THE PERFORMANCE OF TWO ANTENNA DESIGN SHAPES IN ULTRA-WIDEBAND WIRELESS APPLICATIONS

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ABSTRACT

The extensive requirements for small Ultra wideband (UWB) communication systems lead to design active and small size antennas. In this research two rectangular microstrip antennas were designed to cover the UWB operating frequency of 7.5 GHz starting from 3.1 GHz up to 10.6 GHz. The simulation and prototype designs are presented in this paper using CST microwave studio software tools and printed circuit board, respectively. The designs satisfy the requirements of UWB technology and according to the geometrical shape, one is called prong-shape patch antenna and the other is rake-shape patch antenna. The simulated results for return loss (S11) and radiation pattern have been demonstrated that the antenna designs are suitable for UWB communication systems. The measured results for same parameters were concluded by network analyzer and anechoic chamber to reinforce the performance of these antennas in wireless UWB applications. After confirming the performance of these designs, the comparison was done between the two to see the advantages in use.

Keyword: Ultra wideband, prong-shaped and rake-shaped antennas return loss (S_{11}), omni-directional radiation patterns.

INTRODUCTION

After limiting the UWB frequency range from 3.1 GHz to 10.6 GHz and transmitting power of -41.3 dBm/MHz by the Federal Communications Commission (FCC) in the United States [1], the transmission and reception by small antennas were designed to cover this band. Today the microstrip antennas are more suitable in using for commercial and medical applications that operates in UWB bandwidth [2]. Most of these antennas were designed of metallic patch printed on grounded substrate taking different configurations i.e., circular, rectangular, dipole, and helix patches. The used substrates of low dielectric constants are thin in the microstrip antenna designs to provide large bandwidth and better efficiency [3]. These configurations are easy in fabrication using printed-circuit technology (PCT) and can be mounted on a rigid surfaces made of different inexpensive materials. So, the microstrip antennas can be fixed on personal computers, mobile telephone, and other high-performance mechanically robust machines [4]. The proposed design antennas were made small in size to be applicable for required radiation characteristics such as an array of microstrip patches in geometrical arrangement to maximize the radiation in one direction without other trends [5]. The array arrangement consists of separated radiators that are mounted on one substrate structure to radiate most of delivered power from transmitter to the desired direction or all direction to achieve the omni-directional propagation [6]. As the rectangular patches are more suitable in UWB systems applications, a rectangular patch antenna was designed by [7] of 24 x 37.5 mm^2 area for three bands of UWB frequency range using Rogers substrate material with 10.2 dielectric constant. 35mm x 31mm dimensions geometrical patch antenna was simulated and fabricated by [8] to meet the required UWB bandwidth with partial ground and two step notches at the lower slot of the patch. Cored U-shaped slot in the rectangular radiating patch was simulated by [9] with dimensions of 36mm x 34mm using FR-4 substrate material with 4.4 dielectric constant to cover bandwidths ranging from 3.95 GHz to 5.1 GHz and from 5.8 GHz to 9.69 GHz. Ref. [10] represented small size patch with slotted ground plane for multi-input multi-output antenna applications and printed on FR-4 substrate material to cover bandwidth of 8.4-17.8 GHz which is more than UWB frequency range and this is encouraging the systems interference that is operating over frequency of 10.6 GHz. Ring-shaped patch antenna of 30mm x 20mm dimensions was simulated by [11] for UWB frequency range from 2.5 GHz to 9.4 GHz with relative permittivity of 4.4 and this antenna was designed to achieve the Bluetooth, WiMAX, and WLAN frequency bands. Complex patch shape of 19mm x 21mm dimensions was shown in [12] and printed on Teflon material covering range up to 7.8 GHz. In this paper, monopole antennas of prong-shaped and rake-shaped rectangular patches were proposed and fed by input impedance feeder of 50Ω. The advantages of these antennas are small size, easy to fabricate, and simple structure. The designs were performed by running CST microwaves studio software. The sections bellow describe the simulation designs configuration, antennas manufacturing, simulated and measured results and their discussions with manuscript conclusion.

