Study of a Printed Small Size Trisul Shape UWB Antenna for Indoor Communication

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Abstract

An ultra-wideband (UWB) antenna with a narrow frequency notch is presented. The antenna has been fabricated on a FR4 substrate and occupies an area of only 25 × 25 mm^2. Starting from a Circular planar patch exhibiting a VSWR smaller than 2.5 in the 3.5−10 GHz band, a frequency notch at 5.65 GHz is introduced by two open slots above the coplanar waveguide feeding. The measured return loss shows a good agreement with the simulation results and proves that this kind of antenna is suitable for reducing the detrimental interference effects of WLAN, operating around 5.5 GHz, on UWB radio link for indoor communication.

Keywords*: *Trisul, Indoor, UWB, WPAN, Monopole

1. Introduction

Beside UWB, Bluetooth and WLAN are some applications that take advantage of license free frequency of operation in the industrial, scientific and medical (ISM) band covering 2.4-2.484 GHz (IEEE 802.11b and IEEE 802.11g) band. To integrate these bands for use in one device, it is essential to develop dual band antennas. Thus, a printed fork shaped dual band antenna for Bluetooth and UWB applications is investigated. Dual band characteristics with desired bandwidth are obtained by placing a rectangular monopole in a U-shaped UWB antenna. WLAN (IEEE 802.11a) interference is a problem for UWB application systems. UWB applications interfere with existing wireless local area network (WLAN) technologies. To avoid interference from WLAN systems, the UWB antenna with a notched band (5.15-5.825GHz) is proposed. Thus, a simple trisul shaped monopole with band notched characteristics and dual band with WLAN band-notched characteristics are proposed. The Band-rejection characteristic is achieved by introducing simple ground plane and patch structure. The antenna structures are designed, fabricated and tested. The paper is organized in the following sections. Section II describes the antenna design and the 10 dB return loss bandwidth obtained for an optimal design. Section III analyzes the characteristics of the antenna. Section IV presents the time domain performance of the antenna. Section V summarizes and concludes the study.Fig8.1 shows the evolution of the design UWB antenna, which consists of a rectangular partial ground plane and a radiator. The patch radiator has two shape united together one is semicircular radiating patch and second is rectangular shape patch. The antenna size is 50 mm × 50 mm × 1.6 mm and printed on the substrate of the same size. In recent years, more interests have been put into WPAN technology. The future WPAN aims to provide reliable wireless connections between computers, portable devices and consumer electronics within a short range. Furthermore, fast data storage and exchange between these devices will also be accomplished. This requires a data rate which is much higher than what can be achieved by existing wireless technologies.UWB has an ultra wide frequency bandwidth; it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances from 1 to 10 meters [1-10,14,19] In spreading signals over very wide bandwidth, the UWB concept is especially attractive since it facilitates optimal sharing of a given bandwidth between different systems and applications, this caused an UWB technology is a promising technology for WPAN due to its unique characteristics. Ultra-Wideband (UWB) was approved by the Federal Communications Commission (FCC) in Mar. 2002 for unlicensed operation in the 3.1-10.6 GHz band subject to modified Part 15 rules. The rule limits the emitted power spectral density (P.S.D.) from a UWB source measured in a 1 MHz bandwidth at the output of an isotropic transmit antenna at a reference distance to that shown in Figure 1. Further, the transmitted signal must instantaneously occupy either i) a fractional bandwidth in excess of 20% of the center frequency or ii) in excess of 500 MHz of absolute bandwidth to be classified as a UWB signal. The maximum allowable P.S.D. for UWB transmission of -41.3 dBm/MHz corresponds to approximately 0.5 mW of average transmit power when the entire 3.1-10.6 GHz band is used, effectively limiting UWB links to shorts ranges. Nevertheless, the potential for exploiting such low power UWB links for high data rate wireless PAN connectivity (in excess of 100 Mbps) at ranges up to 10 m particularly for in-home networking applications has led to considerable recent interest in this technology .Ultra-wideband (UWB) radio technologies draw big attentions considering the applications to the short range wireless communication, ultra-low power communication, ultra-high resolution radar etc., among them, the standardization of the UWB radio is ongoing under IEEE 802.15 WPAN High Rate Alternative PHY Task Group 3a (IEEE802.15.3a) [7, 9, 21, 22,] and wireless personal area network (WPAN) is originated by the Bluetooth (IEEE802.15.1). IEEE802.15.3a is trying to establish the new standard of WPAN to drastically increase the data rate, which is a weak point of Bluetooth. Now IEEE802.15.3a considers the use of UWB, following the tentative regulation of FCC (Federal Communications Commission, USA), to achieve the bit rate of 110 Mb/s at 10 m and 200 Mb/s at 4 m [6-7, 9-24]

