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A BAND NOTCH RECTANGULAR PATCH UWB ANTENNA WITH TIME DOMAIN ANALYSIS

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ABSTRACT

Design and construction of band notch microstrip Ultra-wideband (UWB) antenna is proposed. As the WLAN 802.11a operates ranging from 5.15GHz to 5.35GHz and 5.725GHz to 5.825GHz. In contrast, HIPERLAN/2 operates ranging from 5.15GHz to 5.35GHz and 5.47GHz to 5.725GHz. Therefore, a band notched filter is required in order to reduce potential interferences between the UWB antenna and WLAN or HIPERLAN/2 bands. The proposed UWB antenna has capability of notching these operating frequencies approximately around 5GHz to 6GHz. The antenna parameters in frequency domain analysis have been investigated to show its capability as an effective radiating element. Furthermore, time domain Gaussian pulse excitation analysis in UWB systems is also demonstrated in this paper. As a result, the simulation results demonstrated reasonable agreement with the measurement results and good band notched ultra-wideband linear transmission performance has also been achieved in time domain.

Keywords: ultra-wide band (UWB), FR4, microstrip, patch antenna, frequency domain, time domain, gaussian pulse.

INTRODUCTION

An antenna is defined as a device or structure between free space and electronic circuitry which is very useful for transmitting and receiving radio waves that contain information. As for that, the antenna becomes a part of electrical devices in wireless communication system after late 1888; Heinrich Hertz (1857-1894) were first demonstrated the existence of radio waves [1]. From those early days until now antenna used as transducer, transformer, radiator and energy converter in wireless communication system.

The UWB technology can open new door for wireless communication system, since the current wireless system increasing exponentially. Back from spark-gap impulse to pulse radio, UWB system plays a dominant role in communication system as the antenna is possible to become one of the wireless communications part. The transmitting information or energy from transmission line converts into electromagnetic energy or waves, and spreads it into free space. At the receiving end, the incident electromagnetic energy strikes on antenna will be converted back to electrical signal for further process. The design of transmitters (Tx) and receivers (Rx) antenna for wireless communication can be in many different shapes and types which is based on application.

UWB system is based on the use of very narrow pulses on the order of nanoseconds, which covers a very wide bandwidth in the frequency domain. In Other term, its directly transmits narrow pulses rather than employing continues wave carrier to convey information. Recently, UWB technology with an extremely broad frequency range has been proposed for imaging radar, communications, and localization applications [2]. In 2002 Federal Communication Commission (FCC) [2] authorized unlicensed use of UWB band ranging from 3.1GHz to 10.6GHz. Since then, the design of broadband antennas has become an attractive but very difficult part of the system design. In general, the antennas for UWB systems should have sufficiently broad operating bandwidth for impedance matching and high-gain radiation in desired directions.

Most of the UWB antennas have a continuous broad bandwidth, covering bands for other wireless applications as well. Therefore, the UWB antenna system can become interference with other wireless system. As there are wide ranges of communication devices operating in different frequency band, the needs of filters and antenna which can integrate together in system are on demanding stage. Designer designs antenna with frequency notch within pass band have become common to avoid interferences between systems. For instance, the existing wireless networking technologies such as IEEE 802.11a in the U.S. 5.15GHz to 5.35 GHz, 5.725GHz to 5.825GHz and HIPERLAN/2 in Europe 5.15GHz to 5.35GHz, 5.47GHz to 5.725GHz coexists with the UWB frequency band of 3.1GHz to 10.6GHz.

