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Spade-Shaped Patch Antenna for Ultra Wideband Wireless Communication Systems

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Abstract

In recent years many studies are concentrated on UWB microstrip antenna structures for important purposes in wireless communication systems, medical imaging, and radar sensor resolution. In this paper, we printed a spade-shaped radiator patch on nearly rectangular substrate of (30 x 28mm) made of Taconic TLY-5 material. The relative dielectric constant was 2.2, and the thickness of the material was 1.575mm. The patch was fed by a transmission line feeder, and there was a gap between the patch and the ground plane. The computer simulation test (CST) microwave studio software was used in the simulation, and anechoic chamber with a network analyzer was used during the experimental tests. The simulated and measured results demonstrated that the proposed antenna achieved a wide impedance bandwidth from 3.7 GHz to 12 GHz with a return loss of less than -10 dB with a feed gap of 1 mm. The simulated and measured radiation patterns were maintained to be nearly omni-directional radiation characteristics.

Keywords

Ultra wideband wireless communications, microstrip patch antenna, simulated and measured radiation patterns, spade-shaped patch antenna.

1. Introduction

UWB utilizes very narrow pulses of less than one nanoseconds that are used in the sensors and wireless communication systems. The Federal Communications Commission (FCC) in USA adopted the first licensed report about UWB technology [1]. The FCC allocated a bandwidth of 7.5 GHz as a dynamic range from 3.1 GHz to 10.6 GHz and a power spectral density of -41.3 dBm/MHz throughout the frequency range and noise limitation. There are several advantages of using UWB systems: 1) they operate with low transmission power that the UWB signals avoided the multi-path systems interference and do not cause significant effects on human body [2], 2) the frequency range can achieve transmission capacity of several gaga bit per second (Gbps) of distance of 1 to 10 meters in indoor and about 100 meters in outdoor propagation [3], 3) low cost and low complexity according to small UWB chips that were the first produced by Free-scale Semiconductor Company [4], 4) suitable in applications for location and tracking systems because of having high time resolution. These advantages make UWB signals are suitable for short range indoor transmitting and receiving radiation through the wall communication and ground reflections. Due to high data rate transmission and low power consumption, high gain antennas need to be designed to cover the characteristics of UWB systems. The main design of this microstrip patch antenna is frequently used in UWB wireless systems due to its lightweight, low cost, and easy in fabrication. There were many UWB microstrip patch antenna designs discussed and fabricated to achieve the requirements of transmission and reception of wide bandwidth signals. A small monopole antenna with diamond shape has been designed by [5] with printed patch of 30 x 26 mm^2 to cover the UWB frequency range. An antenna structure of symmetrical dipoles with three semicircular metal patches has been simulated by [6] to obtain an UWB frequency range. The design of planar inverted cone antenna was simulated and measured by [7] to achieve impedance bandwidth from 1.3GHz to 11GHz and omni-directional radiation patterns. In [8], antenna with three co-directional complementary split ring resonators was proposed to achieve the resonances at four rejection bands and the simulated and measured results show the validity of this antenna structure. A design of UWB planar printed circuit board antenna was introduced by [9] with bandwidth ranging from 2GHz to 11.3GHz to satisfy the additional narrow band systems. Multi-path environments monopole antenna was proposed by [10] for studying the performance comparison when using ground plane

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made of FR4 and ground plane made of Taconic TLY-5 materials. In this research a small size UWB antenna design was simulated and fabricated for future applications.

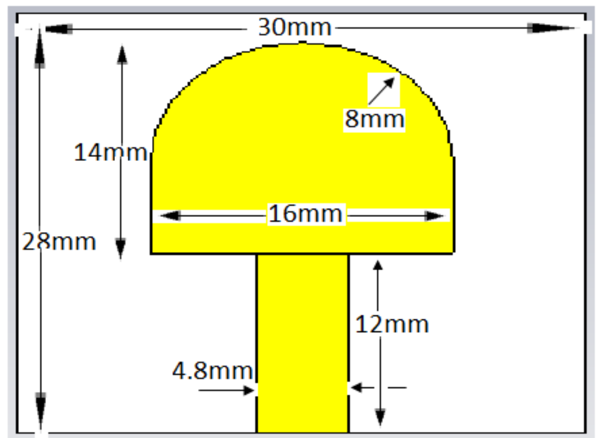
2. UWB Printed Antenna

The dielectric substrate material that was chosen for this proposed antenna was Taconic TLY-5, which had a dielectric constant, ε, of 2.2, a dielectric loss tangent of 0.0009, and a height of 1.575 mm. We chose material with a small dielectric constant for which we could minimize conductor losses in order to maximize the radiation efficiency, an imperative requirement for the UWB antenna because the transmitted power was -41.3 dBm/MHz, which is quite low compared with the power of narrow-band systems. The proposed spade-shaped patch antenna as shown in Figure 1 with front view, back view, and dimensions is small size and simple structure to produce low distortion with wide bandwidth to be applied in ultra wideband systems.

