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A Small Design of Ultra-Wideband Printed Antenna with Notched and Raked Planar Patch

Abstract- In this research, patch was printed on a rectangular radiating substrate Taconic material. The Taconic material used is TLY-5 of 30 x 30 mm² dimensions and 1.575 mm thickness. Its Relative dielectric constant (ϵ_r) of 2.2 was taken in this research. The rectangular radiator of the proposed design was notched with two-step notches. These notches were cut at the bottom of the slotted patch with three similar dimensions slots. A transmission line feeder feeds the patch with a gap between the printed ground plane and the radiated patch. The proposed antenna design has been simulated and tested using CST microwave studio software and a network analyzer with anechoic chamber respectively. The measured and simulated results demonstrated that the proposed shape of antenna design achieved a very wide of operating impedance bandwidth starting from 3.5 GHz up to 12 GHz at return loss (S_{11}) below -10 dB at 0.25 mm size of feed gap. The effects of three feed gap different values and the step notches are illustrated in this paper. The radiation measured and simulated patterns were obtained for omni-directional radiation to be suitable for several users.

Keywords- UWB wireless antenna; planar printed patch; simulation patterns; notched patch fabricated antenna.

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1. Introduction

For the data transmission at high rates through outdoor and indoor wireless with obstacles propagation, microstrip antennas of high-efficiency have to be improved and developed to get great quality of services (QoS) at the same time to several users. Previous works by [1,2] were devoted for evaluating the performance of UWB wireless antennas. In the United States, the Federal Communications Commission (FCC) used one of the previous working reports as an input to the power transmission and allowable frequency range of UWB technology [3]. The UWB dynamic range is 3.1 GHz up to 10.6 GHz and -41.3 dBm/MHz as an allowed power spectral density over this dynamic band [4]. To cover the wideband (WB) frequency, microstrip antennas makes array of four elements was designed by [5] to be used for directional propagation. UWB wireless antenna was designed by reference [6] with resonators of three split-ring to improve the input impedance is matching at four narrow bands of resonance. The recent curved-slot patch antenna of 25 mm x 45.75 mm dimensions was proposed by [7]. The operating frequency range from 2.5 GHz up to 12 GHz, which can be used for UWB and X-frequency band communication wireless systems. A circular disc patch of 7.5 mm radius was proposed by [8] and printed over the front view of substrate material with 30 mm x 35 mm

dimensions. In [9], a circular radiated patch antenna of a slit on one view of the patch was designed to cover radiation frequency from 3.3 GHz up to 10.6 GHz. In this worked paper, a high efficiency UWB antenna is designed, fabricated and measured operating at frequency range of 3.5 GHz up to 12 GHz. This UWB range is used to avoid inter-system interference (ISI) with the lower narrow-band communication systems. In second section, the proposed design of raked and slotted planar radiator was printed on substrate material made of Taconic TLY-5 material. The simulated and measured voltage standing wave ratio (VSWR), return loss, two dimensions (2-D) and three dimensions (3-D) omni-directional radiation patterns that are resulted and discussed in bellow fourth section for frequency of three different values. Effects on reflection coefficient by cut notches and feed gap are discussed in fifth section. In sixth section, fabrication measurements are presented while conclusions are shown in seventh section.

2. UWB Antenna Design

The Taconic TLY-5 dielectric substrate material was chosen for the proposed printed antenna which had a ϵ_r of 2.2 which is a relative dielectric constant. The loss tangent of ϵ_r is 0.0009 and material thickness of 1.575 mm. Material of small ϵ_r was chosen to reduce the losses in conductor to optimize the efficiency in radiation. Also to

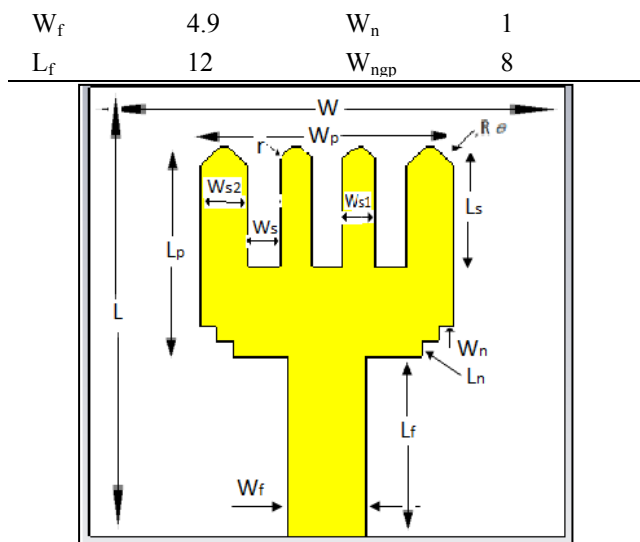
impedance, the requirement of the UWB antenna because of the radiated power was very low as -41.3 dBm/MHz that can be compared with that of radiated power for wireless systems that operate in narrow-band [10, 11].