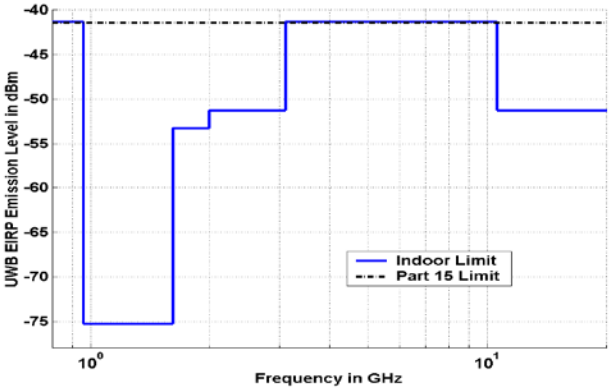


Figure 1. UWB Spectral Mask per FCC (Reproduced) Part 15 Rules [9]

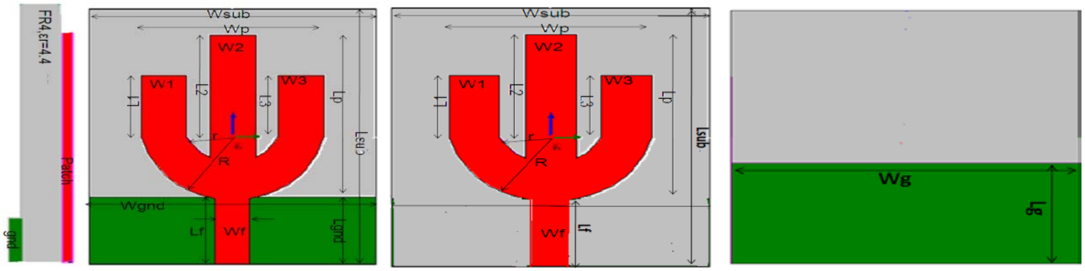
This work focuses on small size low cost UWB antenna design for WPAN application. Unlike traditional narrow band antennas, design and analysis of UWB antennas are facing more challenges and difficulties. A competent UWB antenna should be capable of operating over an ultra wide bandwidth as assigned by the FCC. At the same time, a small and compact antenna size is highly desired, due to the integration requirement of entire UWB systems. Another key requirement of UWB antennas is the good time domain behavior, *i.e.*, a good impulse response with minimal distortion. In the past few years, wireless personal area network (WPAN) has been attracting considerable interest and undergoing rapid development worldwide. A WPAN is a network for interconnecting devices around an individual person's workspace in which the connections are wireless. The future WPAN aims to achieve seamless operation among home or business devices and systems. In addition, fast data storage and exchange among these devices will also be realized. This demands a data rate which is much higher than what has been achieved in currently existing wireless technologies. The maximum available data rate, or capacity, for the ideal band-limited additive white Gaussian noise (AWGN) channel is linked with the bandwidth and signal-to-noise ratio (SNR) by Shannon-Nyquist criterion [1-9,15-24] as given in equation

$$C=B\log2(1+SNR) \qquad (1)$$

Where C represents the maximum transmission data rate, B denotes the channel bandwidth. Equation 1 illustrates that the transmission data rate can be raised by enlarging the bandwidth or amplifying the transmission power. Nevertheless, the signal power can't be easily increased as many portable devices are powered by battery and the potential interference with other radio systems should be also suppressed. Therefore, a huge frequency bandwidth will be the solution to realize a high data rate and which can be achieved with UWB technology

2. Antenna Design and Performance

Figure 1.1 shows the geometry of the designed small size trisul shape UWB antenna. The structure is evolved from the circular monopole radiator to trisul shape radiator