The printed spade-shaped patch radiator was designed to have large impedance bandwidth and made of copper that had a thickness of 0.035 mm and dimensions of 16 x 14 mm^2. The shape that was chosen for this patch was intended to achieve specific requirements in terms of polarization, input impedance, bandwidth, gain, and efficiency. The front curved edge of 8mm diameter was suggested to increase the radiation current density and to obtain omni-directional radiation patterns.

The rectangular microstrip feed line is in direct contact with the lower radiating edge of the patch and it must transfer the microwave energy from the transmission system to the antenna. The rectangular feed structure for this proposed antenna was designed with dimensions of 4.8 x 12 mm^2 to govern the impedance matching at the operating UWB frequency and to enhance radiation performance. The dimensions and shape of feed line was optimized to obtain 50 Ω input impedance and wide impedance bandwidth. Figure 2 shows that, the feed structure and the microstrip patch were fabricated on the front view of the substrate surface and ground plane of 30mm width and 11mm height on the back view to simplify the design using copper material of 0.035mm thickness.

On the back of the simulated and fabricated models, a feed gap of 1mm height (slot) was designed between the ground plane and the patch radiator to improve the reflection coefficient (S_{11}) of the antenna and nearly omni-directional radiation over UWB frequency range. The gap was changed to different dimensions to evaluate the optimization of the feed gap. The optimal dimension of the gap made the antenna capable of extending the bandwidth beyond that defined by FCC. This performance was suitable for future wireless systems with high transmission bit rates and speeds.



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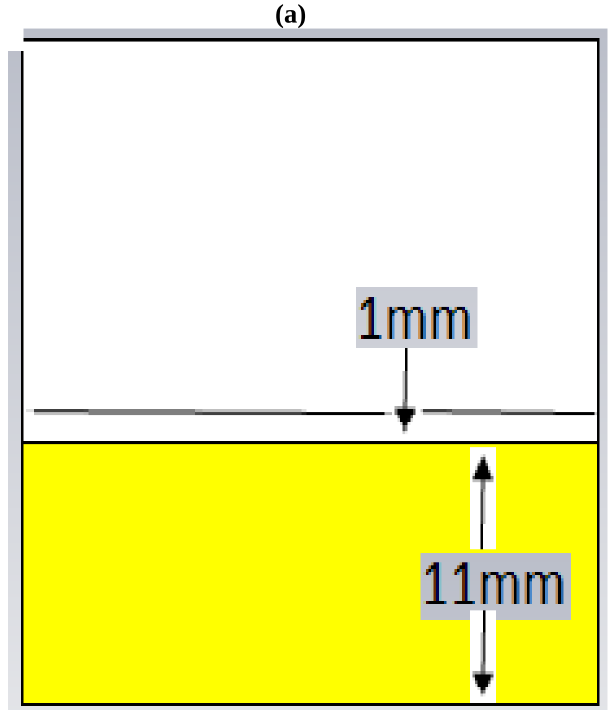
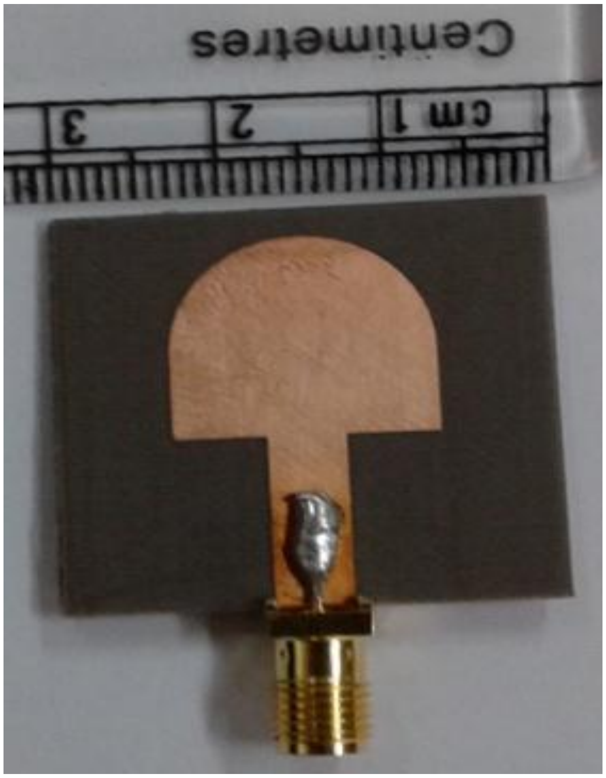


