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A Novel Triangular Shaped UWB Fractal Antenna Using Circular Slot

DOI 10.1515/freq-2015-0110
Received May 18, 2015

Abstract: The article presents the design of triangular shaped fractal based antenna with circular slot for ultra wideband (UWB) application. The antenna is fed using microstrip line and has overall dimension of $24 \times 24 \times 1.6\,\text{mm}^3$. The proposed antenna is covering the wide frequency bandwidth of 2.99–11.16 GHz and is achieved using simple fractal based triangular-circular geometries and asymmetrical ground plane. The antenna is designed and parametrical studies are performed using method of moment (MOM) based Full Wave Electromagnetic (EM) software Simulator Zeland IE3D. The prototype of proposed antenna is fabricated and tested to compare the simulated and measured results of various antenna parameters. The antenna has good impedance bandwidth, nearly constant gain and stable radiation pattern. Measured return loss shows fair agreement with simulated one. Also measured group delay variation obtained is less than 1.0 ns, which proves good time domain behavior of the proposed antenna.

Keywords: UWB antenna, impedance bandwidth, asymmetrical ground plane, fractal antenna

1 Introduction

Since the Federal Communication System FCC) in 2002 approved the frequency band 3.1 GHz to 10.6 GHz for ultra wideband, it became much popular among researcher to the design of UWB antenna [1]. High data rate, lower fading effect from multipath propagation, reduced power requirement and low complexity are some of the key advantages of UWB technology. The large bandwidth and high data rate of UWB technology find applications in short range wireless communication, radar and geo location. Cost, complexity and compactness are important parameter in designing an antenna for UWB application. Designing a compact size antenna is a great challenge among the researcher nowadays to make the antenna applicable in modern wireless devices and RF circuits. Planar monopole is one of the important techniques due to its attractive feature such as compact size, low cost, low profile and ease of fabrication [2]–[7]. Another effective and most important technique to design UWB antenna is fractal. Fractals are complex patterns that are self similar across different scales [8]. Fractals play a big role in designing a low profile, broadband and multiband antenna due to their two important properties: self similarity and space filling [9]–[11]. An ultra wideband antenna using Minkowski-like fractal is presented by utilizing the multiple resonance phenomenon of fractal geometry [12]. An ultra wideband fractal antenna is proposed with CPW feed using concentric heptagonal array structure [13]. A compact third iteration inner tapered tree shaped UWB fractal antenna able to achieve impedance bandwidth of 4.3–15.5 GHz is reported in [14]. The impedance bandwidth is enhanced using CPW ground plane and increasing number of iteration. A compact octagonal-shaped UWB antenna using Sierpinski fractal is presented by combining Sierpinski fractal with octagonal shaped geometry to increase the effective electrical path length in small area by utilizing its space filling properties [15]. In [16], a rectangular patch by cutting stair-like shape and flowery defected ground structure is proposed.

In this article, the design of a new compact and simple fractal based antenna for UWB application is proposed. The proposed compact antenna is microstrip-fed and has a dimension of $24 \times 24\,\text{mm}^2$. The proposed antenna consists of a triangular shaped radiator with circular slot, microstrip feed line and a rectangular shaped asymmetrical ground plane. The design of the antenna is investigated using method of moment based full wave electromagnetic simulation software Zeland IE3D. Various dimensional parameters of the proposed UWB antenna layout are optimized manually. The

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proposed antenna is fabricated and measured. The comparison of measured and simulation results of various antenna related parameters are presented to demonstrate the performances of proposed antenna. Group delay performance and correlation between transmitted and received signal are also analyzed to show the performance of proposed antenna in time domain.