SIMULATED STRUCTURE OF THE PROPOSED ANTENNAS

High speed high data rate of new wireless communication systems increased the demand for suitable antennas in size, weight, and transmit or receive very narrow band signals (less than 1 ns) [13]. Microstrip copper antenna printed on Taconic TLY-5 substrate material can meet the previous requirements and offering

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the ultra wide frequency range laminates. The height (h) of substrate material is 1.575mm and relative dielectric constant (ε_r) is 2.2 with dissipation factor of 0.0009. The proposed antennas of L x M dimensions are shown in Figure-1 with patch radiators of 0.035mm copper thickness (t) were printed on front sides and rectangular ground plane on the back sides of the substrate. The patch dimensions of the proposed designs are denoted as L_p (patch length) and W_p (patch width) with two upper and lower radiating slots for each patch. The other dimensions are presented in Table-1 for prong-shaped patch antenna and Table-2 for rake-shaped patch antenna and in both antennas, a microstrip cross-section line is shown in Figure-2 which is used as a feeder to keep the feeding microstrip line input impedance at 50Ω. Ground plane was printed along the substrate bottom side to compensate the mismatch between radiating patch and feed line. The gaps between ground planes and the patches were chosen to keep radiation in all directions and the performance of radiator depends on the width of the gap (L_{gap}). Practically the actual length and width of the radiator patch which are leading to good radiation efficiencies can be calculated as [14]:

$$W_p = \frac{c}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L_p = \frac{\lambda}{2} - \Delta L_p \tag{2}$$

$$\lambda = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\varepsilon_{reff} = \frac{(\varepsilon_r^2 - 1)\sqrt{W_p}}{2\sqrt{W_p + 12h}} \tag{4}$$

$$\Delta L_p = \frac{(\varepsilon_{reff} + 0.3)(W_p + 0.264h)}{(\varepsilon_{reff} - 0.258)(W_p + 0.8h)} \tag{5}$$

$$f_r = \frac{c}{2L_p\sqrt{\varepsilon_r}} \tag{6}$$

$$L_{peff} = L_p + 2\Delta L_p \tag{7}$$

Where c is the light speed in free space, ΔL_p is the patch extension length, ε_{reff} is the effective relative permittivity, L_{peff} is the effective patch length, and f_r is the resonance frequency. The prong-shaped patch is slotted by two slots to produce two resonance frequencies and the rake-shaped patch is slotted by three slots to produce three resonance frequencies. The advantages of these slots are to produce broad-band characteristics with simple topology [15].

Table-1. The values of the prong-shaped patch dimensions.

Parameters	**Values** (mm)
W	40
L	35
W_p	24
L_p	19
L_{gp}	11.6
θ	45
L_{gap}	0.4
W_f	4.7
L_f	12
W_s	3
L_s	10
W_{fing}	6
R	3
W_{n1}	4
L_{n1}	1.5
L_{n2}	2

Table-2. The values of the rake-shaped patch dimensions.

Parameters	**Values** (mm)
W	30
L	28
W_p	16
L_p	14
L_{gp}	9.45
R	1.75
r	1.25
W_f	4.9
L_f	10
W_s	2
L_s	8
W_{s1}	3
L_{gap}	0.55

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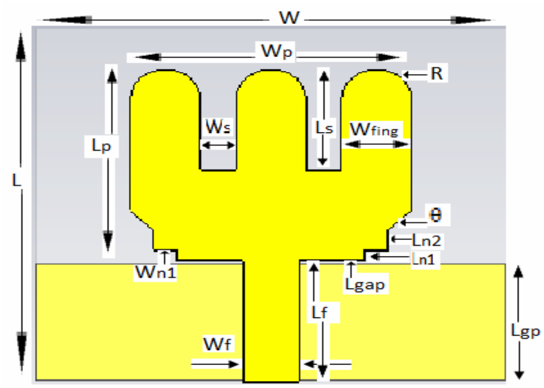

