fig. 1. Geometrical configuration of the proposed UWB slot antenna.

0.275 mm, respectively. As illustrated in Fig. 1, the designed antenna has a compact size of $0.305\lambda_0 \times 0.313\lambda_0 \times 0.012\lambda_0$ at 2.35 GHz. The detailed dimensions of the proposed UWB fractal antenna are listed in Table 1.

## III. RESULTS AND PARAMETRIC STUDY

The electromagnetic solver, CST Microwave Studio [17], was used to numerically calculate and optimize the proposed fractal antenna. The reflection coefficient $|S_{11}|$of the simulated antenna, with the optimized parameters listed in Table 1, is depicted in Fig. 2. As a consequence of applying isosceles trapezoidal fractal elements on the proposed antenna the impedance bandwidth is enlarged by a 4.79 GHz; the high-frequency side is shifted up from 8.35 GHz to 12.75 GHz and the low-frequency side of the working bandwidth is also shifted down from 2.66 GHz to 2.27 GHz. Thereby, a 60.8% fractional bandwidth expansion is achieved (from 77.7% to 138.5%). Therefore, a UWB ranging from 2.27 to 12.75 GHz is exhibited which covers the entire UWB spectrum from 3.1 to 10.6 GHz. to show the effect of the antenna parameters on the bandwidth performance, a parametric study was carried out by changing one of the parameters while keeping all other parameters fixed as listed in Table 2. The first parametric study is on the length $h_1$ of the trapezoidal fractal notch elements. The influence of this parameter on the impedance bandwidth and the adaptation of the simulated antenna for different values 0.5, 1.5, 3.2, 4.5, and 5.5 mm are plotted in Fig. 3 (a). It can be seen that as the length $h_1$ augments from 0.5 to 3.2 mm the impedance bandwidth increases greatly by 36.52% (from 102.07% to 138.62%). However, the bandwidth decreases when the length $h_1$ exceeds 3.2 mm. Therewithal, the optimal length of the trapezoidal corrugations is found to be at $h_1$=3.2 mm. In addition, the lower frequencies of the bandwidth change slightly by increasing the length $h_1$ of the trapezoidal notches, while at the middle and the high frequencies, the augmentation of this parameter combines the resonances of the bandwidth that leads to improving the upper frequency of the bandwidth from 8.3 to 12.4 GHz

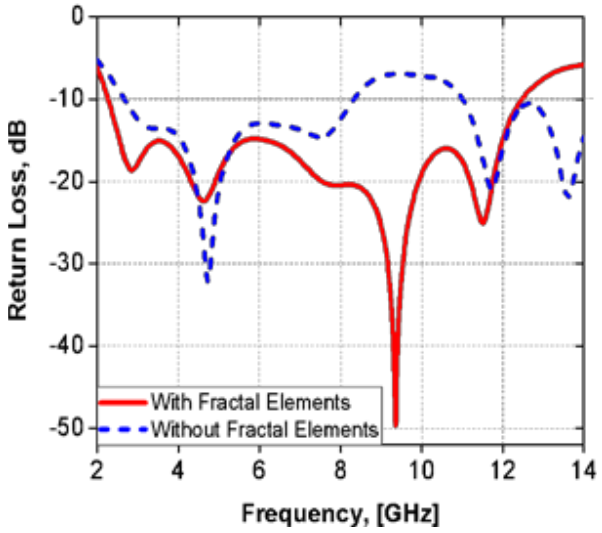


Fig. 2. Simulated return loss of the two antennas: for referenced antenna (dashed line); for the proposed UWB slot antenna (solid line).