2 Design of proposed antenna and parametric study

The proposed antenna is designed on FR4 substrate with dielectric constant of 4.4, thickness 1.6 mm and loss tangent is 0.02. The antenna is excited by 50-Ω microstrip line of feed line width 3 mm which is directly connected to the radiating patch. The proposed design philosophy was to make a fractal antenna using triangular patches with circular slot inscribed and the size of the antenna to be compact. The basic structure of proposed radiator is a triangular patch of optimized height 10.5 mm with circular slot of optimized radius 3 mm. As the initial profile i. e. the iteration 0 profile is small, the process to make the proposed antenna up to the 2^{nd} iteration for the purpose of fabrication feasibility. These iterations are shown in Figure 1(a). The 1^{st} iteration of proposed antenna is obtained by inserting another triangle inside circular slot and etching circular slot of optimized radius 1.4 mm in inner triangle. This process is repeated once again for 2^{nd} iteration. The geometry of proposed UWB antenna with optimized geometrical parameters is shown in Figure 1(b). The ground plane of proposed antenna is a rectangle asymmetrical with reference to patch and feed line for better impedance bandwidth over the entire UWB. All the dimensional parameters as mentioned in the layout are optimized for good impedance bandwidth over the entire desired bandwidth. The ground plane parameters are w_1, w_2, w_3 and h_1, the variable related to the gap between ground plane and radiating patch is d. The effect of asymmetrical ground plane i. e. feed position (related variable is w_4) is also analyzed and optimized. The parameter h_2 indicates the height of patch and is optimized to obtain the desired frequency bandwidth of interest.

Parametrical studies for different antenna parameters are performed and their effects on scattering parameter (S-parameter) are investigated for better understanding. Effect of gap between ground plane and patch (d) on return loss is shown in Figure 2. Better impedance matching [for $|S_{11}| \geq 10$ dB] is observed for d = 0.9 mm. The effect of parameter w_1 on return loss characteristic is shown in Figure 3. Optimized value of w_1 is observed around 1.5 mm. Higher or lower values of w_1 deteriorate the impedance bandwidth.The variation of $|S_{11}|$ (dB) with

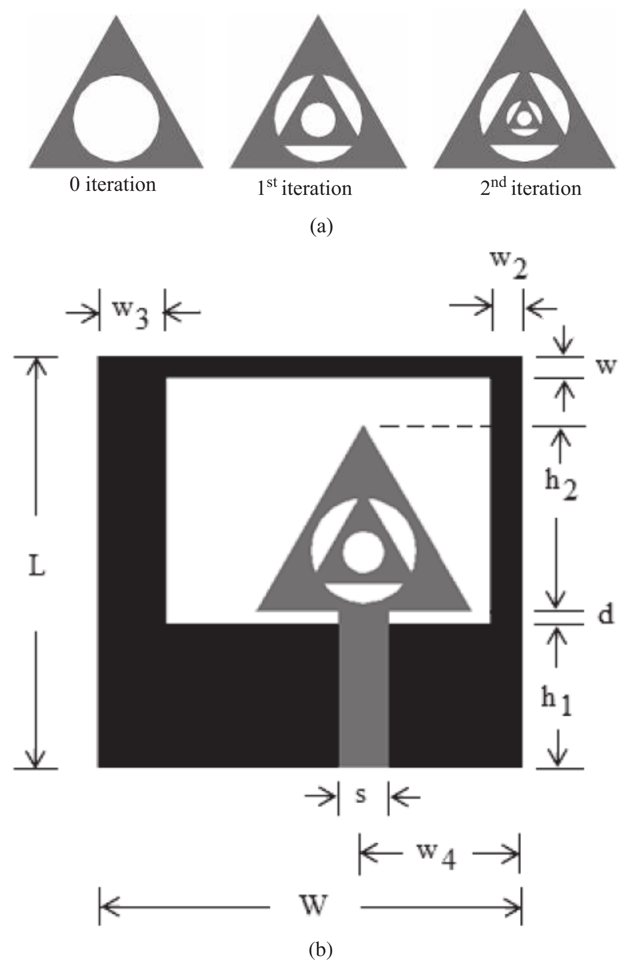


Figure 1: Geometry of proposed antenna (a) Different iterations of proposed antenna (b) Dimensional view.