(b)

Figure 1: Geometry spade-shaped microstrip patch antenna: (a) front view; (b) back view.



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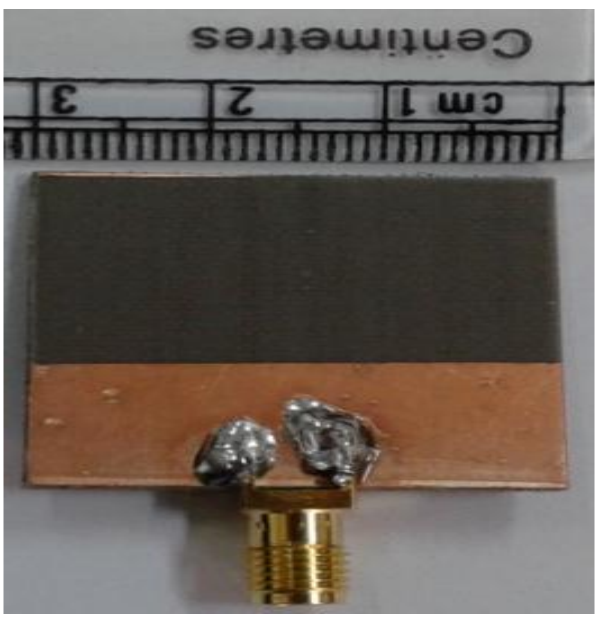

(b)

Figure 2: Fabricated spade-shaped microstrip patch antenna: (a) front view; (b) back view.

3. Experimental and Simulated Results

The CST microwave studio sftware was used for simulation results and an anechoc chamber with network analyzer were used for fabrication results as shown in Figure 3. The simulation was done at 50 **Ω** input impedance and the measurement was done by using a 50 **Ω** connector that was soldered to the end edge of the feed line, which was connected to the network analyzer by an RF cable. The simulated and measured return loss (S_{11}) curves for the proposed antenna are shown in Figure 4 of below -10dB along a wide bandwidth to achieve the UWB requirements and Figure 5 shows the picture of measured return loss by using network analyzer. Figure 6 shows the measured and simulated results of voltage standing wave ratio (VSWR), with the data being taken from the network analyzer and the CST software, respectively. These VSWR data were drawn on the same scale in order to compare the simulated and measured results of S_{11} and the VSWR parameters. The small differences between the simulated and measured readings were attributed to the type of connector and the type of solder used.

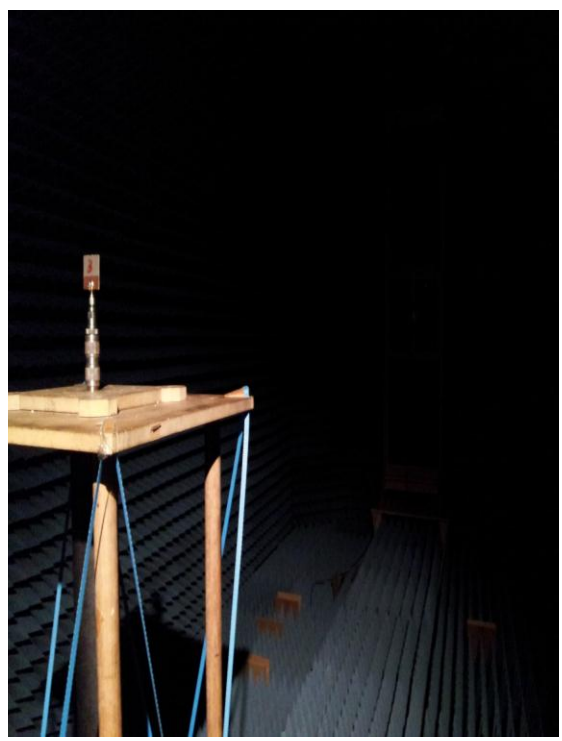

Figure 3: Photograph of the spade-shaped antenna in the Labrotory of anechoic chamber.