Among the UWB antenna design in the recent literature, the monopole planar antenna type is widely used due to its wide bandwidth, simple structure and low cost. It has become one of the most considerable candidates for UWB application. Several designs of monopole planar UWB antenna have been proposed [3–14]. For the band notch UWB Antenna, there are various methods to achieve the band-notched function. The conventional methods are cutting a slot on the patch, inserting a slit on the patch, or embedding a quarter-wavelength tuning stub within a large slot on the patch. Another way is putting parasitic elements near the printed monopole as filters to reject the limited band or introducing a parasitic open-circuit element, rather than modifying the structure of the antenna's tuning stub [15-18]. However, some of these antennas involve complex calculation and sophisticated fabrication process. Therefore, we propose a simpler method to design the frequency notched UWB antenna

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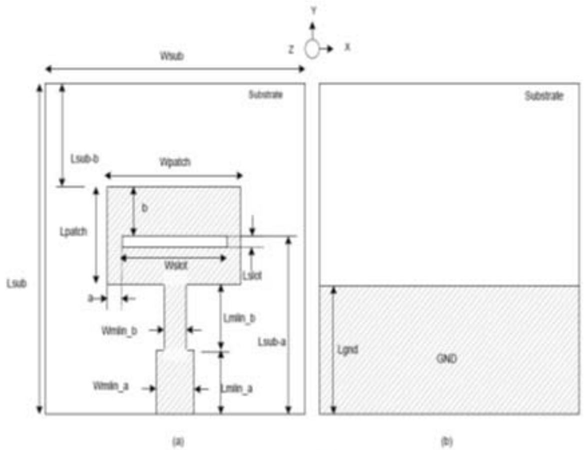
based on microstrip rectangular patch calculation using simple transmission line model analysis.

ANTENNA DESIGN GEOMETRY AND EXPERIMENTAL SETUP

In this paper, the proposed rectangular patch antenna design is based on transmission line model analysis [19] and the detailed geometry and parameters are shown in Figure-1 and Table-1, respectively. The design antenna is simulated to meet certain characteristics such as, operating bandwidth, notch band bandwidth, radiation and others parameters as usually for antenna design consideration.

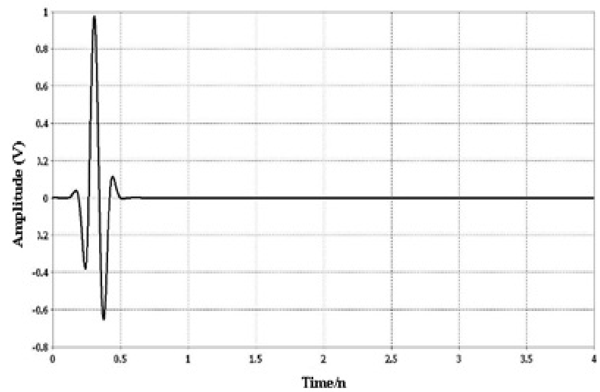


(a: top view, b: bottom view)

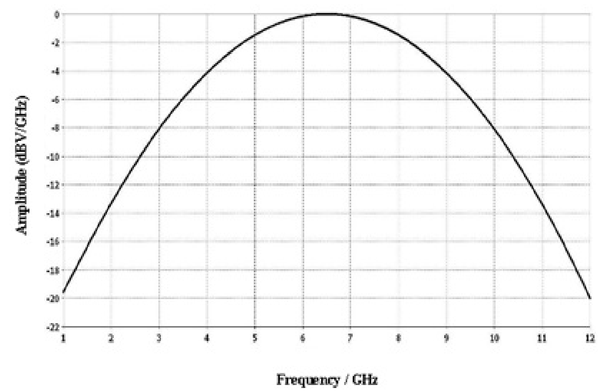
Figure-1. The design geometry of the proposed UWB patch antenna.

Table-1. The detailed parameters for proposed UWB patch antenna.

Symbol	Size (mm)
Wsub	36
Lsub	34
Lsub_a	17
Lsub_b	11.5
Wpatch	18
Lpatch	11
Wmlin_a	3
Lmlin_a	5.5
Wmlin_b	2.5
Lmlin_b	6
Wslot	16
Lslot	0.5
a	1
b	5.5
Lgnd	11



(a) Gaussian pulse



(b) power spectrum density

Figure-2. Excitation signal in time domain and power spectrum density.