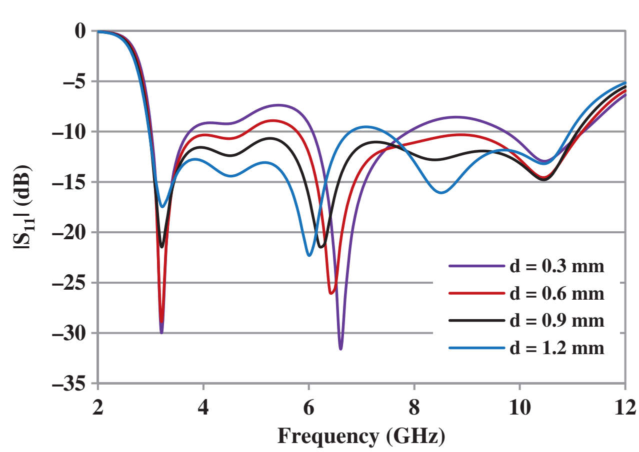


Figure 2: Effect of gap d on return loss characteristics.

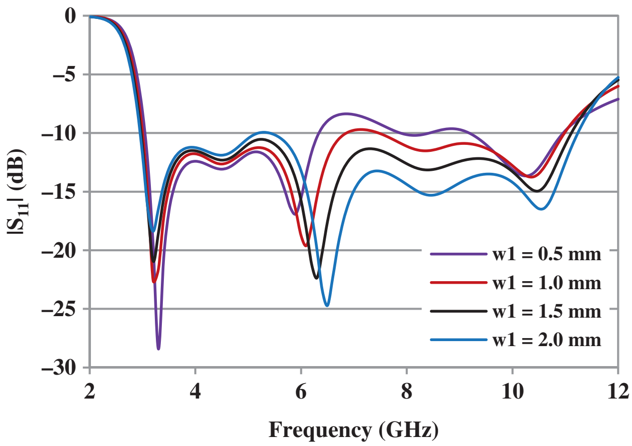


Figure 3: Effect of width w_1 on return loss characteristics.

parameters w_2 and w_3 are shown in Figures 4 and 5 respectively. Decrease in dimensional value of w_2 shifted the cut-off frequencies to the lower end of frequency and also deteriorate the return loss performance in lower frequency band. It is observed that with increased dimension of w_3, resonance frequencies are shifted to the higher frequencies. From Figures 4 and 5, the optimized values of w_2 and w_3 found to be 1.5 mm and 4.0 mm respectively. The other factors that affect the performance of proposed antenna such as feed position w_4 and number of iteration are also analyzed. Comparative return loss performance with the feed position is shown in Figure 6. It is observed that with the shift of feed position to the left or right (after interchanging dimensional values of w_3 and w_2 and taking w_4 from left or right) from the centre of ground plane improves the performance of proposed antenna. Better impedance bandwidth is observed for $w_4 = 8.0$ mm. The effect of increasing the number of iteration is depicted in Figure 7. It can be seen that the response is better for first iteration. For $|S_{11}| \geq 10$ dB, impedance-bandwidth is 2.991–11.157 GHz and 2.99–11.16 GHz for 2nd iteration and 1st iteration respectively. Increased number of iteration slightly shifts the higher

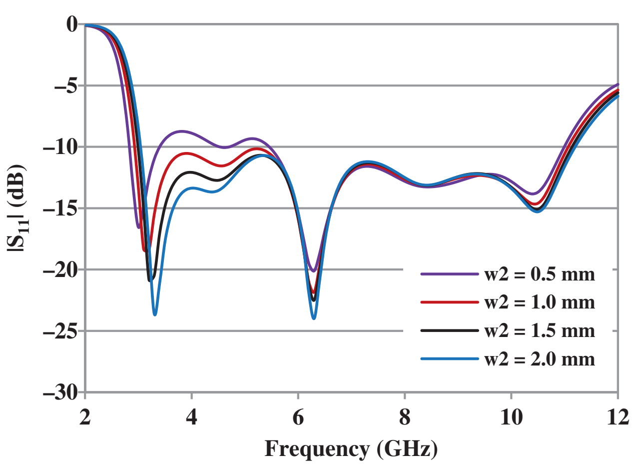


Figure 4: Effect of width w_2 on return loss characteristics.