Table 2: Optimized dimensions of the proposed slot antenna in term of wavelength at 2.35 GHz

| Parameters | Dimensions [m] | Parameters | Dimensions [m] |
|---|---|---|---|
| A | $0.1269\lambda_0$ | $L_{sub}$ | $0.3055\lambda_0$ |
| B | $0.0823\lambda_0$ | $W_{sub}$ | $0.3133\lambda_0$ |
| $h_1$ | $0.0251\lambda_0$ | $W_f$ | $0.0227\lambda_0$ |
| $h_2$ | $0.0501\lambda_0$ | $L_f$ | $0.0760\lambda_0$ |
| $h_g$ | $0.0204\lambda_0$ | g | $0.0021\lambda_0$ |

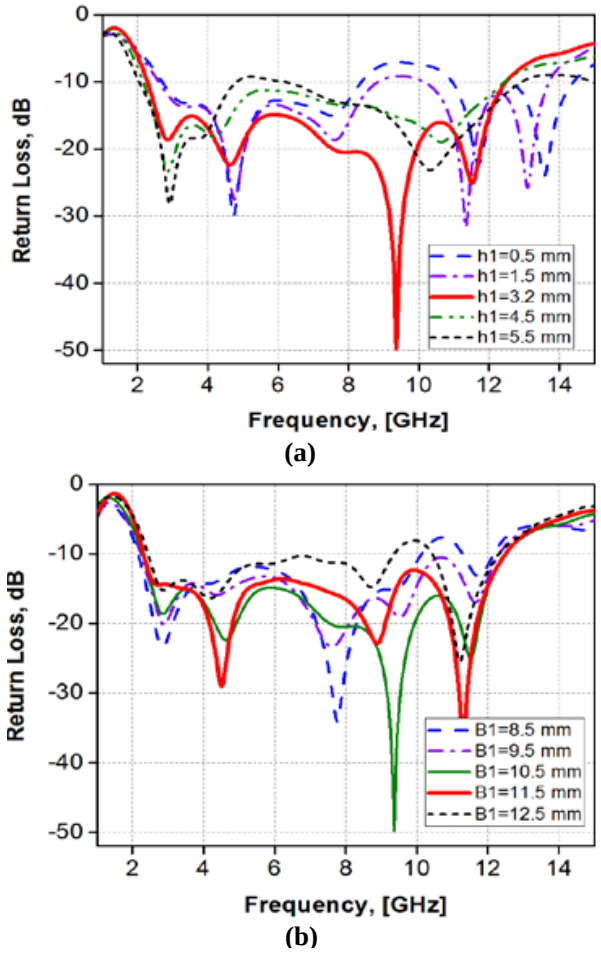


Fig. 3. *Continued*.

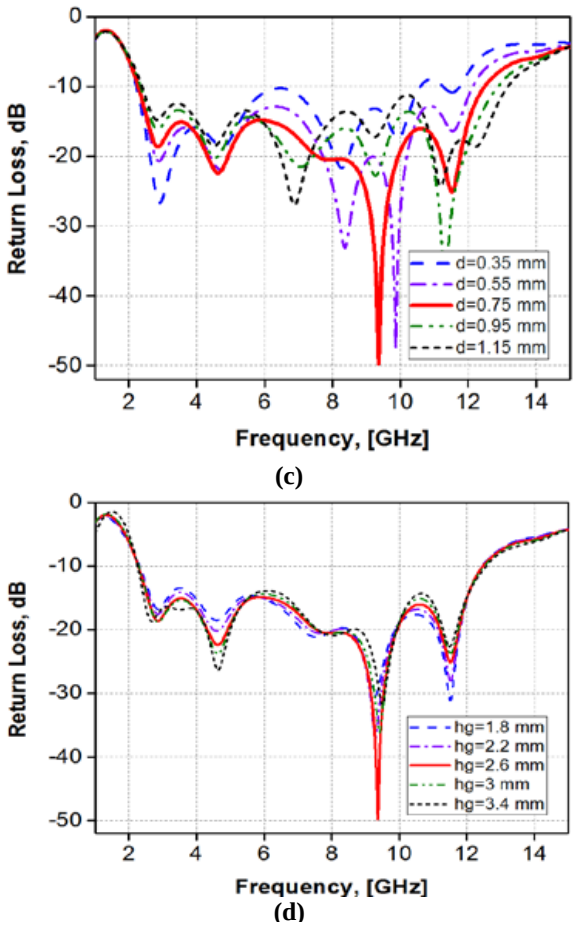


Fig. 3. Effect of different parameters on the reflection coefficient of the proposed antenna: (a) effect of the trapezoidal notch length; (b) effect of the parasitic patch length; (c) effect of the gap between the parasitic patch and the ground plane; (d) effect of the ground plane length.