The Simulation to optimize design is done using CST Microwave Studio which is in time domain, and for comparison purpose Ansoft HFSS in frequency domain software's are used. Many type of time domain signals are used for UWB system; the Gaussian signal offer a good mix between time and frequency domain compactness. There also other type of time domain signal which are Edges, Sincs and truncated sine wave. The input signal is Gaussian pulse was used for simulation in CST. As the antenna is UWB type, a good frequency domain performance cannot necessarily ensure that the antenna also behaves well in time domain. Therefore, in order to ensure the antenna having good characteristic in time domain, Gaussian pulse as shown in Figure-2 is used as excitation signal and also shown the power spectrum density (PSD) of Gaussian pulse.

The antenna, successfully fabricated on FR4 PCB with dielectric constant (ε_r) of 4.4, loss tangent (tanδ) of 0.02, substrate thickness (h) of 1.6mm, and copper foil thickness (t) of 35μm. Measurement is done using calibrated HP8733ES Network Analyzer. For simulation as well as measurement, frequency swept from 1GHz to 12GHz is used. The simulation results show reasonable agreement with the measurement.

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RESULTS AND DISCUSSION

Parametric study

Parametric study has been conducted to optimize the design of the antenna. This study is crucial as it gives approximation measure before antenna fabrication can be done. Wideband rectangular patch antenna without any slot has study and simulated before band notched frequency antenna optimization. Parametric study over ground patch length and feed line have carry out on rectangular patch design to improve return loss over operating frequency. Figure-3 shows return loss S11 (dB) over function of length ground patch.

It is observed that for full ground patch; Lgnd of 34 mm, the antenna is not able to operate as a wideband antenna; even it resonates at 7.5GHz and 10.1GHz. However, the return loss of the antenna improves dramatically when the length of ground patch reduces gradually and the best result is obtained at the height of ground plane, Lgnd of 11 mm. 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.

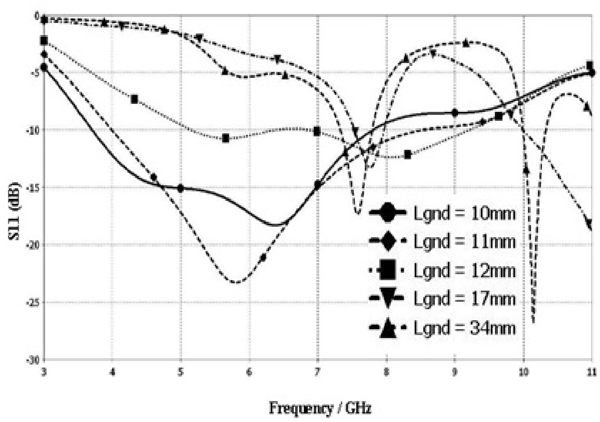


Figure-3. Parametric study of return loss (S11) over the lengths of the ground patch.

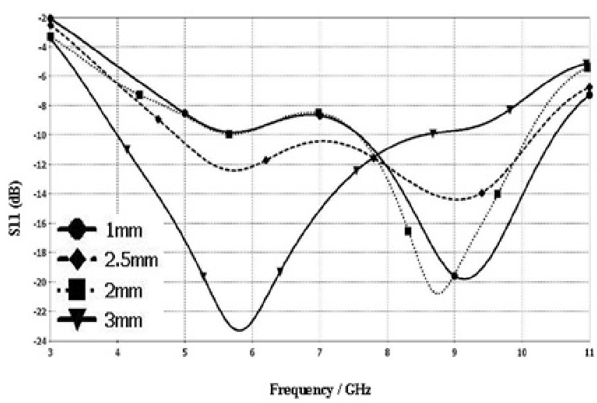


Figure-4. Parametric study of return loss (S11) over the width of feed line.