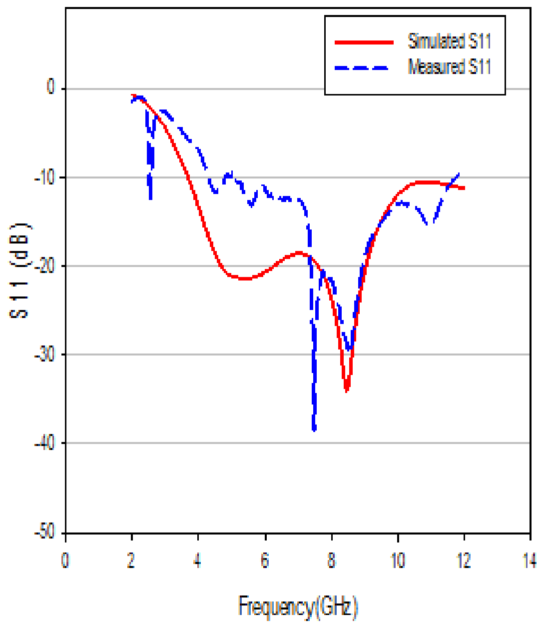

Figure 4: Measured and simulated return loss of the proposed antenna.

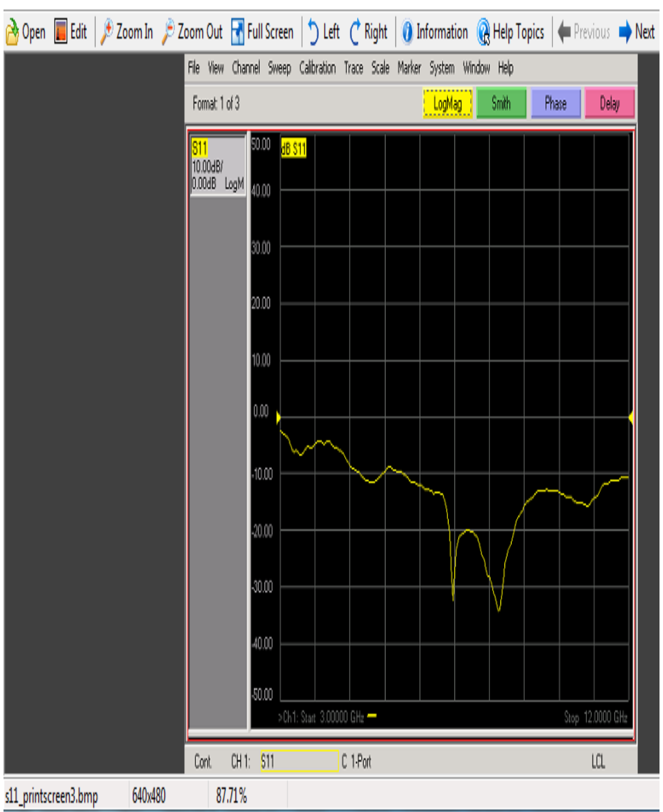

Figure 5: Photograph of network analyzer display to show the measured S11 characteristic.

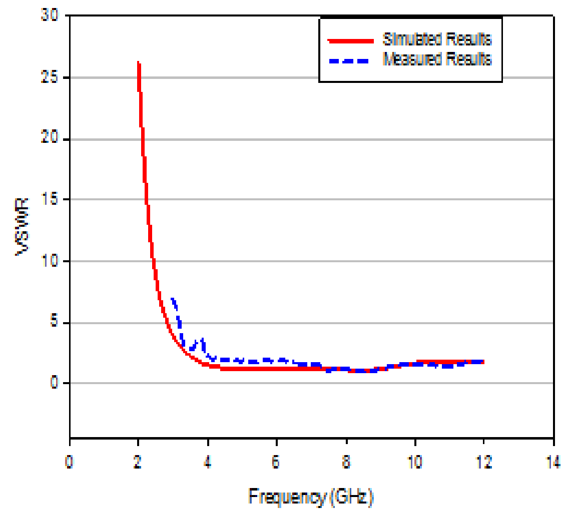

Figure 6: VSWR characteristics of simulated and measured antenna design.