Substrate **(a) Whole structure** **(b) Top view** **(c) Bottom view**

Figure 1.1. Geometry of Designed TMP UWB Antenna (TMP)

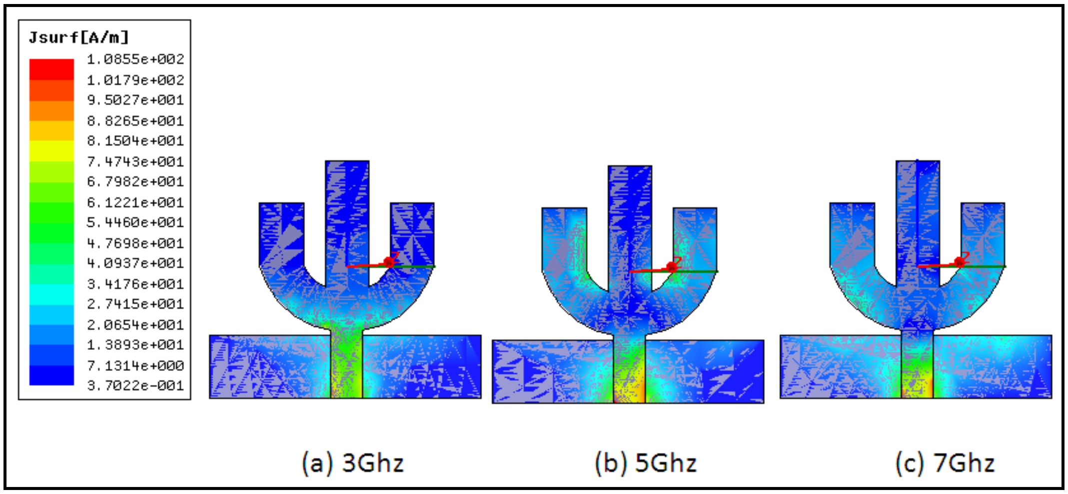
A trisul shape monopole antenna with a 50 Ω microstrip feed line is printed on the top side of the dielectric substrate. Wsub and Lsub denote the width and length of the dielectric substrate, respectively. The width of the microstrip feed line is fixed at 3mm to achieve 50Ω impedance. On the other side of the substrate, the conducting ground plane with a length of Lg=6 mm is etched. Lf is the length of the feed line. The simulations are performed using the HFSS11 which use finite element method for electromagnetic computation [25]

Table 1-A. Dimensions (in mm) of Designed TMP UWB Antenna (25mm×25mm×1.6mm)

Wsub	**Lsub**	**Wp**	**Lp**	**Wg**	**Lg**	**Wf**	**Lf**
25	25	16	17	25	6	3	6
W1	**L1**	**W2**	**L2**	**W3**	**L3**	**R**	**r**
4	6	4	11	4	6	8.25	4.48

A. Current Distributions

The simulated current distributions at different frequencies for the optimal design with Wsub=25mm, Lsub=25mm,W1=4mm,L1=6mm,W2=4mm, L2=11mm, W3=4, L3=6, Wp=16mm, Lp=17mm, R=8.25, r=4.48, Wf=3, Lf=6, Wg=25, Lg=6mm are shown in Figure 1.2. Figure 1.2(a) shows the current pattern for the first resonance at 3 GHz. The current pattern near the second resonance at 5GHz is given in Figure 1.2 (b). Figure1.2(c) illustrates current pattern at 7GHz, corresponding to the third order harmonicas shown in Figure 1.2(c), the current is mainly distributed along the edge of the U shape patch, which indicates that the first resonant frequency is associated with the dimension of the U shape disc.



(a) 3Ghz (b) 5Ghz (c) 7Ghz

Figure 1.2. Surface Current Distribution of Designed TMP UWB Antenna at 3, 5 and 7 GHz

Near the feed point, the current is mainly distributed on the Upper edge along the y-direction. That means the portion of the ground plane close to the u shape acts as the part of the radiating structure. Consequently, the performance of the antenna is critically dependent on the length of the ground plane Lg. Simulations have shown that when the length Lg of the ground plane is more than 7 mm, the performance of the antenna is almost independent of Lg.