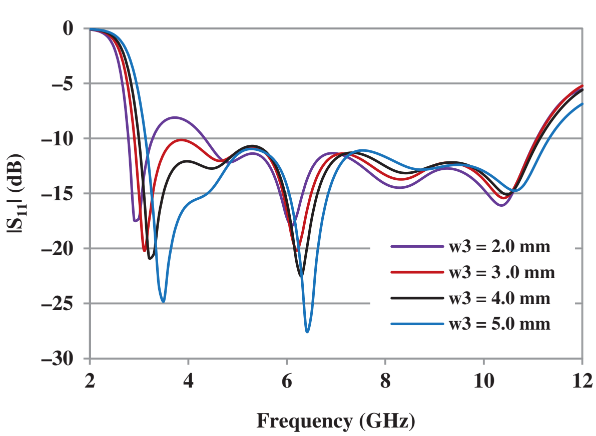


Figure 5: Effect of width w3 on return loss characteristics.

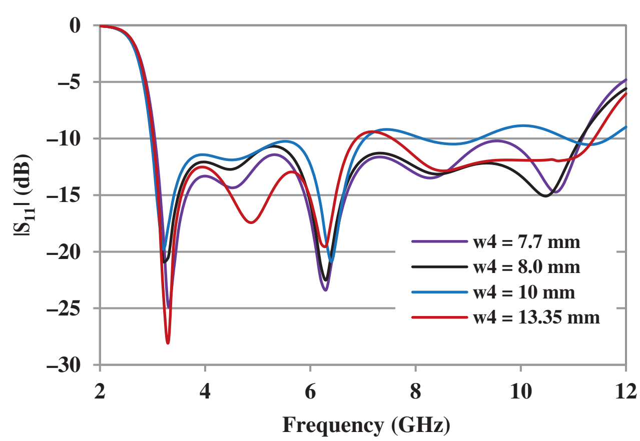


Figure 6: Effect of feed position w4 on return loss characteristics.

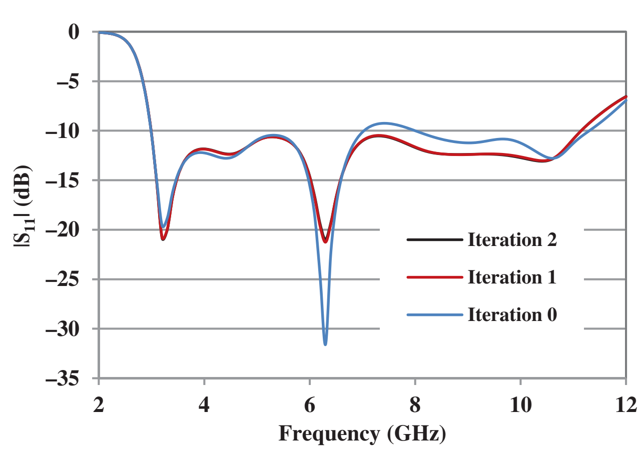


Figure 7: Effect of number of iteration on return loss characteristics.

cut-off frequency to the left thus reducing overall frequency bandwidth. As no improvement in frequency bandwidth is observed for 2nd iteration, the 1st iteration of proposed antenna layout is considered for fabrication and measurement purpose. Also design complexity is increased and fabrication becomes difficult with increased number of iteration. The height of patch (h_2) is optimized primarily to obtain the requisite UWB bandwidth. A sensitivity analysis is performed to obtain the optimum patch height. S-parameter graph for different patch heights is shown in Figure 8. It is observed that the patch height of 10.5 mm provides better impedance-bandwidth. The performance of proposed antenna with ground plane height parameter h_1 is depicted in Figure 9. Increase in impedance bandwidth is observed with increase in h_1, but the dimension L is also increased at the same time and so the overall size of proposed antenna.