The radiator of patch-shaped was printed by copper, which had a 0.035 mm thickness and W_p mm x L_p mm dimensions. The chosen patch's shape was produced to achieve specific important requirements. The previous requirements are such input impedance, polarization, efficiency, bandwidth, and gain. In radiator, three cut slots of same dimensions were cut to increase the current density by extending the radiation edges. The lower side of the printed patch was notched by two-step notches in order to widen the input impedance bandwidth to cover the UWB frequency range. The feeder structure was designed with W_f x L_f mm² dimensions to govern the antenna input matching impedance of 50 Ω which operates along UWB operating frequency and enhancing the wireless radiation performance. Figure 1 shows the printed planar patch and feeder structure were fabricated on one view surface to simplify the proposed design by reducing the copper used.

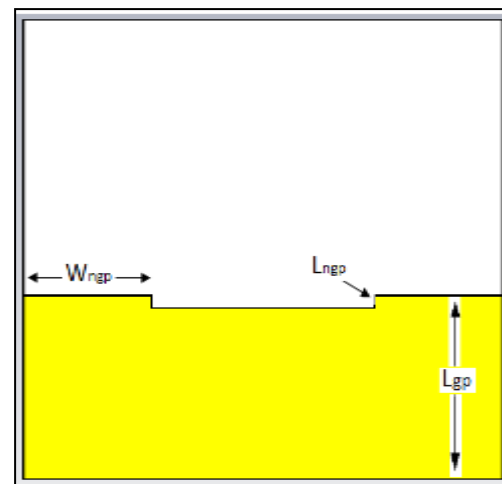
At the back view of the proposed antenna model, there is a feed gap of 14 mm x 1 mm dimensions was unprinted between the patch radiator and ground plane. This feed gap is used to enhance the return loss (S_{11}) for the proposed antenna and to guide the propagation as a circular radiation. The ground plane was slotted and printed along the substrate width, and the dimensions of the gap were changed to several different values to evaluate the optimized feeder gap. The optimized gap dimensions are required to make the printed antenna capable for reception and transmission of extending the operating frequency range beyond that reported and defined by United States FCC. This antenna performance is suitable for G5 or future updated wireless communication systems with high propagation speeds and high transmission indoor or outdoor bit rates. The optimal dimensions for the antenna design are shown in Table 1 to get acceptable simulated and measured results.

Table 1: The Proposed Antenna Dimensions.

Parameters	Value (mm)	Parameters	Value (mm)
W	30	W_s	2
L	30	L_s	10
W_p	16	r	0.75
L_p	15	R	1.25
L_{gp}	11	W_{s1}	2
θ	45°	W_{s2}	3
L_{ngp}	1	L_n	1



(a)



(b)

Figure 1: Geometrical simulated UWB printed antenna design: (a) antenna front view; and (b) antenna back view.

3. Results and Discussion

Figure 2 represents the measured and simulated S_{11} curves for previous antenna design with same size two-step notches. By using software of CST microwave studio, the simulation was run and the practical measurements were done with input 50 Ω connector impedance. This connector was soldered to the bottom edge of the antenna feed line and connected in antenna laboratory by RF cable to network analyzer instrument. Figure 3 indicates the simulated and measured results of VSWR (voltage standing wave ratio). This figure depends on the data has been taken from the CST software and the network analyzer, respectively. Obtained readings of VSWR were sketched on the same scale. The same scale shows the comparison between measured and simulated

results of VSWR and return loss (S_{11}) parameters. There is a little bit differences between measured and simulated readings because of the connector type and the kind of solder used.