and, consequently, the UWB characteristic of the proposed antenna is achieved. Therefore, the parameter $h_1$ represents a major impact on the impedance-matching performance of the proposed antenna. The impact of adjusting the patch side length B on the bandwidth performance is also studied. The antenna was calculated for different values of parameter B commencing from 7.5 to 11.5 mm with an increment of 1 mm, the obtained results are presented in Fig. 3 (b). As can be observed, the impact of patch length B on the impedance bandwidth and the adaptation performances is clearly visible. It is shown that the antenna bandwidth becomes wider by 9% (from 129.62% to 138.62%) when increasing the side length B from 7.5 to 10.5 mm. However, the bandwidth does not augment any further when the side length exceeds 10.5 mm. It can be noticed that as the patch augments in length a better adaptation performance is achieved over the working bandwidth. As illustrated in Fig. 3 (b), when $B_1$ exceeds 9.5 mm, the matching characteristics of the proposed antenna are enhanced at 10.7 GHz. When the length $B_1$ exceeds 10.5 mm, the $|S_{11}|$becomes narrower because of the growth of the capacitive coupling between the radiating element and the ground plane. Thus, the patch leads to augmenting greatly the upper frequency of the operating bandwidth. Thereby, the optimum value of the parameter $B_1$ is taken at 10.5 mm. The mutual coupling between the feed and the patch has an important impact on the antenna adaptation performance. For this reason, the impact of the gap d separating the patch and the ground plane is furthermore studied. Figure 3 (c) depicts the $|S_{11}|$for various values of gap d varying between 0.35 and 1.15 mm with an increment of 0.2 mm. As it is shown, this gap d augments the upper side of the bandwidth augments, whereas, the lower side is nearly invariable. Therefore, the adaptation improves and the total impedance bandwidth augments. The optimum distance separating the patch and the ground plane is obtained at 0.75 mm. When the gap d exceeds 0.75 mm, the $|S_{11}|$becomes narrower because the antenna impedance matching is going bad.

Figure 3 (d) presents the impact of the ground plane length $h_g$ on the $|S_{11}|$. Its influence was studied for different lengths of the ground plane ranging from 1.8 to 3.4 mm with an increment of 0.4 mm. It can be seen that as the length $h_g$ augments, the lower side of the impedance bandwidth as well as the upper side of the bandwidth changes slightly. Therefore, it is clearly observed that the length $h_g$ has not a considerable impact on the antenna bandwidth. The optimum ground plane length for the proposed antenna was optimized at 2.6 mm.

## IV. MEASURED RESULTS AND DISCUSSION

To give credence to the calculated results, a prototype of the proposed UWB slot antenna with the optimized geometrical dimensions were constructed and measured. Figure 4 presents a photograph of the realized prototype. The reflection coefficient $|S_{11}|$of the fabricated antenna is then measured using an Agilent 8722ES vector network analyzer. Figure 5 shows the measured reflection coefficient against their simulated results. It indicates that the fabricated antenna exhibits a measured impedance bandwidth as large as 8.32 GHz and covers the band ranging from 2.35 GHz to 10.67 GHz, relatively about 127%, which is suitable for UWB applications.

The comparison between simulated and measured results of the coefficient reflection indicates that there is a slight difference. At lower frequencies, an excellent concordance is observed between the calculated and measured results. Besides, there is a little disagreement at high frequencies which is mainly due to the fabrication tolerance and connector soldering.

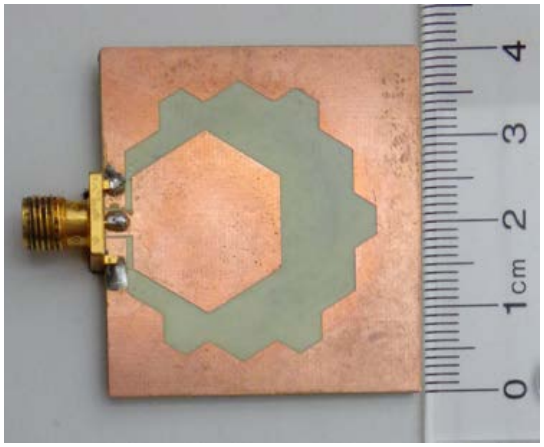


Fig. 4. Photograph of the proposed CPW-fed UWB slot antenna.