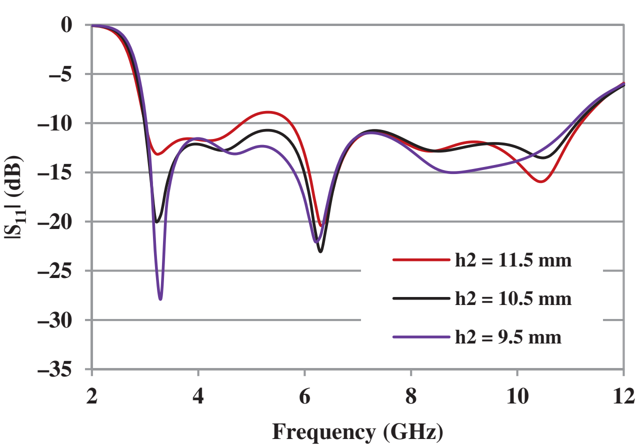


Figure 8: Effect of patch height on return loss characteristics.

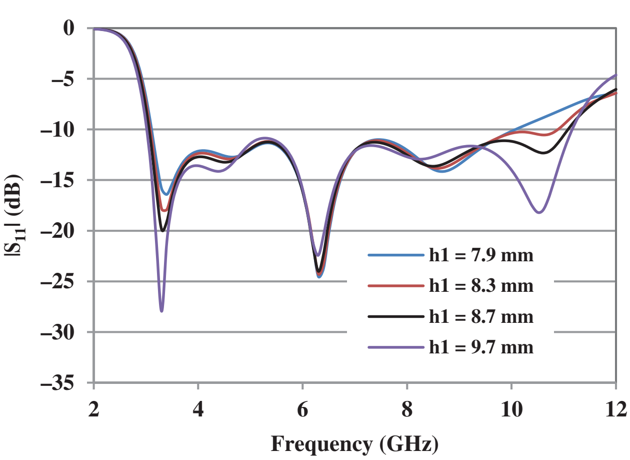


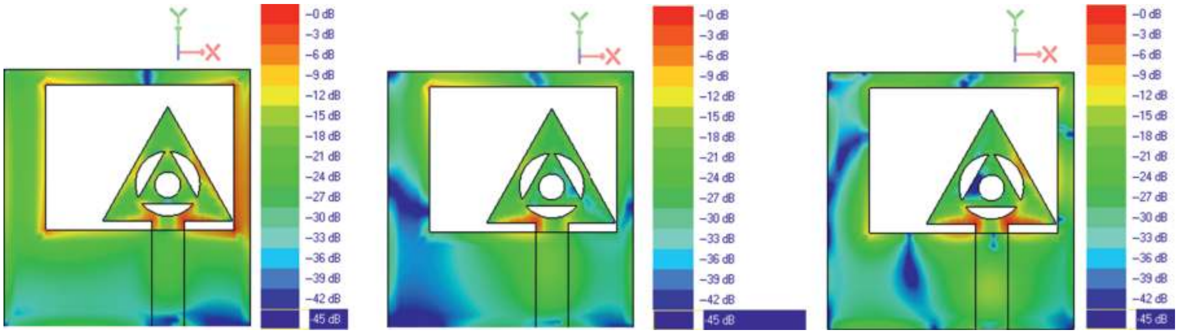
Figure 9: Effect of parameter h_1 on return loss characteristics.

Figure 10 displays the current distribution over the antenna surface at resonance frequencies 3.2 GHz, 6.3 GHz and 10.5 GHz. At 3.2 GHz, the greater concentration of current distribution is observed in ground plane along the rectangular ring covering the ground. At higher frequencies (at 6.3 GHz and 10.5 GHz), it can be observed that concentration of current is more in triangular patch compared to ground plane. Thus increase of current concentration in patch proves contribution of patch to improve impedance matching at higher frequencies. The optimized dimension of different antenna parameters is shown in Table 1.