B. The Effect of the Dimension of the Ground Plane

The first resonance always occurs at around 5.6 GHz for different Lg when Lg equals to 6mm. Furthermore, When Lg =6.2 is very close to the quarter wavelength at the first resonant frequency which is around 7 mm. Figure 1.3 presents the simulated return loss curves for different dimensions of the ground plane with their respective optimal designs (Lg=6mm, Wg=25mm, r=4.48mm, R=8.25mm, Lf=6mm, Wf=3mm, Lg=6.2mm, Wg=25mm, r=4.48mm, R=8.25mm, Lf=6mm, Wf=3mm, Lg=6.4mm, Wg=25mm, r=4.48mm, R=8.25mm, Lf=6mm, Wf=3mm, Lg=6.6mm, Wg=25mm, r=4.48mm, R=8.25mm, Lf=6mm, Wf=3mm,

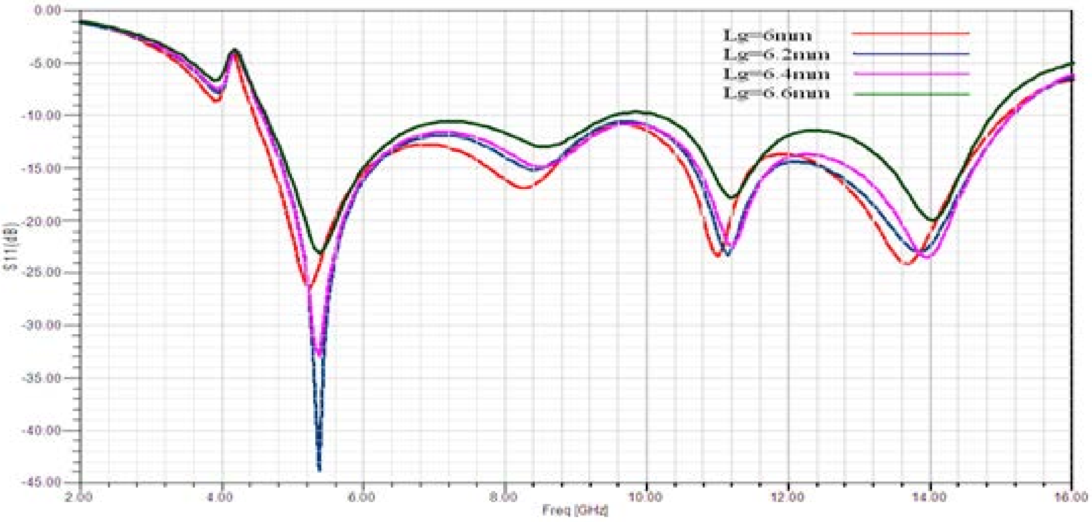


Figure 1.3. Simulated Return Loss Curves for Different Dimensions of the Ground Plane with the Optimal Designs of the TMP UWB Antenna

Figure 1.3 demonstrates that the first resonant frequency is determined by the length of the ground plane, which approximately corresponds to the quarter wavelength at this frequency. So the lower end frequency of the 10 dB return loss bandwidth of the antenna is directly related to the dimension of the ground plane.

Table 1-B. Simulated -10dB Bandwidths of TMP UWB Antenna for Different Lg Values

Lg (mm)	Lower edge of bandwidth(Ghz)	Upper edge of bandwidth(Ghz)	Absolute bandwidth(Ghz)	Fractional Bandwidth %
6mm	Fl1=4.4	Fh1=15	10.6	109
6.2mm	Fl1=4.6	Fh1=15.2	10.6	107
6.4mm	Fl1=4.6	Fh1=15	10.4	106
6.6mm	Fl1=4.6	Fh1=14.8	10.2	105

C. The Effect of the Dimension of the Radius

Change in the ground plane dimension has indicated that the first resonant frequency is associated with the ground plane dimension. Actually, it is noticed in the simulations that the first resonance always occurs at around 5.6 GHz for different value of Lg. Furthermore, the smaller radius of the disc is 4.48mm and bigger radius dimension of the disc is 8.25mm, which is very close to the quarter wavelength at the first resonant frequency which is around 5.3mm. Figure 1.4 presents the simulated return loss curves for different dimensions of the outer disc radius with their respective optimal design. Wsub=25mm, Lsub=25mm, W1=4mm, L1=6mm, W2=4mm, L2=11mm, W3=4, L3=6, Wp=16mm ,Lp=17mm, Wf=3, Lf=6,Wg=25, Lg=6mm R=8.25, R=8.5mm, R=9mm, R=9.5mm. It is seen in Figure 1.4 that the first resonant frequency decreases with the increase of the radius of the U shape disc.