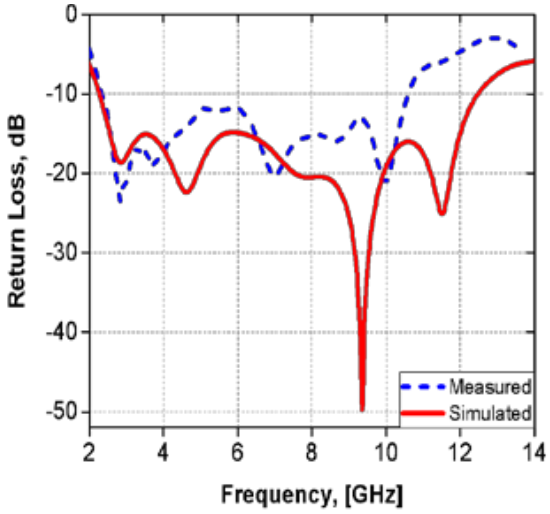


Fig. 5. Simulated and measured return loss $S_{11}$ [dB] against frequency.

Furthermore, the H- and E- plane patterns of the fabricated antenna were measured in an anechoic chamber and compared with the predicted ones. Figure 6 shows the both measured and simulated 2-D far-field radiation patterns of the fabricated antenna in two principal planes, the E and H-planes for three respective frequencies 3, 5, and 9.5 GHz. Excellent agreements are achieved between the measured results and the calculated ones. In addition, the quasi-omnidirectional patterns can be observed in the H-plane at all frequencies, while in the E-plane, a bidirectional radiation pattern is achieved at the frequencies 3 and 5 GHz. At high frequencies around 9.5 GHz, the measured radiation pattern in the E-plane is no longer bidirectional. The small deformation at higher frequencies is probably due to the excitation of higher-order modes [18–19]. Figure 7 depicts the measured and

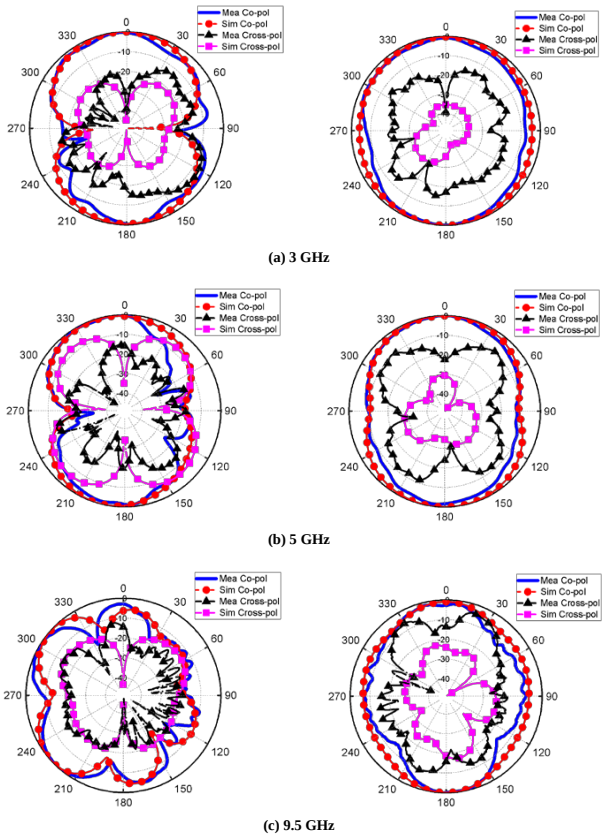


Fig. 6. Measured and simulated normalized radiation patterns of the proposed UWB slot antenna in E-plane (left) and H-plane (right) at three frequencies: (a) 3 GHz, (b) 5 GHz, and (c) 9.5 GHz.