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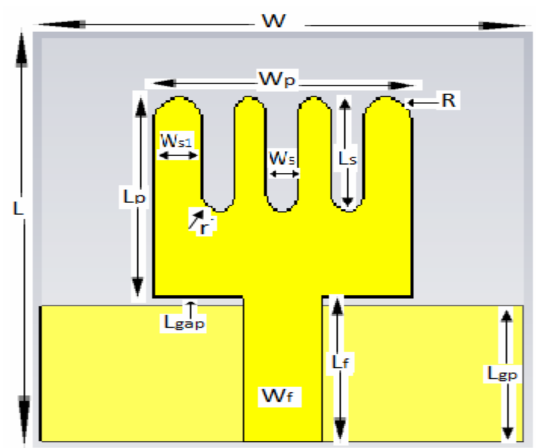

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Figure-1. CST simulation design with dimensions of the proposed antennas (a) prong-shaped patch, (b) rake-shaped patch.

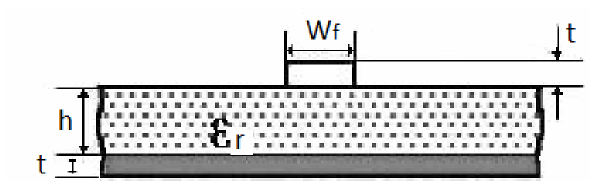
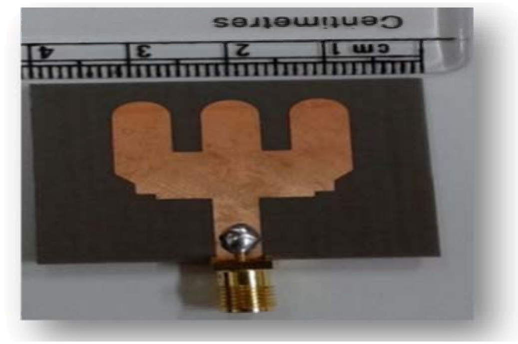


Figure-2. Microstrip cross-section line.

FABRICATED STRUCTURE OF THE PROPOSED ANTENNAS

Figure-3 and Figure-4 of front and back views are showing the practical implementation of the proposed antennas which are printed on PCBs to be easily integrated with other RF circuits and embedded with UWB devices. Mainly, the printed antennas consist of oppositely patch radiator and ground plane on a dielectric substrate. There is a gap between planar radiator and ground plane of 0.55 mm in prong-shaped and 0.4 mm in rake-shaped patches. The radiators are coplanar with radiators and fed by a microstrip line of 4.8 mm in both antennas and soldered with coaxial feed connector of 50Ω input impedance to be contact with network analyzer.



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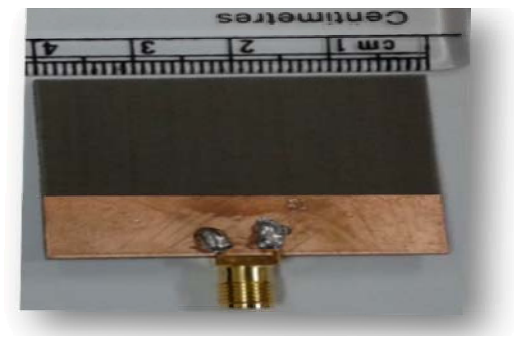

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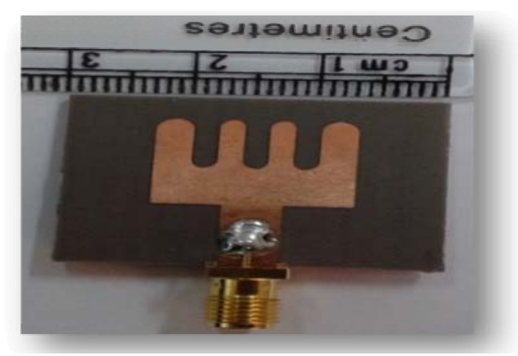
Figure-3. Photograph of the fabricated prong-shaped antenna (a) front view (b) back view.



(a)

(b)

Figure-4. Photograph of the fabricated rake-shaped antenna (a) front view (b) back view.