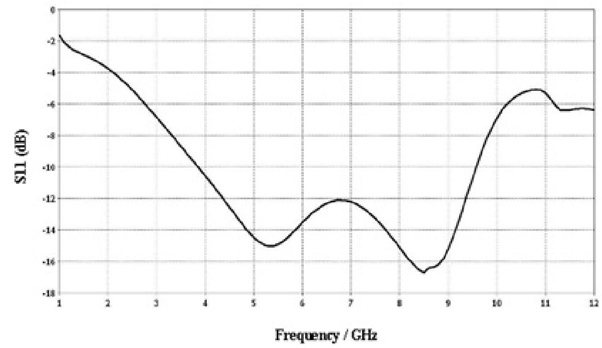


Figure-5. Return Loss of the optimized rectangular patch antenna.

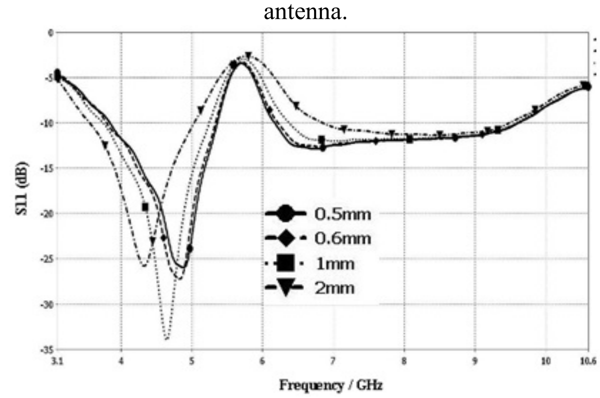
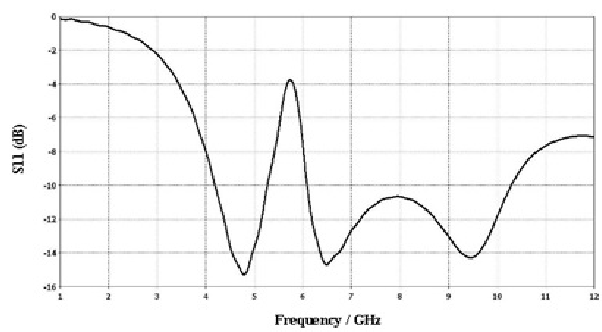
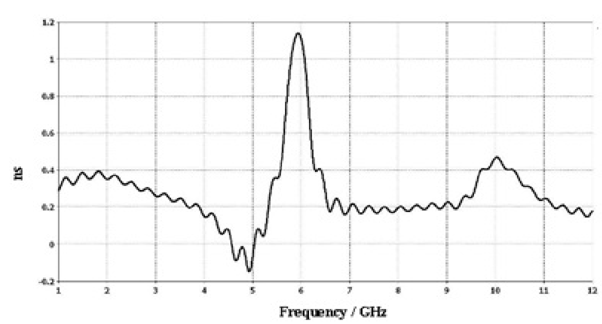


Figure-6. Parametric study of return loss (S11) over the length of the slot.



(a)return loss, s11 (dB)



(b)group delay

Figure-7. Return Loss and Group Delay of the optimized proposed antenna.

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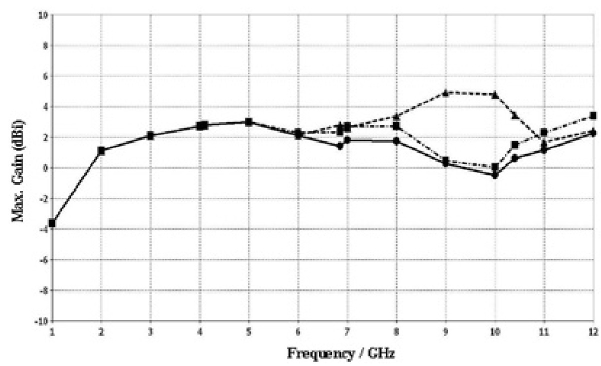
In order to further improve its overall bandwidth, two steps of feed line are used. After done parametric on feed line as the results shown in Figure-4, two steps of feeding line methods are used to improve bandwidth. The first feed line width is 3mm which is connected to SMA connector follow by second line with width of 2.5mm. 3mm line for lower bound frequency range and 2.5mm line for upper bound frequency range. This technique leads to good impedance matching and subsequently, the bandwidth increases gradually. Figure-5 shows the return loss of the optimum design for rectangular patch antenna.