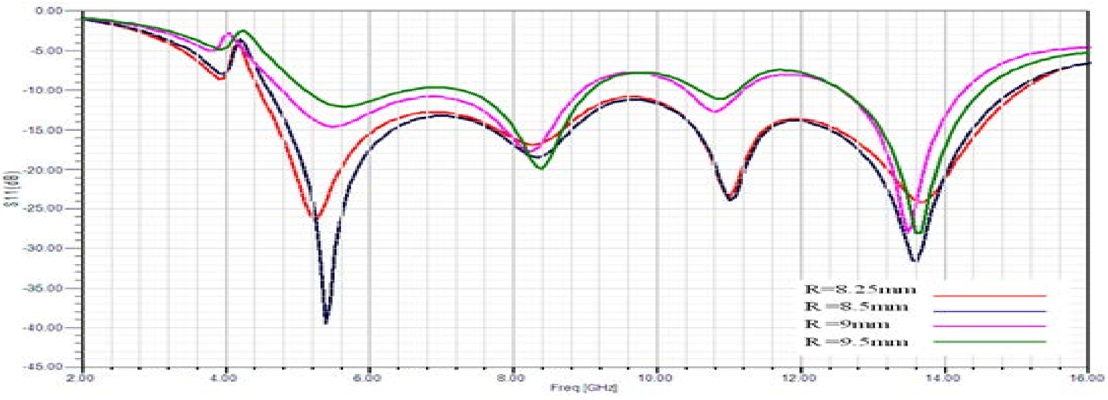


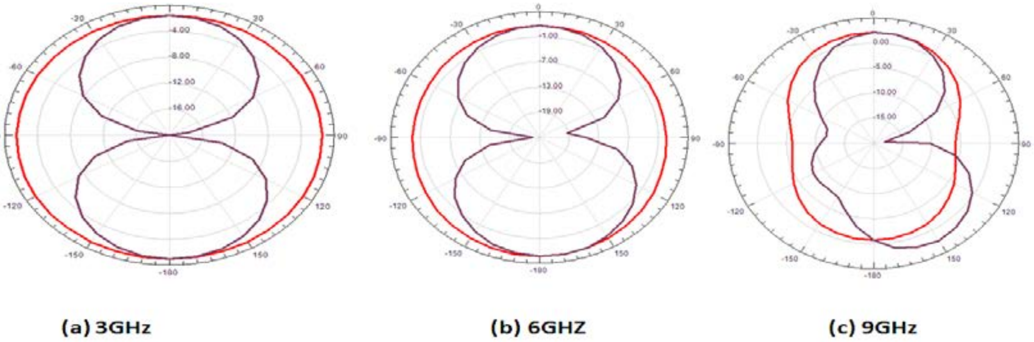
Figure 1.4. Simulated Return Loss Curves for Different Dimensions of U Shape Disc Radius of Designed TMP UWB Antenna

Table 1-C. Simulated -10dB Bandwidths of TMP-B UWB Antenna for Different Values of Outer Radius

R (mm)	Lower edge of bandwidth(Ghz)	Upper edge of bandwidth(Ghz)	Absolute bandwidth(Ghz)	Fractional Bandwidth %
8.25mm	Fl1=4.4	Fh1=15	10.6	109
8.5mm	Fl1=4.6	Fh1=15	10.4	106
9mm	Fl1=4.8 Fl2=10.4 Fl3=12.6	Fh1=9 Fh2=11.2 Fh3=14.4	4.2 0.8 1.8	60.86 7.4 13.33
9.5mm	Fl1=5 Fl2=10.6 Fl3=12.6	Fh1=9 Fh2=11.2 Fh3=14.6	4 0.6 2	57.14 5.5 14.7