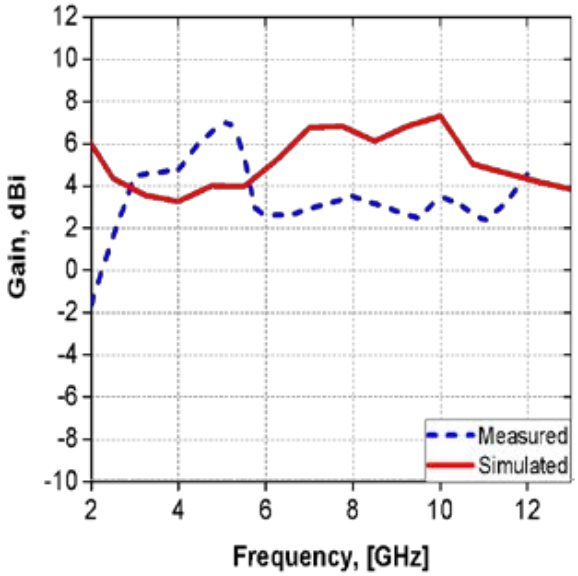


Fig. 7. Gain of the proposed UWB slot antenna versus frequency.

Table 3: Comparison of the fabricated antenna with other recently published antennas

| Ref. No. | Antenna structure | Ground plane (GP) | Substrate/ permittivity | Electrical size | Bandwidth (GHz) | Bandwidth (%) | Peak Gain (dBi) | Ease of fabrication |
|---|---|---|---|---|---|---|---|---|
| [24] | Microstrip line-fed monopole antenna | Partial GP | FR4 $\varepsilon_r$=4.6 | $0.338\lambda_0$ $\times 0.347\lambda_0$ $\times\ 0.014\lambda_0$ | 2.6-12.3 | 130.2 | 5.52 | Easy |
| [25] | CPW-fed U-shaped monopole antenna | Partial GP | FR4 $\varepsilon_r$=4.4 | $0.402\lambda_0$ $\times 0.435\lambda_0$ $\times\ 0.0201\lambda_0$ | 4.02-10.7 | 90.76 | 3.54 | Easy |
| [26] | L-shaped feed line aperture antenna | Slotted GP | FR4 $\varepsilon_r$=4.4 | $0.568\lambda_0$ $\times 0.568\lambda_0$ $\times 0.0116\lambda_0$ | 2.9-8 | 93.5 | 4.9 | Easy |
| [27] | CPW-fed printed monopole antenna | Partial GP | FR4 $\varepsilon_r$=4.4 | $0.358\lambda_0$ $\times 0.358\lambda_0$ $\times 0.0057\lambda_0$ | 2.15- 6.97 | 105.70 | 5 | Easy |
| [28] | Metasurface-based microstrip-fed planar antenna | Partial GP | FR4 $\varepsilon_r$=4.4 | $0.34\lambda_0$ $\times 0.34\lambda_0$ $\times 0.05\lambda_0$ | 3.1-10.6 | 109.49 | 6.8 | Hard |
| [29] | Coaxial probe-fed microstrip patch with metamaterial-inspired reactive impedance surface | Full GP | RO4003 $\varepsilon_r$ =3.38 | $0.58\lambda_0$ $\times 0.58\lambda_0$ $\times 0.1\lambda_0$ | 4.64-7.3 | 44.5 | 7.2 | Hard |
| [30] | CPW-fed cauliflower shaped antenna | Partial GP | RO-4350B $\varepsilon_r$=3.48 | $0.368\lambda_0$ $\times\ 0.417\lambda_0$ $\times 0.015\lambda_0$ | 3.05-10.96 | 113 | 5.68 | Hard |
| [31] | Microstrip line-fed question mark shaped antenna | Partial GP | FR4 $\varepsilon_r$=4.4 | $0.347\lambda_0$ $\times 0.393\lambda_0$ $\times 0.017\lambda_0$ | 3.47-12.11 | 110.91 | 6 | Easy |
| This work | CPW-fed slot antenna with fractal shaped isosceles trapezoidal | Slotted GP | RO-4350B $\varepsilon_r$=3.66 | $0.305\lambda_0$ $\times\ 0.313\lambda_0$ $\times\ 0.012\lambda_0$ | 2.35-10.65 | 127 | 7.02 | Easy |