Slot on rectangular patch have introduced to change the antenna characteristic on operating frequencies. By removing small square type patch, the antenna has capability to filter out certain band of frequency. The slot is placed at center down on the rectangular patch as shown in Figure-1. Here, again the parametric study has been conducted on slot height to meet better notch band. Figure 6 shows the parametric S11 for different length of the slot and the width of slot is fixed to 16mm. Slot length of 0.5mm capable to notch frequency around 5.1GHz to 6.1GHz.

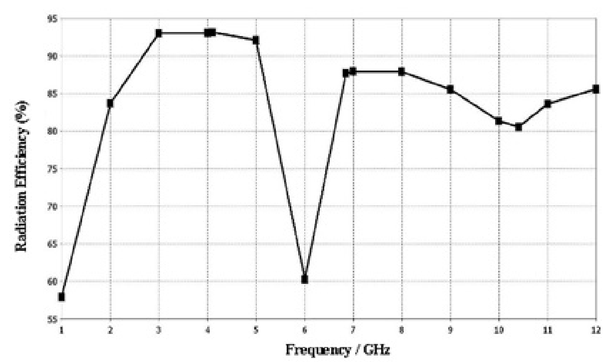
The optimize slot inserted rectangular patch antenna design has been simulated; and Figure-7 shows the return loss and group delay for frequency band 1-12GHz. Notch band around 5.1GHz to 6.1GHz has been achieved to avoid interference from WLAN or HIPERLAN/2 bands. The group delay is an important parameter in UWB antenna design, which represents the distortion of pulse signal. From the Figure-7a, the simulated group delay shows less variation on broader bandwidth except for sharp changes at the notch band frequency.

The antenna gain and efficiency also present how good the design antenna is. The radiation efficiency is used to relate the gain and directivity. Larger the efficiency lesser the heat loss, which mean most power is radiated from antenna. For the gain it is the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the accepted by the antenna were radiated isotropically. The simulated results of maximum gain in dBi and radiation efficiency of the designed antenna are as shown in Figures-8, respectively. The gain and efficiency are simulated at the fix point on azimuth angle of φ at 0°, 45° and 90° and at different elevation angle of θ. It is observed that the antenna gives less variation on gain. The efficiency remains the same along the operating bandwidth and angle. As required for band notch antenna, the efficiency from 5.1GHz to 6.1GHz drops drastically.

Antenna radiation pattern demonstrates the radiation properties on antenna as a function of space coordinate. For a linearly polarized antenna, performance is often described in terms of the *E* and *H*-plane patterns. The *E*-plane is defined as the plane containing the electric field vector and the directions of maximum radiation while the *H*-plane as the plane containing the magnetic field vector and the direction of maximum radiation. The *x-z* plane elevation plane with some particular azimuth angle φ is the principle *E*-plane while for the *x-y* plane azimuth plane with some particular elevation angle θ is the principle of *H*-plane. Figure-9 shows the simulated two dimensional *E* and *H*-plane at three frequencies. In the *E*-plane, the value of azimuth angle φ of 0°, 45° and 90° while in *H*-plane, the value of elevation angle θ of 0°, 45°, and 90° are taken into consideration. The plot for radiation is utilized for three frequencies within pass band, which are 4.2GHz at the lower bound, 6.85GHz at the middle bound and 10.4GHz at the upper bound. The designed antenna almost radiated energy in omnidirectional manner which prefers most. In both E and H-plane at 90˚ the radiation is not really omnidirectional. As for 6.85GHz and 10.4GHz the radiation pattern shows, at 45˚ also slightly non-omnidirectional, but still acceptable.



(a) Maximum gain



(b) Efficiency (η)

Figure-8. Maximum antenna gain and radiation efficiency (η).