CST MICROWAVE STUDIO SIMULATION RESULTS

Simulated reflection coefficients and radiation patterns

In wireless communication, the antenna frequency range is required to provide a reflection coefficient less than -10dB, that mean 90% of the power supplied to the antenna is transmitted. The CST software simulated results for reflection coefficients (S_{11}) are shown in Figure-5 across the UWB frequency range which is achieved from overlapping resonance frequency bands. In prong-shaped patch design, there are three resonance bands are centered at 3.75 GHz, 4.82 GHz, and 7.65 GHz. While in rake-shaped patch design, there are two resonance bands are centered at 5.95 GHz and 8.04 GHz. Figure-6 shows the E-plane and H-plane radiation patterns for prong-shaped at the resonance of 4.82 GHz and Figure-7 shows the radiation patterns for rake-shaped patch at resonance of 5.95 GHz. In prong-shaped and rake-shaped designs, the patterns are apparent as omni-directional in E-plane at $\varphi = 45^{o}$ and H-plane at $\theta = 45^{o}$ and 90^{o}. The E-plane patterns are bidirectional for both designs at $\varphi = 90^{o}$ as illustrated in Figure-6 (a) and Figure-7 (a). From simulated results, these designs are suitable for most of UWB devices and mobiles that have omni-directional antennas for transmission and reception in the horizontal plane.

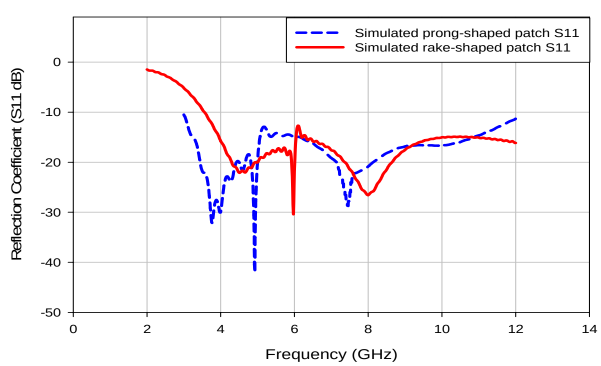
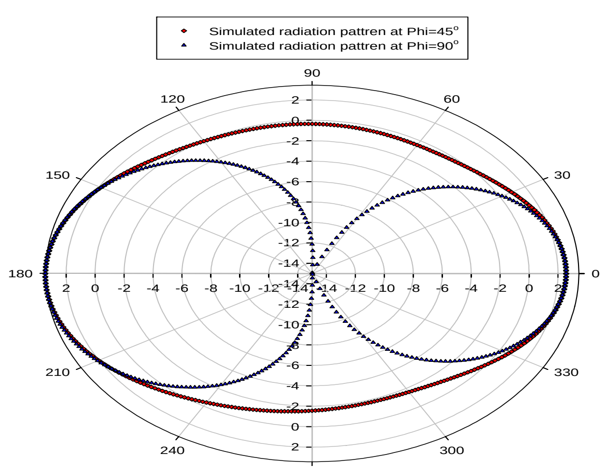


Figure-5. Simulated $|S_{11}|$ of the two proposed antennas.



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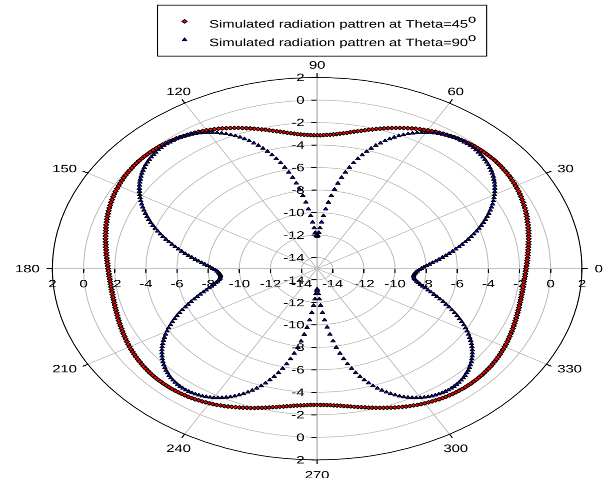