Figure 7 shows the 2-D view of the H-plane simulated radiation patterns at a frequency of 7.5 GHz. These patterns indicated that the antenna exhibited omni-directional radiation capabilities in the H-plane. Figure 8 shows the measured 2-D view of the radiation patterns for the proposed antenna at a frequencies of 7.5 GHz and 10 GHz in the E-plane (Phi = 90^{o}). The simulated E-plane and measured H-plane radiation patterns show omni-directional patterns at frequencies of 7.5, and 10 GHz.

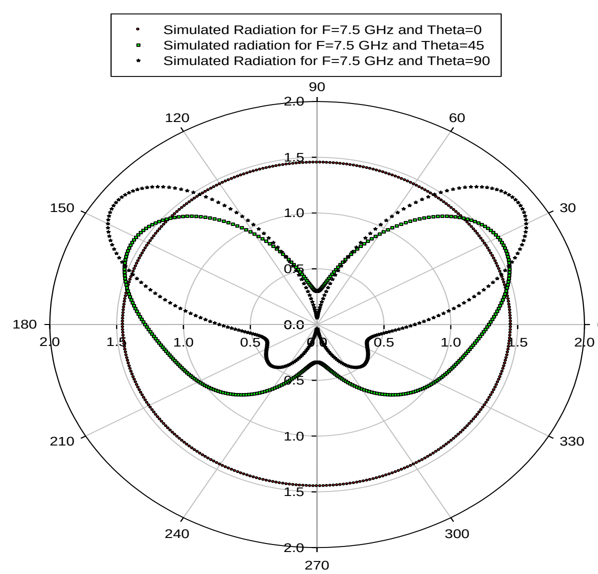

Figure 7: Simulated radiation patterns of the proposed antenna in H-plane at 7.5 GHz.

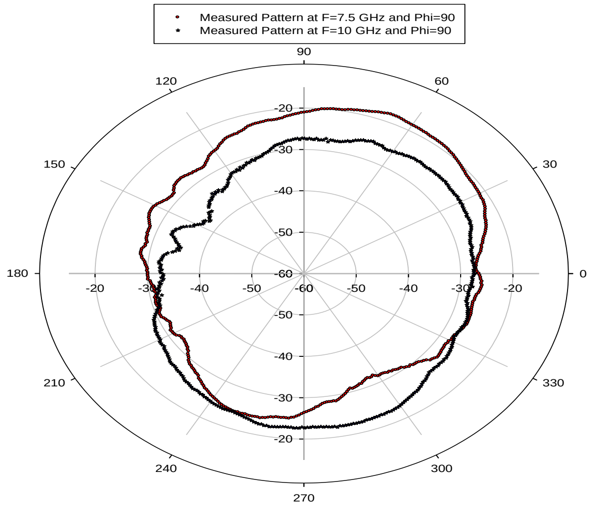

Figure 8: Measured radiation patterns in E-plane at 7.5 GHz and 10 GHz.

4. Effect of Feed Gap Height between Ground Plane and Patch Radiator

The feed gap between the lower edge of the patch and the ground plane affected the impedance bandwidth. The printed ground plane on the back side of the substrate acted as an impedance-matching element to control the impedance bandwidth of the rectangular patch. During the simulation run, different values of the gap height of 1 mm, 0.75 mm, 0.5 mm, and 0.25mm were taken to determine the optimum size of the feed gap between the ground plane and the antenna patch. Figure 9 shows the simulated return loss (S_{11}) curves for these different heights of feed gap that were bellow -10 dB operating frequency of the proposed antenna which varied with changing the value of the gap. Table 1 shows the calculated, fractional bandwidths for different values of feed gap; the optimal feed-gap height was 1 mm with a fractional bandwidth of 129.26%. The fractional bandwidth was calculated as a ratio of bandwidth (BW) to the central frequency (F_c) by ‘‘(1)’’ [11].

$$\frac{BW}{F_c} = \frac{2(F_U - F_L)}{F_U + F_L} \qquad (1)$$

where F_U is the upper frequency, and F_L is the lower frequency. The results of these calculations indicated that, the fractional bandwidth reduces to less value when the feed gap is decreased to narrow height and it is 110.11% at gap of 0.25 mm.