Figure 4 shows the three dimensional (3-D) views in simulation process of radiation patterns as in (a) at a 7.5 GHz frequency and (b) at 10 GHz frequency. From these omni-directional patterns are indicated to clear that the proposed antenna design exhibited capabilities of radiation in all radiations in H-plane and E-plane. Figure 5 shows the simulated polar radiation patterns of the proposed printed antenna at the elevation-plane ($\Phi = 0^\circ$ and 90°) and at horizontal-plane ($\Theta = 0^\circ$ and 90°). The simulated radiation patterns of H and E planes show clear omni-directional radiation patterns at antenna resonance frequencies of 4.5 GHz, 7.5 GHz, and around 10 GHz.

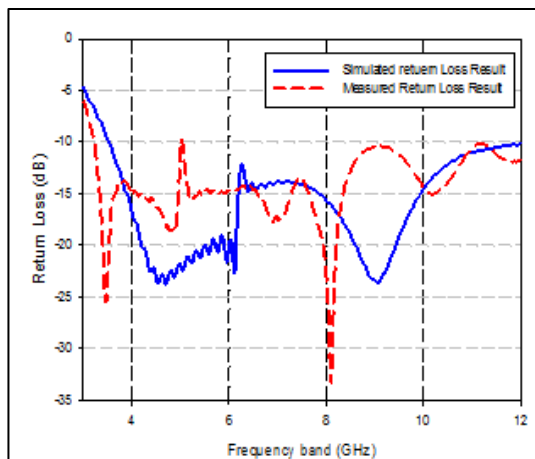


Figure 2: Comparison between measured and simulated return loss for the proposed two-step cut notches antenna

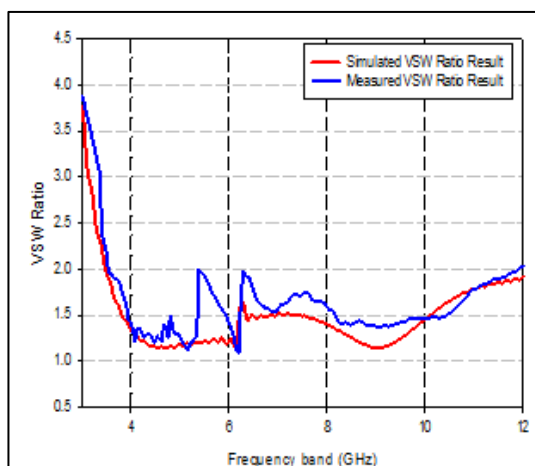
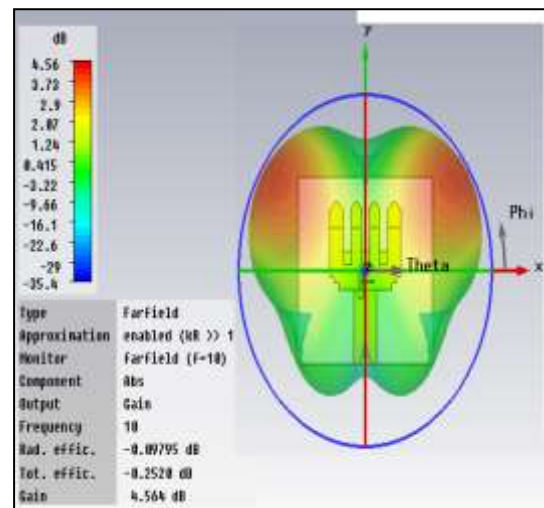
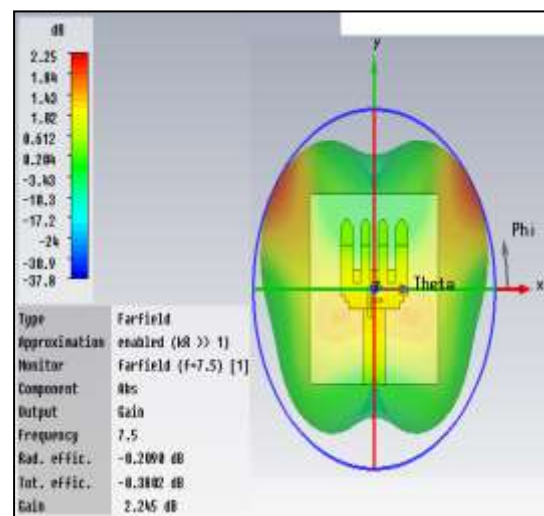


Figure 3: Measured and simulated characteristics of VSWR for cut two-step notches antenna.