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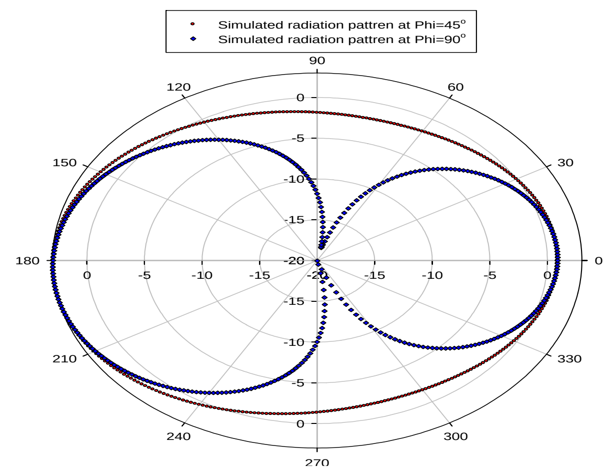
Figure-6. Simulated radiation patterns of prong-shaped antenna at 4.82 GHz in (a) E-plane and (b) H-plane.



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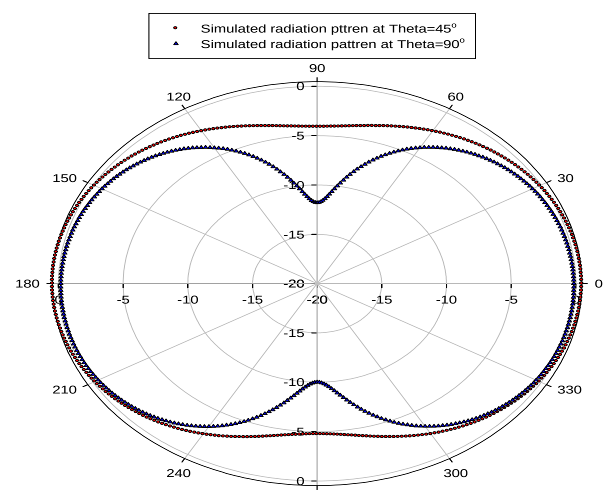

(b)

Figure-7. Simulated radiation patterns of rake-shaped antenna at 5.95 GHz in (a) E-plane and (b) H-plane.

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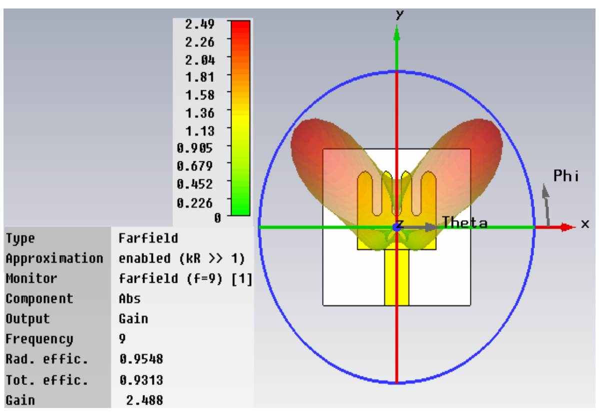
3-D simulated radiations and surface current distributions

To compare the proposed antennas with other literatures, i.e., [16], they have relatively small size, that mean the antenna presented in [16] is 20% bigger in size than the prong-shaped antenna and 30% bigger in size than the rake-shaped antenna. The article designs are rectangular patches fed by microstrip line and they have their 3-D simulated radiations in Figure-8 (a) for rake-shaped and (b) for prong-shaped antennas. The 3-D radiators were simulated at frequency of 9 GHz to show the behavior of radiators and to represent the gain and radiation efficiency at this frequency. The distribution of surface current on the patches and feeders are illustrated in Figure-9(a) for rake-shaped and (b) for prong-shaped patches. The simulated results were done at frequency of 9GHz which indicate the current distributions on the patches and feeders surfaces. The current density is the biggest on the feeders and edges of the radiators which mainly computes the radiation field. The surface current on the rake-shaped radiator of three slots is greater than that on prong-shaped radiator of two slots which is bigger in size of substrate dimensions.