3 Experimental results and discussions

Antenna parameters are finalized based on parametric studies and through optimization of each of the dimensional parameters. The prototype of proposed antenna is implemented and fabricated and is presented in Figure 11. Experimental results of proposed UWB antenna is obtained using Agilent N5230A PNA series Vector Network Analyzer (VNA). Return loss characteristic of proposed antenna is measured and compared with simulated result as shown in Figure 12. Good agreement is observed between simulated and measured return loss characteristics. Measured impedance bandwidth for $|S_{11}| \geq 10$ dB is from 3.1 GHz to 10.8 GHz irrespective of simulated impedance bandwidth from 2.99 to 11.16 GHz. Some disagreement between simulated and measured results may have been caused due to the tolerance of substrate parameters, manufacturing accuracies and effect of SMA connector loss. Simulated and measured peak antenna gain verses frequency plot is illustrated in Figure 13. Good agreement is observed between simulated and measured results with little discrepancy at higher frequencies. Also it is seen that the gain is almost constant throughout the UWB frequency band.

Omnidirectional radiation pattern is the necessity for an antenna in UWB applications. The simulated and measured co-polar and cross-polar radiation pattern at 3.2 GHz, 7 GHz and 10.6 GHz are shown in Figure 14. Almost stable and omnidirectional radiation patterns are observed throughout the desired UWB frequency range in H-plane. At low frequency, the radiation pattern in E-plane looks similar to conventional bidirectional or monopole antenna. But some ripples are observed at higher frequencies – this effect may be due to the propagation of higher order modes and spurious emissions and



(a) (b) (c)

Figure 10: Current distribution at (a) 3.2 GHz (b) 6.3 GHz (c) 10.5 GHz.

Table 1: Optimized values of antenna parameters.

Parameter	L	W	s	h_1	h_2	d	w_1	w_2	w_3	w_4
Dimensions (mm)	24	24	3	8.7	10.5	0.9	1.5	1.5	4.0	8.0

also may be attributed to the change in equivalent radiating area with frequency and other reflecting object in surrounding area. The discrepancy observed in simulated and measured cross polarizations patterns at higher frequencies are because of increased sensitivity to antenna geometry at higher frequencies and measurement setup error.

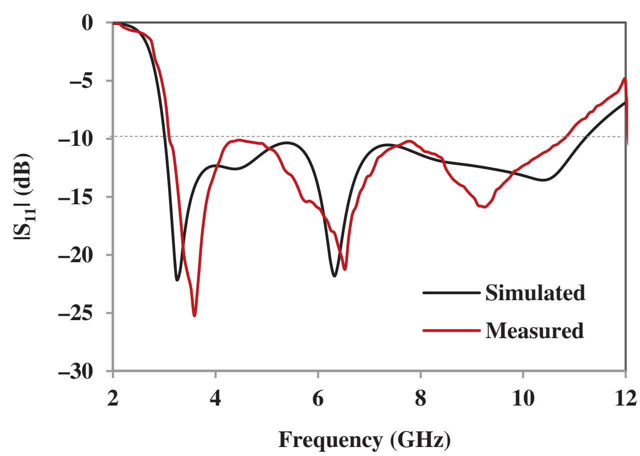
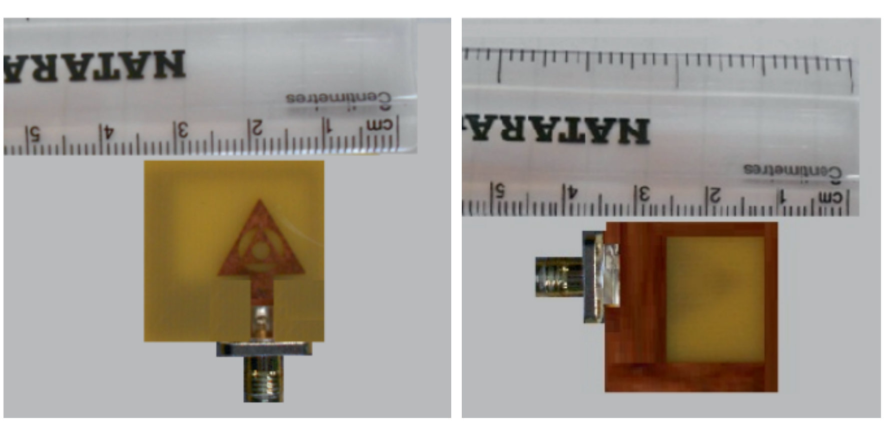


Figure 12: Comparison of simulated and measured return loss.