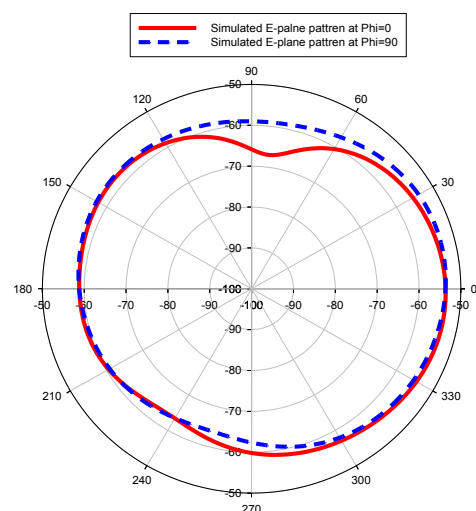


(a)

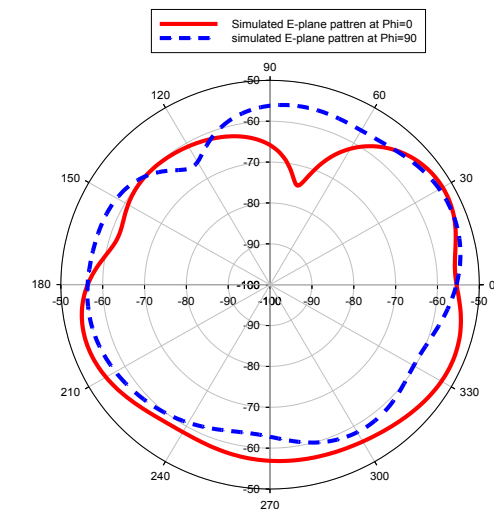


(b)

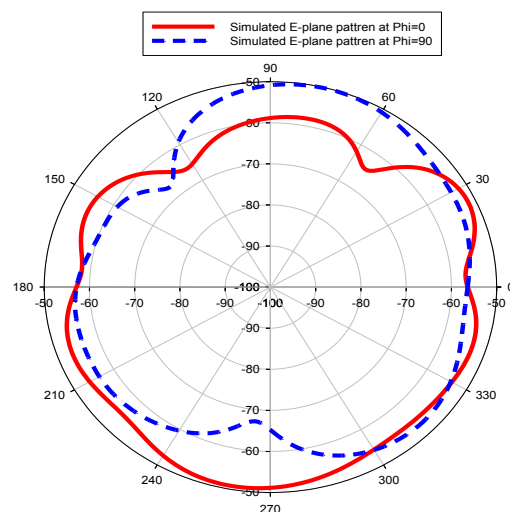
Figure 4: 3-D simulated views to show the omni-radiation antenna patterns: (a) at 10 GHz (b) at 7.5 GHz.