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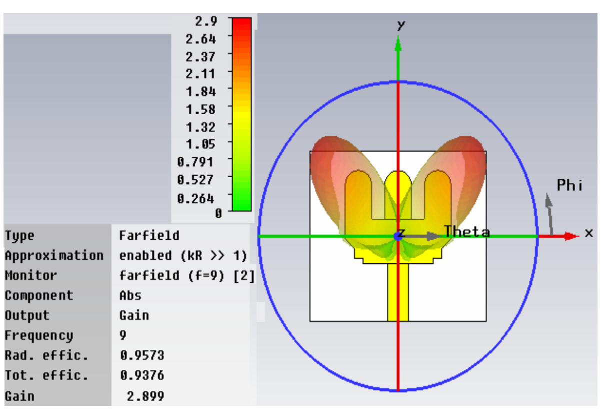

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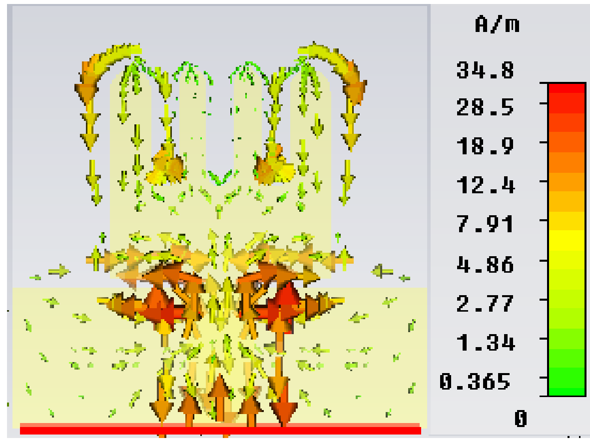
Figure-8. 3-D simulated radiations at 9GHz (a) rake-shaped patch radiation pattern (b) prong-shaped patch radiation pattern.



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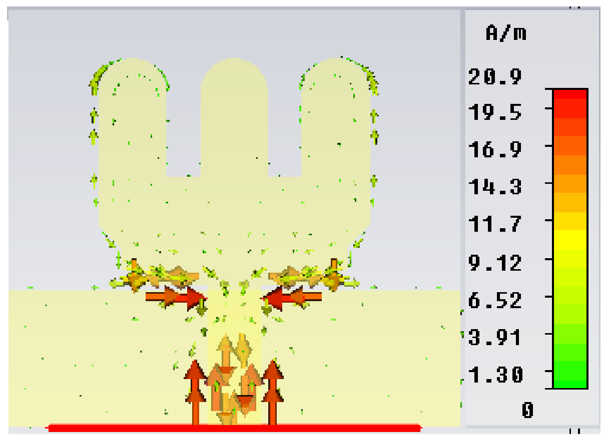

(b)

Figure-9. Simulated surface current distribution at 9 GHz on the: (a) rectangular rake-shaped patch antenna and (b) rectangular prong-shaped patch antenna.

Gain and efficiency simulated results

The variations of gain and efficiency are a function of antenna frequency and these variations are represented in Table-3 for both antennas. Firstly, the lowest gain for prong-shaped antenna is 2.759dB at frequency of 6 GHz and the largest gain is 6.209dB at 12 GHz. The highest efficiency was 96% in the range of frequencies between 6 GHz and 8 GHz. These results at frequency range between 3 GHz and 11 GHz showed the high performance of the designed antenna when gain is less the 5dB and high efficiency which could be considered a great to consume low power. Secondly, from Table-3, the maximum gain for rake-shaped antenna was 4.73dB at 12 GHz and the minimum gain was 1.904dB at 3 GHz. The greatest efficiency was 95% at frequency range between 7 GHz and 8 GHz and the lowest value was 78% at 3 GHz. According to the second antenna, the design has gain less than 5dB at frequency range between 3 GHz and 11 GHz with great efficiency, so that this antenna also considered being great for consuming low power.

Table-3. Efficiency and gain simulated results for both antennas.