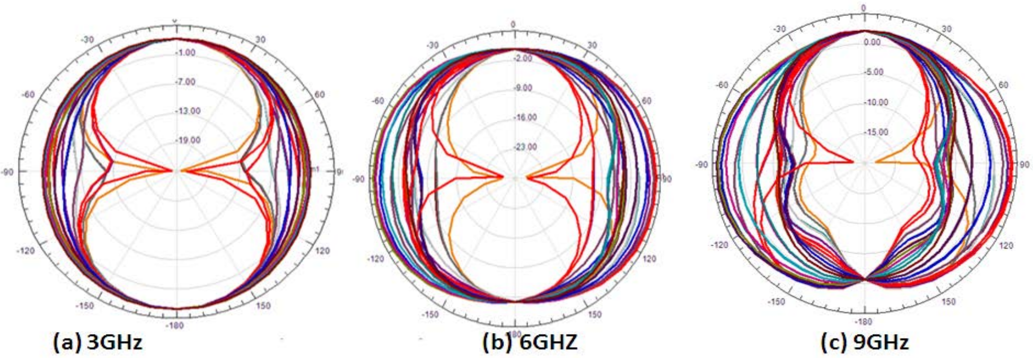
D. Radiation Patterns and Gain

Radiation patterns are also taken for the small size trisul shape UWB antenna at each of the aforementioned frequencies. Antenna radiation pattern demonstrates the radiation properties of antenna as a function of space coordinate. For a linearly polarized antenna, performance is often described in terms of the azimuth and elevation plane patterns. The radiation patterns have been simulated. The simulated normalized Re_{total} radiation patterns at 3, 6 and 9 GHz are plotted in Figure 1.5. The plots in red indicate the H plane measurement, and the plots in grey indicate the E plane measurements. The simulated results show that the radiation patterns at all of the three frequencies satisfy this requirement well. As shown in Figure 1.5 the antenna also has a sharp gain decrease at the notched band, so the antenna can avoid the potential interference with the existing WiMAX lower WLAN communication system. The designed antenna has nearly omni directional radiation characteristic in the H plane and a figure of eight radiation pattern in the E plane over the desired band. The proposed antenna provides more than 90% radiation efficiency except at the notched frequency bands as shown in Figure 1.5.



(a) 3GHz (b) 6GHZ (c) 9GHz

Figure 1.5. Radiation Pattern (Retotal) with 10dB Normalized Value in the phi=0^0 and phi=90^0 Planes of the Designed TMP UWB Antenna at 3,5 and 7GHz



(a) 3GHz (b) 6GHZ (c) 9GHz

Figure 1.6. Simulated Gain of Designed TMP UWB Antenna at $\theta=0^0$to 360^o , Ø=$0^0$to 360^o

Figure 1.6 indicates that the shape of the antenna gain pattern is typical of what would be expected (*i.e.*, Maximum radiation at zero degrees, and minimum radiation and nulls at the back).The gain is above 0dB at most of the points throughout the radiation pattern, indicating good radiation efficiency.

3. Time Domain Performance

A good impulse response, *i.e.*, time domain characteristic, is an essential requirement for an UWB antenna. The printed trisul shape monopole antenna has also been tested for its impulse response in the simulation in order to validate the efficiency of the antenna; the pulse base signal is excited. It can be related to the dispersion of receive signal compared to transmitter signal. The time domain characteristics viz. group delay of the proposed antenna can be measured. The simulated group delay is constant over the operating bands shown in Figure 1.7. In UWB system; linear phase response of the radiated field as well as stable group delay response is desirable for not distorting the shape of the transmitted electric pulse.