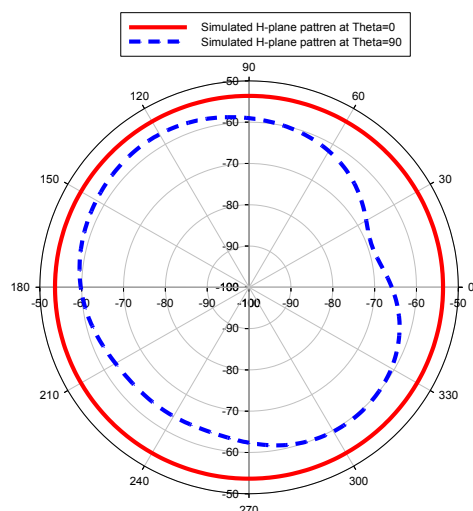
(a) E-plane



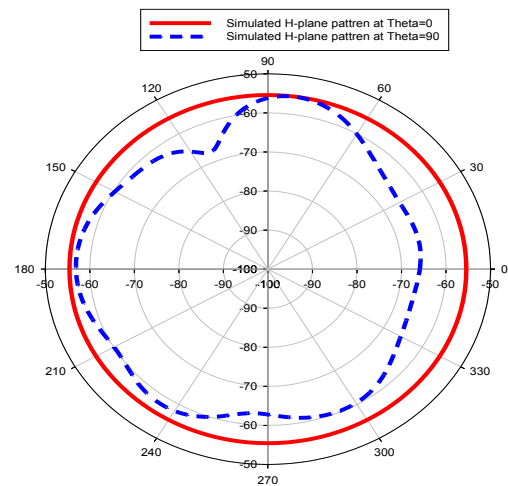
(a) H-plane



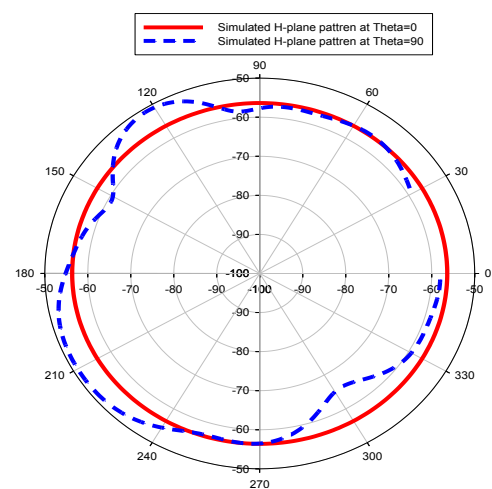
(b) E-plane



(b) H-plane



(c) E-plane



(c) H-plane

Figure 5: Simulated patterns for elevation radiation in E-plane and azimuth radiation in H-plane design of antenna at three frequencies: (a) at 4.5 GHz, (b) at 7.5 GHz, and (c) at 10 GHz.

4. The Effect of Bottom Radiator

As shown above, Figure 1 shows the dimensions of rectangular patch antenna, which are: cutting notch of bottom edge is 1mm x 1mm, feed line of width (W_f) is 4.9 mm, and feed line (L_f) of length is 12 mm. To change the distance between the ground planes and patch radiator, cutting-notches technique was done in order to tune the capacitive coupling between antenna radiator and ground plane. Figure 6 shows the return loss of the designed antenna with two-step cut notch, one-step cut notch, and no-step notch designs at lower edge of the patch radiator. The S_{11} curve must cover all the UWB frequency range, which is starting from 3.1GHz up to 10.6 GHz to be used in wireless systems that are working in UWB technique and other narrow band wireless systems in the same frequency range. Due to the S_{11} curves, the two-step cutting, one-step cutting,

and no-step cutting notches designs are covering the working bands of 3.6 GHz to 11 GHz, 3.5 GHz to about 12 GHz, and 3.5 GHz to about 10 GHz, respectively. At two-notch, one-notch, and no-notch characteristics, the resonances are occurred at frequencies of 9 GHz, 9.55 GHz, and 8.2 GHz, respectively. Notches effects on fractional bandwidth are shown in table 2 by calculation the ratio of BW (Bandwidth) over central frequency (f_c) that represented by [12]:

$$\frac{BW}{f_c} = \frac{(f_u - f_L)}{\frac{1}{2}(f_u + f_L)} \quad (1)$$

where parameters f_u and f_L are values of upper and lower frequencies, respectively. After calculation, the indicated results are 104.4 % at two-notch and 110.3 % at one-notch configurations.

5. The Feed Gap Effects on Return Loss

The unprinted feed gap space (L_{ngp}) lies between lower patch edge and the planar printed ground plane and affected on the input impedance of the antenna bandwidth. On the back view of the substrate material, the printed ground plane acted as an element for impedance matching. This input impedance matching is used to control the required impedance bandwidth range of the printed rectangular-shaped patch. At simulation run, the dimensions of the gap were taken as 14 mm x 1 mm, 14 mm x 0.5 mm, and 14 mm x 0.25 mm to optimize the required dimensions for feed gap. Figure 7 is showing the simulated S_{11} behaves for the mentioned different feed gap dimensions. These behaves are below -10 dB loses at operating frequency band of the designed antenna and varied at changing of L_{ngp} dimensions. Table 3 represents the computed fractional bandwidths for antenna at different dimensions for radiator feed gap and the optimal one was found to be 14 mm x 0.25 mm, with 133% fractional bandwidth was calculated. The S_{11} simulation behavior is shown in Figure 8. The behavior at 0.25 mm feed gap (L_{ngp}) dimension and frequency range starting from 2 GHz up to 20 GHz. Radiator operating range of bandwidth was 3.3 GHz to about 16.6 GHz at S_{11} below -10 dB. In addition, table 4 shows comparison results of the small-proposed antenna design. This comparison was done with those of [13], [14] and [15] in the last literature review for two symmetrical proposed radiators.