Frequency (GHz)	**Prong-shaped antenna**		**Rake-shaped antenna**	
	Gain (dB)	**Efficiency** (%)	**Gain** (dB)	**Efficiency** (%)
3	2.465	90	1.904	78
4	3.053	91	2.604	85
5	3.43	79	2.984	88
6	2.759	96	3.032	89
7	3.883	96	2.783	92
8	4.48	96	2.850	95
9	4.623	95	3.959	95
10	4.559	95	4.813	93
11	5.337	95	4.986	92
12	6.209	95	4.730	91

EXPERIMENTALLY RESULTS DISCUSSIONS

Network analyzer measured results

Practically, the variation in the parameters, such as, probe size, patches dimensions, connector input impedance, and location can dramatically change the antennas behavior. The measured results of S_{11} are presented in Figure-10 for both antennas with two resonance frequencies each to show the operating bands. The measure $\leq$-10dB S_{11} bandwidth of rake-shaped patch antenna is 8.8 GHz (3-12 GHz) while the simulated is 9 GHz (3-12 GHz), so that the antenna shows stable behaviors over the UWB range. The approached simulation and measurement bandwidths give an excellent performance to support the desired UWB characteristics. The measure $\leq$-10dB S_{11} bandwidth of prong-shaped patch antenna is 8.5 GHz (3.5-12 GHz) while the simulated is 7.8 GHz (4.2-12 GHz), so that the antenna shows less performance over the UWB range.

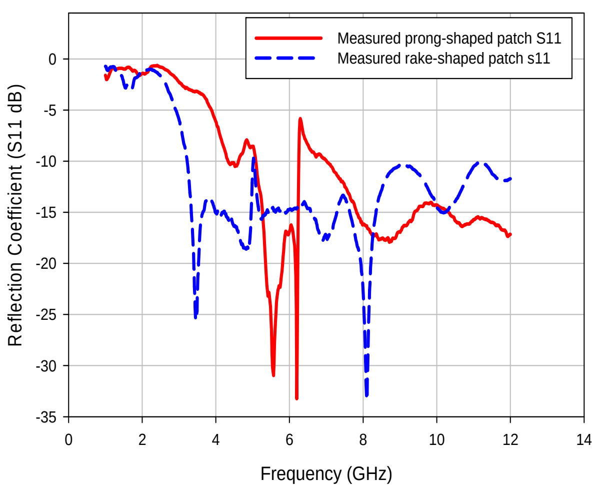

Figure-10. Tested $|S_{11}|$ of the two fabricated antennas.

Anechoic chamber measured results

The antenna prototypes were produced in Figure-3 and Figure-4 are soldered with connectors of 50Ω and fixed in a microwave anechoic chamber as shown in Figure-11. After carrying the measurements, the experimental radiation pattern results are shown in Figure-12 for prong-shaped antenna at frequency of (a) 7.5 GHz and (b) 10 GHz in E-plane. These results suggest that the prong-shaped patch show pleasing omnidirectional radiation throughout the previous operating frequencies. The measured and simulated radiation patterns of rake-shaped patch are illustrated in Figure-13 corresponding to relevant frequencies of (a) 7.5 GHz and (b) 10 GHz in E-plane. The E-plane patterns are omnidirectional at both frequencies, thus, the radiation patterns are generally omnidirectional over the required UWB frequency bandwidth.

Figure-11. Photograph of used rectangular anechoic chamber.

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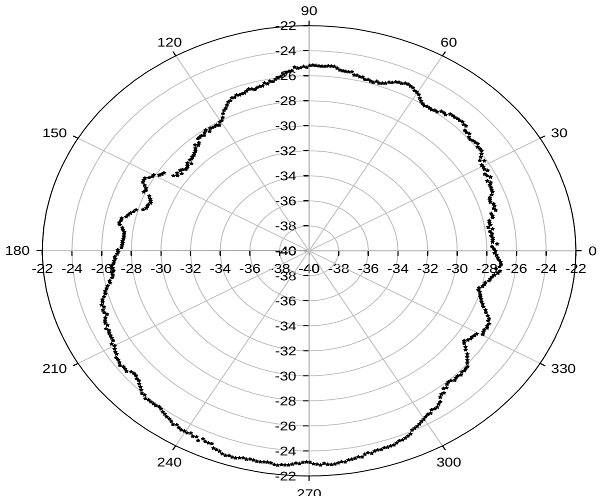