Table 1: Effects of the gap on the simulated -10 dB bandwidths of the proposed antenna.

Gap (mm)	F_L (GHz)	F_U (GHz)	BW (GHz)	Fractional BW
1	3.4	13	10.6	129.26%
0.75	3.6	13.2	9.6	114.28%
0.5	3.8	13.5	9.7	112.14%
0.25	4	13.8	9.8	110.11%

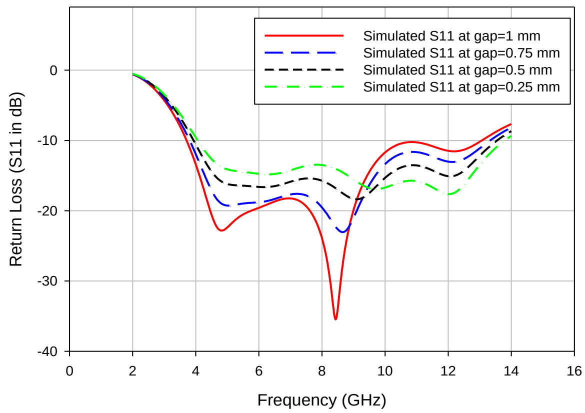

Figure 9: Return loss due to varying feed gap height.

5. Effect of Feed Width on Reflection Coefficient (S_{11})

The transmission line feed width at the lower edge of the patch and the ground plane affected the impedance bandwidth. Figure 10 shows the simulated results of S11 at different values of line feed width which is feeding the radiator and was set to 4.8 mm, 4.5 mm, and 4 mm. The return loss curves versus radiation frequency are supposed to cover the UWB frequency (3.1 to 10.6 GHz) to be used in UWB systems and other narrow band systems through this band. According to these return loss curves, the feed width of 4.8 mm has resonance frequency at less than -30 dB reflection coefficient with a fractional bandwidth of 101.84% as mentioned in Table 2. When the feed width is reduced to 4.5 mm, the resonance frequency occurs at S11 of -29dB and fractional bandwidth increases to 113.25%. Based on Figure 10 results, impedance matching is greatly improved at 8.5 GHz due to 4.8 mm feeder width.

Table 2: Fractional bandwidths below -10 dB of S_{11} for different feed width dimension.

Feed width (mm)	F_L (GHz)	F_U (GHz)	The BW (GHz)	Fractional BW
4.8	3.5	12.8	8.3	101.84%
4.5	3.6	13	9.4	113.25%
4	3.7	13.1	9.4	111.9%

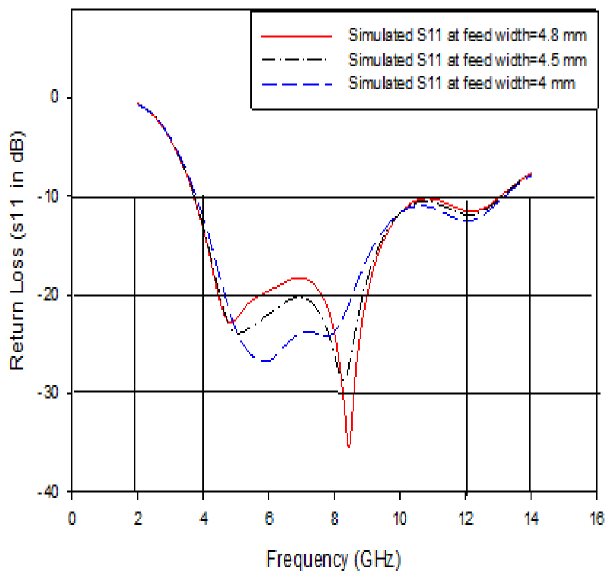

Figure 10: Return loss due to reduced feed width.

6. Conclusion

This manuscript presents the proposed design of a UWB antenna with a spade-shaped radiator of two curved edges was printed on a rectangular substrate with a feed gap of 1mm between the patch and the ground plane. The performance analysis was improved by using CST microwave studio simulation software over the UWB frequency range for a return loss less than -10 dB and a VSWR less than 2. The effects of the notches and size of the feed gap were evaluated to extend the impedance bandwidth and to obtain different resonance frequencies. The fabrication process was done to compare the measured results with simulated results of the same parameters using an anechoic chamber and a network analyzer. The radiation patterns for both the simulation and the fabricated antennas were omni-directional in order to meet the requirements for indoor wireless propagation

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