Table 2: Notch effects on simulated bandwidth under -10 dB of the designed printed antenna

Step Notch	F_L in GHz	F_U in GHz	BW in GHz (mm)	Fractional BW in GHz
0	3.77	10.5	6.73	94 %
1	3.53	12.2	8.67	110.3 %
2	3.64	11.6	7.96	104.4 %

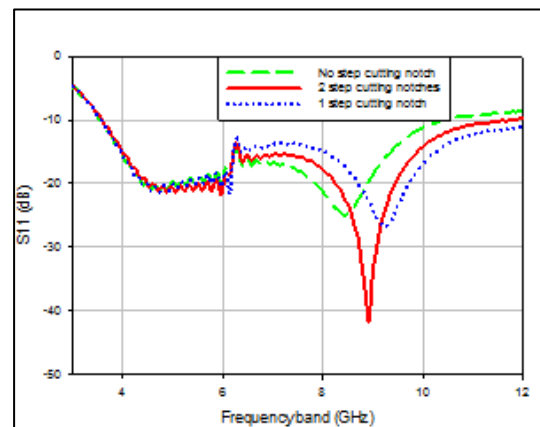


Figure 6: Simulated behavior of return loss for printed patch with cutting step notches at bottom edge radiator

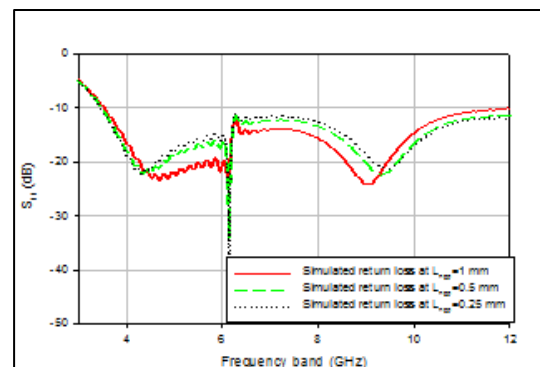
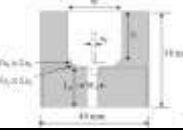
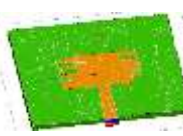


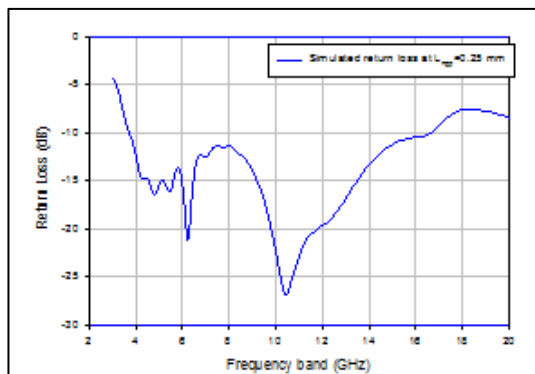
Figure 7: S_{11} simulated curves at different feed gap dimensions

Table 3: Calculated Fractional bandwidths bellow -10 dB return loss for proposed different dimensions of feed gaps

L_{ngp} in mm	F_L in GHz	F_U in GHz	The BW in	Fractional BW in GHz
0	3.63	11.74	8.11	105.5 %
0.5	3.75	12.52	8.77	117.8 %
0.25	3.15	13.8	10.65	126 %

Table 4: Comparison between printed previous and proposed antennas.

Referen ce	Substrate material Used	Antenna Dimensions	Coverage Bandwidth (< -10 dB)	Antenna Gain Values Over UWB	Specified Figure in the Reviewed Papers
Propose d antenna design	Taconic TLY-5 of $\epsilon_r = 2.2$	30 x 30 mm^2	(3.5-16.6) GHz	(2 – 6) dBi	
Telanth e et al., 2012 [13]	FR4 material of $\epsilon_r = 4.4$	40 x 38 mm^2	(2 – 12) GHz	(2.9 – 6) dBi	
Mohan & Mathew , 2014 [14]	FR4 material of $\epsilon_r = 4.4$	34 x 36 mm^2	(3.6 – 6) GHz (7.6 – 10) GHz	(2.2 – 4.9) dBi	
Telanth e et al., 2012 [13]	FR4 material of $\epsilon_r = 4.4$	(40 x 40) mm^2	(3.5 – 140) GHz	(0.5 – 2) dBi	