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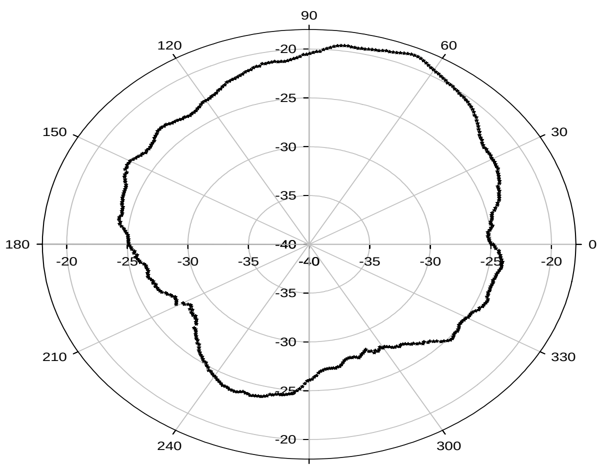
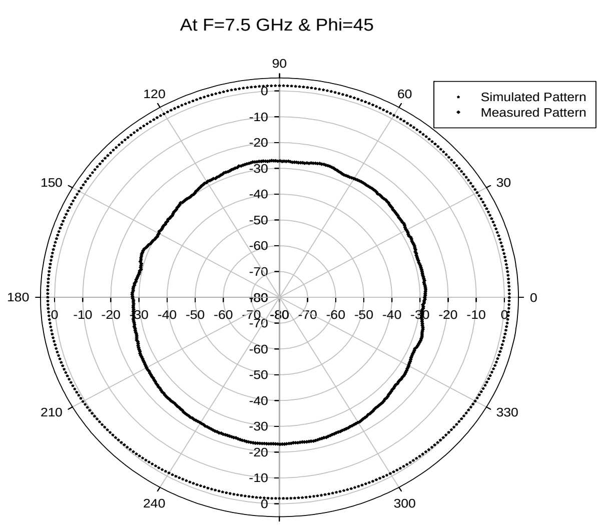


(b)

Figure-12. Measured radiation patterns of prong-shaped antenna at: (a) 7.5 GHz, (b) 10 GHz.



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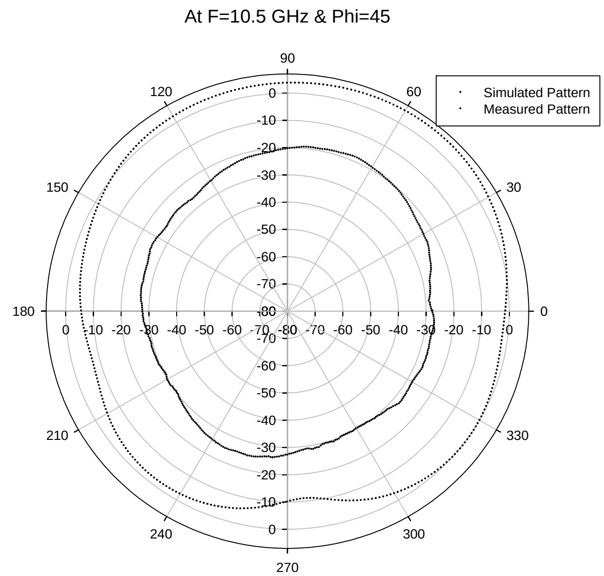

(b)

Figure-13. Comparison between simulated and measured radiation patterns for E-plane of the rake-shaped antenna at (a) 7.5 GHz, (b) 10 GHz.

CONCLUSIONS

A rectangular shaped patches accord UWB antennas with two slots as in prong-shaped patch and three slots as in rake-shaped patch. The dimensions of these slots and patches are different from prong-shaped to rake-shaped. The prong-shaped has notched with two set notches at the bottom corners of the radiator. The simulated results were obtained over the UWB frequency range for S_{11} (dB) less than -10dB in both designs and extended to 12 GHz. Also the radiation patterns have been presented as omni directional radiations to make the proposed antennas be used for all-direction propagation. The measured results for the main antenna parameters performed show reasonable agreement with the simulated ones.

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