simulated peak gain of the fabricated prototype. Acceptable values are achieved in the whole UWB range with a maximum gain of 7.02 dBi attained at about the frequency of 5.15 GHz. The discrepancy between the simulated and measured gains may be due to many reflections into the electromagnetic waves between the tested antenna and reference antenna (double ridged horn antenna AH-118 operating between 1 and 18 GHz). The reflections may come from the room floor and ceiling, chamber scattering, and track inside the anechoic chamber. Figure 8 shows that the designed CPW-UWB slot antenna reveals acceptable values of efficiency within the operating band which are nearly over 80% that are superior to the ones achieved in [20–21]. The simulated group delay along the working bandwidth is plotted in Fig. 9 for a distance of 30cm between the front faces of two similar CPW-fed UWB slot antennas. A feeble variation below 1ns is obtained which is nearly comparable to the results presented in [22–23]. To demonstrate the usefulness of the fabricated model, the main parameters of the

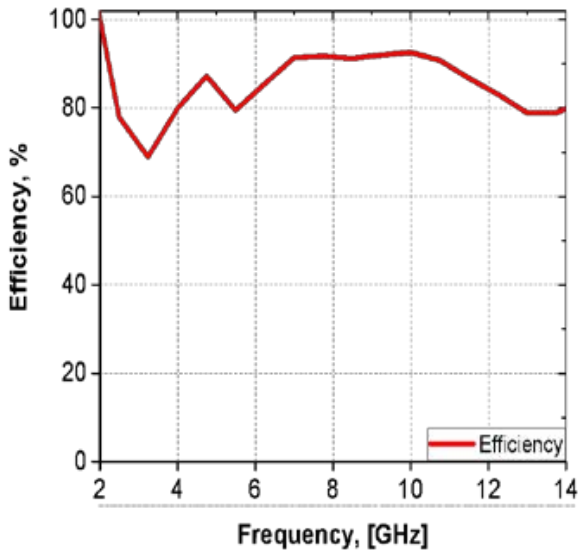


Fig. 8. Efficiency of the proposed UWB slot antenna versus frequency.

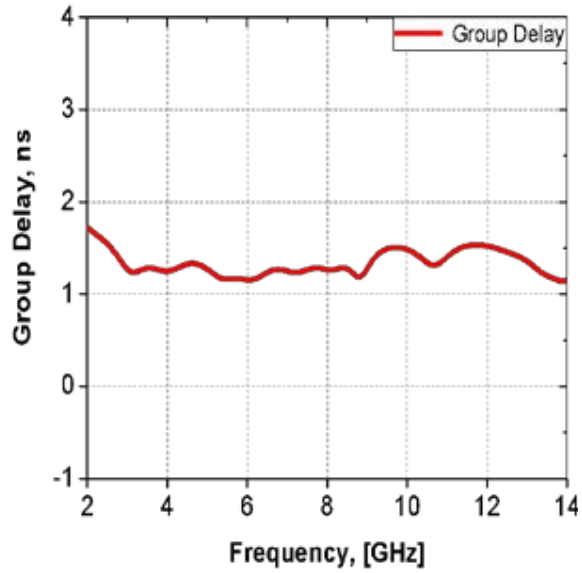


Fig. 9. Group delay of the proposed UWB slot antenna versus frequency.

proposed antenna are compared with the ones of some existing antennas in Table 3. It can be deduced that the parameters of the fabricated model are better or comparable to those of other existing antennas.

## V. CONCLUSION

A compact printed CPW-fed slot antenna using fractal-shaped isosceles trapezoidal corrugations for UWB applications has been designed and measured in this work. The implementation of the isosceles trapezoidal fractal structure along the edge of the hexagonal slot has improved the working bandwidth. Experiments have been implemented to prove the antenna performances confirming that the fabricated antenna offers a large impedance bandwidth of about 127%, extending from 2.35 GHz to 10.67 GHz; which covers the entire UWB. Moreover, stable radiation patterns measured with an acceptable peak gain are measured over the whole working bandwidth. Thus, it can be concluded that the proposed design can be an advantageous candidate for many wireless communication systems.

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