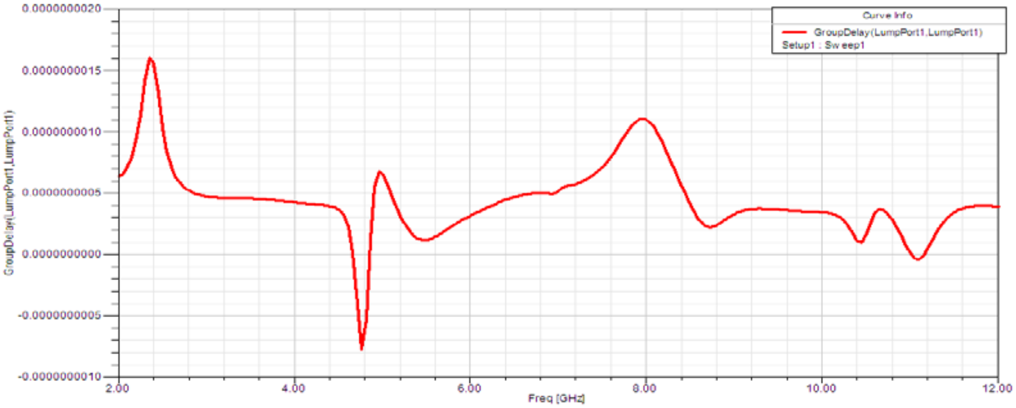


Figure 1.7. Simulated Group Delay of Designed TMP UWB Antenna

The simulated TDR-Impedance is constant over the operating bands except over the 0-1 ns range as per the Figure 1.8.

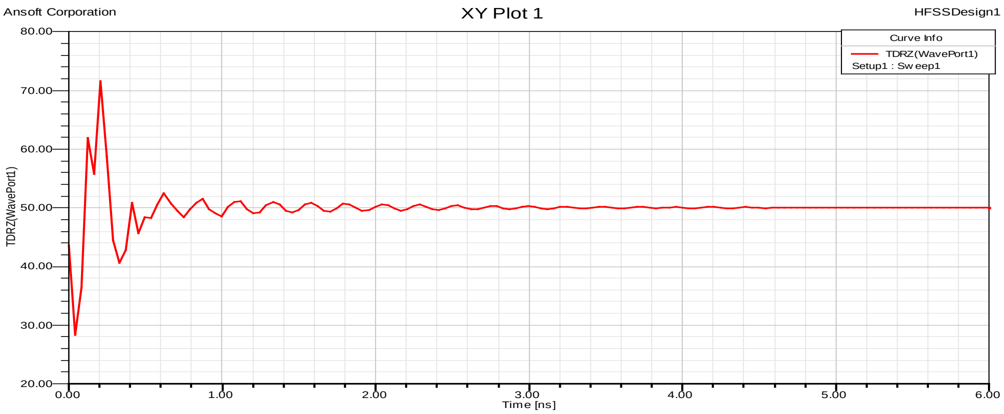


Figure 1.8. Simulated TDR Impedance Curve of Designed TMP UWB Antenna

4. Fabrication and Measured Results

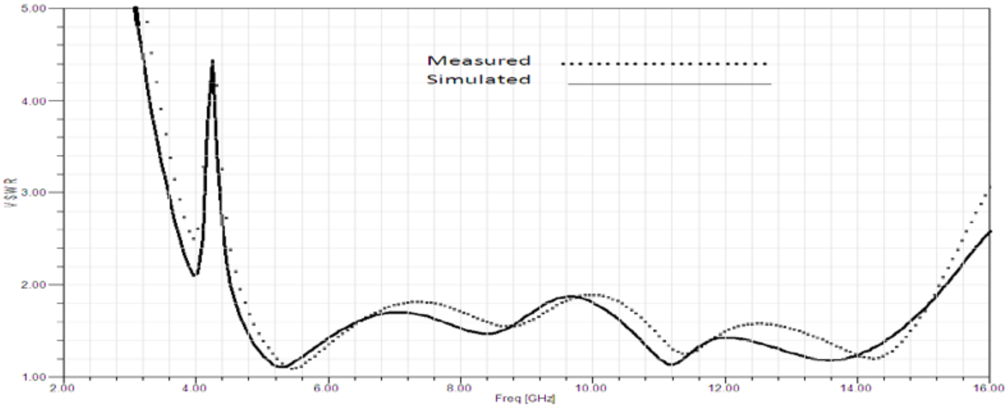


Figure 1.9. Measured and Simulated Value of VSWR Curve of Designed TMP-B UWB Antenna

The fabricated antenna is shown in Figure 2.1. The measured results reasonably agree with simulated results. The designed and fabricated antenna performs good impedance matching over the UWB band except the rejected band.