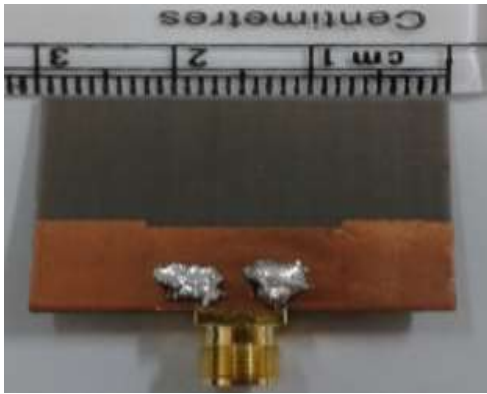
**Figure 8: Simulation result for return loss at 0.25 mm feed gap**

6. Measurement Results and Prototype

Figure 9 shows the proposed UWB antenna photograph with printed back front views on substrate material made of Taconic TLY-5 material and was done in Perlis University of Malaysia (UniMAP). In this photo prototype, practical measurements were processed and conducted by soldering a small connector. The input resistance of this connector is 50Ω to the lower edge of the printed microstrip transmission line. In UniMAP's antenna laboratory, the fabricated antenna was connected by an RF cable to the network analyzer instrument to display the reflection coefficient (S_{11}) as shown in Figure 10. Practically, UWB anechoic chamber was used to test the fabricated antenna as represented in Figure 11. This chamber was used to perform the

tested radiation space patterns of the proposed antenna. The measured results of omni-directional radiation patterns that are performed in Figure 12 with different frequencies are 4.5 GHz, 7.5 GHz, and 10 GHz. However, there are some small differences between measured and simulated results of the printed antenna imported parameters were expected. The small differences appear according to the considerable effect of the coaxial cable and mismatch between soldered connector and adapter. Because of no sensitive cut, there is some degradation in the performance of the proposed antenna that caused by misalignment between dielectric substrate two-sides and microstrip line.

**(a)**



(b)

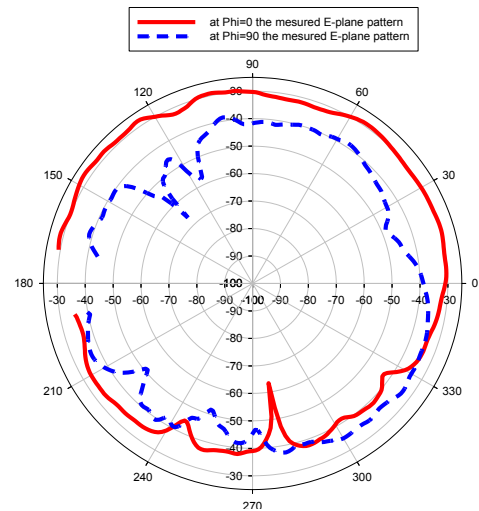
Figure 9: Shows the fabricated antenna photograph: (a) front antenna view; and (b) back antenna view



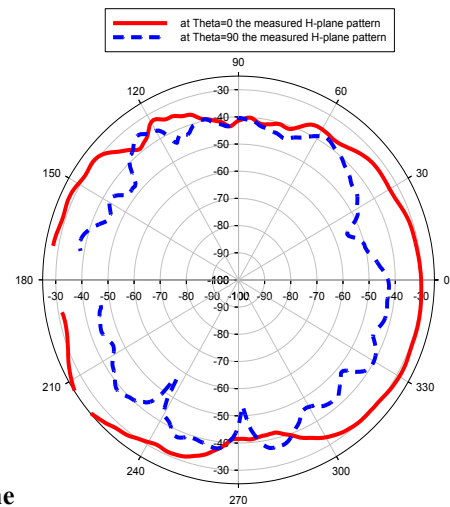
Figure 10: Shows a photograph of measured S11 of the practical connection of the Taconic TLY-5 antenna



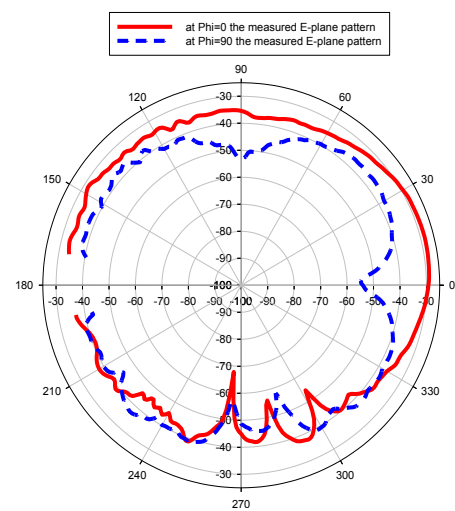
Figure (11): The proposed antenna photograph in the Anechoic Chamber