4 Time domain analysis

As UWB system is based on short pulse transmission, analysis of time domain behavior is an important feature. Although the proposed antenna has wideband frequency response, it does not assure whether the time domain response of the antenna is good. Group delay response is used to show any non-linearity present in phase response and it also indicates degree of distortion in the transmitted signal. Group delay should be constant over



(a) Top view (b) Bottom View

Figure 11: Prototype of fabricated antenna.

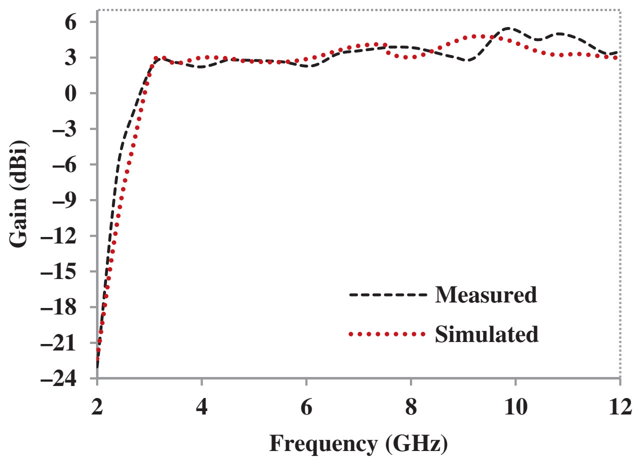


Figure 13: Simulated and Measured peak gain of proposed antenna.

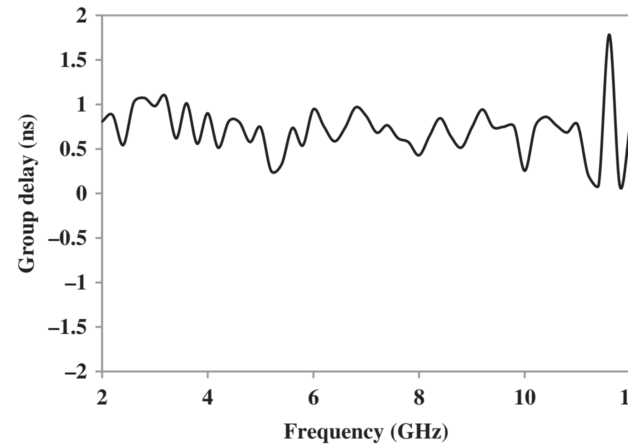


Figure 15: Measured group delay of proposed antenna.