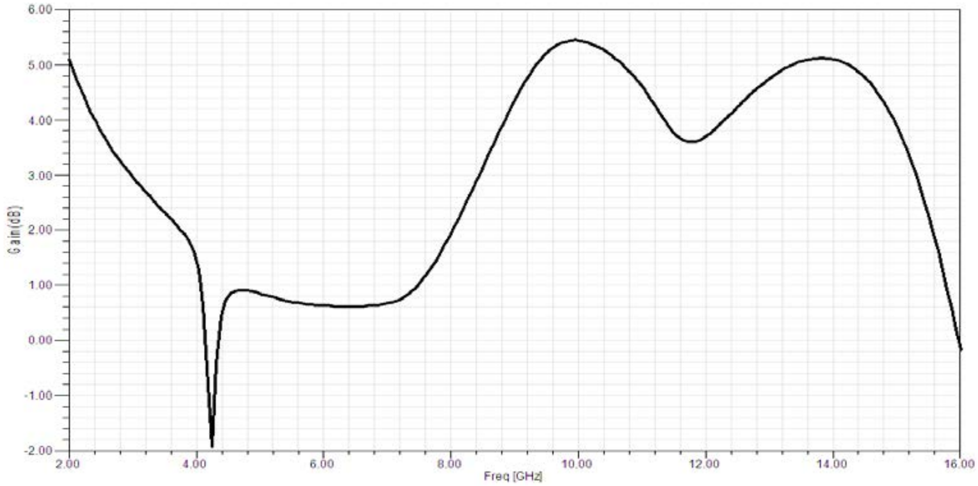
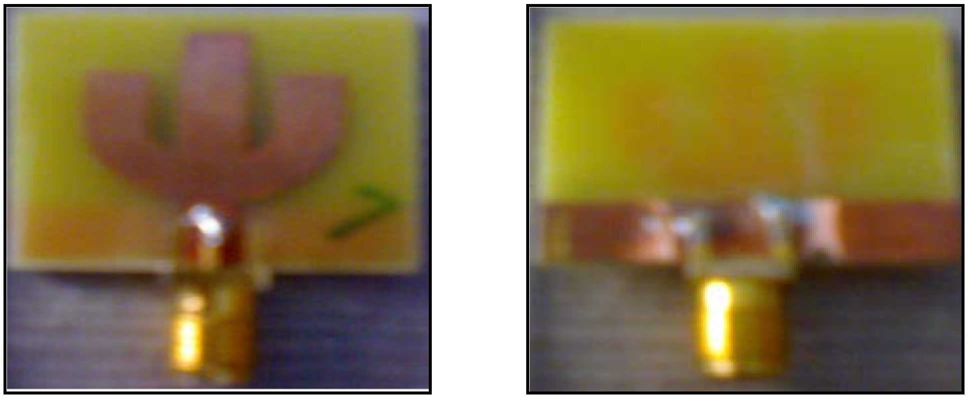


Figure 2. Measured Gain of the Designed Antenna



(a) Top view (b) Bottom view

Figure 2.1. Photograph of Designed TMP-B UWB Antenna

5. Conclusion

The printed trisul shape monopole antenna fed by microstrip line is investigated in this paper. It has been shown that the performance of the antenna in terms of its frequency domain characteristics is mostly dependent on the feed gap h, the length of the ground plane, Lg and the dimension of the antenna. The first resonant frequency is directly associated with the dimension of the semicircular shape radiating patch of the antenna because the current is mainly distributed along the edge of the radiating patch. The partial ground shows better return loss compared to full ground patch on the bottom because the antenna is transformed from patch-type to monopole-type by the partial ground. This paper investigates antenna performance in terms of the radiation pattern and reflection coefficient. To control antenna behavior, it is necessary to observe the current distribution. The proposed antenna is fabricated on FR4 with $\varepsilon r=4.4$, $\tan\delta=0.02$ and the thickness is 1.6mm with the proposed dimension of 25mm x 25 mm×1.6mm. The simulated results of proposed antenna for return loss is less than -10 dB and VSWR is less than 2 satisfies the system requirements for S-DMB, WiBro, and WPAN application at the operating frequency of 7 GHz.

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