(a) E-plane



(a) H-plane



(b) E-plane

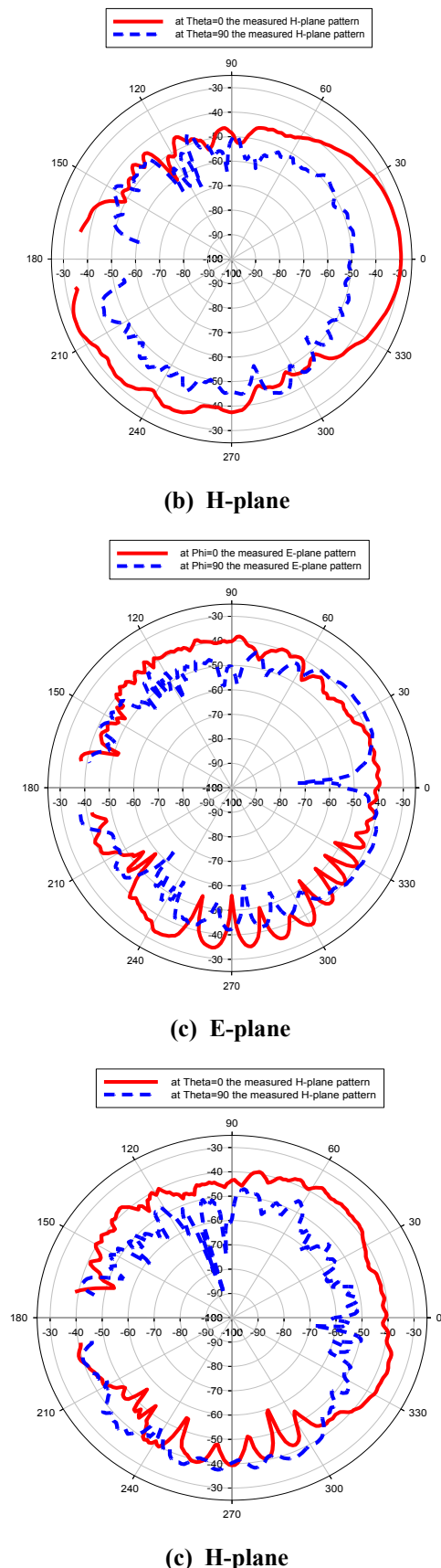


Figure 12: Measured plane patterns of the proposed antenna in H-plane and E-plane (a) at 4.5 GHz frequency, (b) at 7.5 frequency, (c) at 10 GHz frequency.

7. Conclusion

This manuscript presents the simulated and practical design of a UWB wireless antenna. The antenna of rectangular radiator was designed with three printed slits on a square-shaped substrate material with a feed gap of 1mm dimension at the top of ground plane under the patch. There are two-step cutting notches were cut at the lower side corners for patch radiator. The performance of the proposed antenna design was tested by running CST microwave (studio simulation software). The run was taken over the frequency range of UWB for a S_{11} below -10 dB. Also VSWR is below 2 along UWB frequency range. The general effects of the feed gap size and notches were evaluated for extending the bandwidth of input impedance and to get several low resonance frequencies. In addition, the proposed antenna fabrication was processed to produce the comparison between simulated and measured results. This process was done at same chosen parameters using a network analyzer and an anechoic chamber. The omni-directional radiation patterns were obtained for both processes of simulated and fabricated antenna designs. In addition, patterns proved the daily requirements for indoor wireless systems.

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Author biography



Dr. Rashid Ali Fayadh received his B.Sc. degree from Middlesex University/Engineering College / UK , in 1986 and worked as an electronic warfare engineer in Iraqi air force up to 1998. He received the M.Sc. degree from University of Technology/ Al-Rasheed College / Baghdad-Iraq in 2000 and Ph.D from University Malaysia Perlis in 2014. He started as a lecturer from 2001 up to now in the College of Electrical Engineering Techniques, Middle Technical University, Baghdad, Iraq. He is head of electrical power engineering departement. He is IEEE member and working in interesting fields of wireless communication, signal processing, and antenna designs with specific focus on ultra-wideband (UWB) technologies. He has published 48 papers in international and local reviewed journals and conferences.