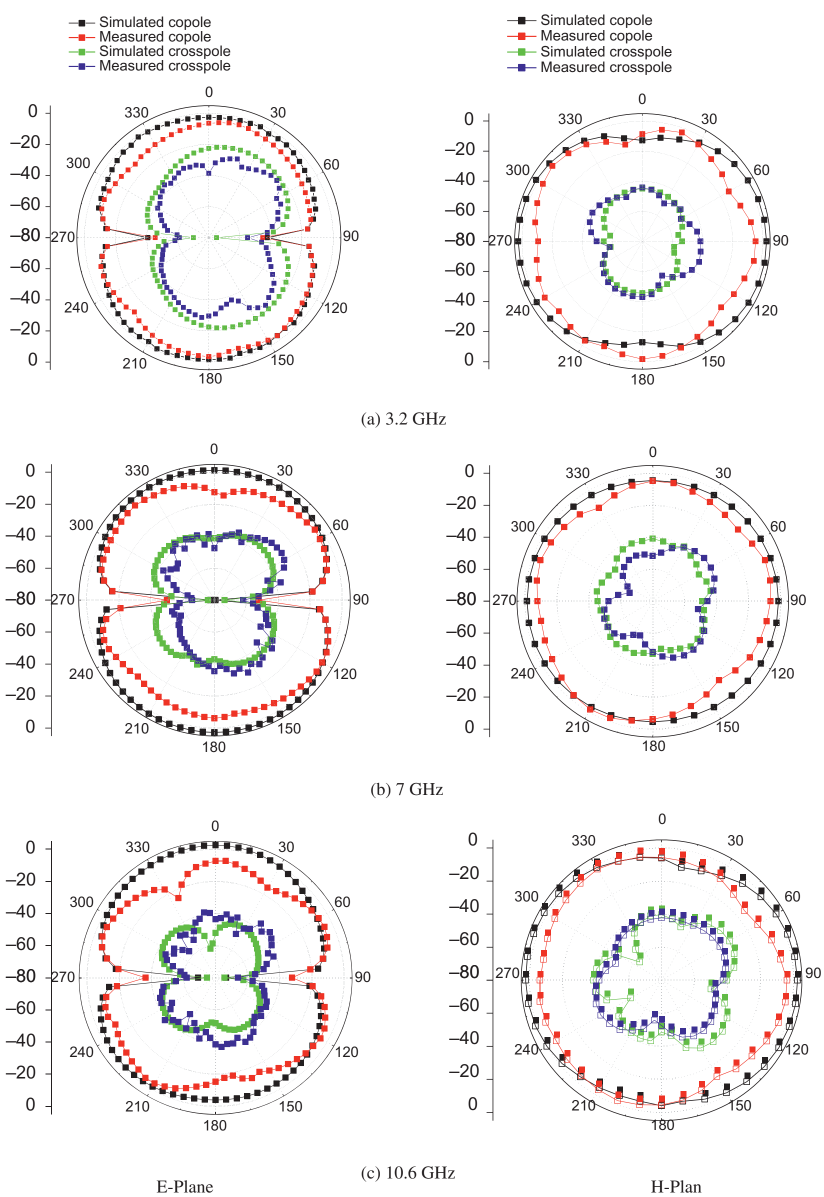


Figure 14: Simulated and measured radiation pattern.

the entire band for UWB application. Group delay variation of less than 1.0 ns indicates the linear phase response in far-field region and distortion free pulse transmission. To show the group delay performance two identical antennas placed face to face at the distance of 30 cm were mounted on the two ports of Vector Network Analyzer (VNA), where they serve as transmitter and receiver. Figure 15 shows the measured group delay response of proposed antenna. It is observed that the variation in group delay is within 1.0 ns over the entire UWB frequency band, so it proves that proposed antenna has good time domain characteristic and can be useful for UWB application. In order to further determine the fidelity between transmitted and received signals, calculation of correlation coefficient is performed and defined as [17]:

$$\rho = \max\tau \left[\frac{S_1(t)S_2(t-\tau)\mathrm{d}t}{\sqrt{S_1^2(t)\mathrm{d}t}\sqrt{S_2^2(t)dt}} \right]$$

where, τ is delay and, $S_1(t)$ and $S_2(t)$ are transmitted and received signals respectively. To measure the correlation coefficient, identical antennas are placed face to face and side by side at the distance of 30 cm. In case of perfect matching between transmitted and received signals, maximum fidelity is observed and the value of ρ is equal 1. It also indicates that received signal is identical to transmitted one and antenna system is distortion free. The value of correlation coefficient obtained is 0.89 when the antennas are placed face to face and 0.93 when placed side by side.

5 Conclusion

A compact microstrip line fed UWB fractal antenna has been designed and presented. The proposed antenna is fabricated on FR4 substrate of dielectric constant 4.4 and thickness 1.6 mm with compact size of $24 \times 24\,\mathrm{mm}^2$. Measured result shows that the proposed antenna is able to achieve impedance bandwidth from 3.1 GHz to 10.8 GHz for $|S_{11}| \geq 10$ dB. Also the proposed antenna gives omnidirectional radiation in H- plane and almost figure of eight or monopole like pattern in E- plane over the entire UWB range with stable gain. Measured group delay of the proposed antenna varies within 1.0 ns which indicates good time domain behavior for ultrafast and short range communications. The simplicity, compactness and performance of the proposed antenna in different antenna related parameters make it a suitable candidate for UWB applications.

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