Time domain analysis

In order to validate the efficiency of the UWB antenna in time domain, the pulse base signal is excited with Gaussian pulse. It can be related to the dispersion of receive signal compared to transmitter signal. Theoretically for antenna, prefer for non-dispersive receive signal. Figure-10 shows the radiated E field which is virtually place probe in simulation to study the effect of radiated signal. From this figure, the antenna is fixed at azimuth angle ϕ of 90, and the probe is placed at three different positions for θ of 0°, 45° and 90°. It is proved

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that the proposed antenna has good potential in transmitting UWB signals with minimum distortion. Furthermore, the time domain UWB pulse signal received by the electric probe shows stable performance where the received pulse signal is, with less variation to the transmitted pulse signal.

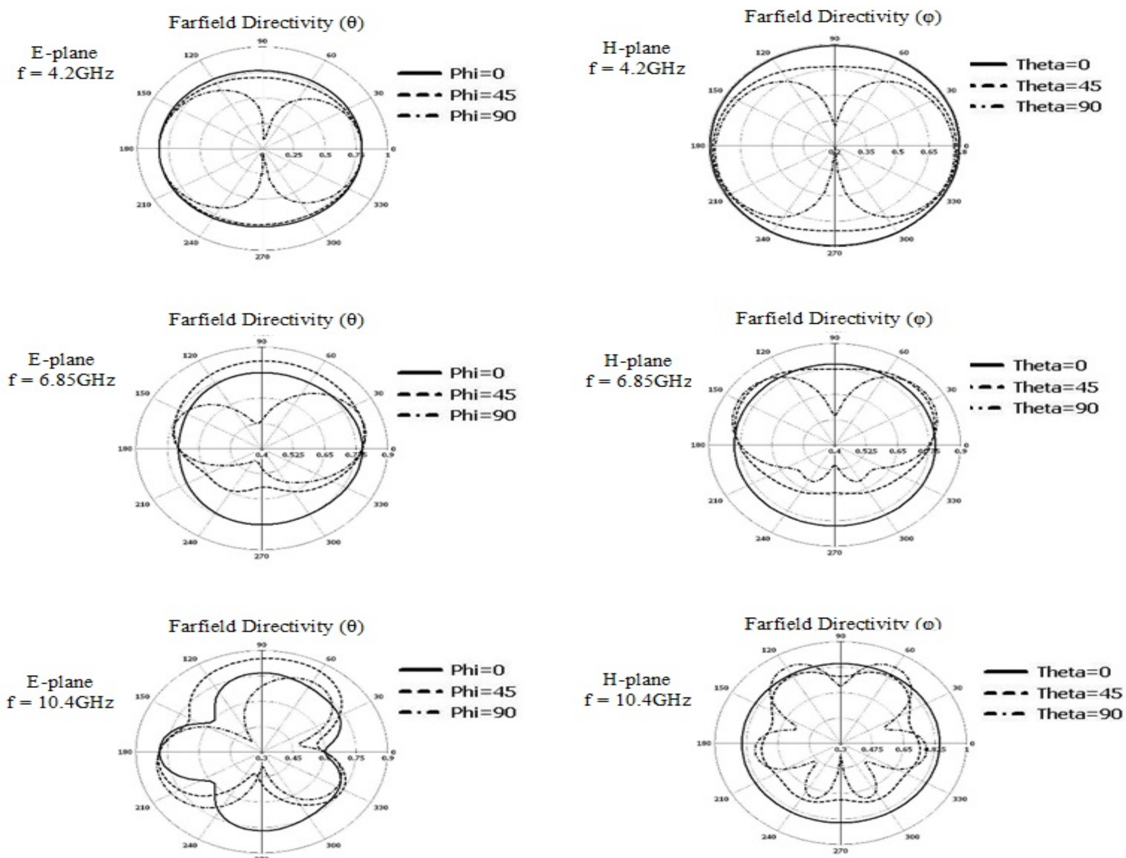

Figure-9. Radiation pattern of the band notch rectangular UWB patch antenna.

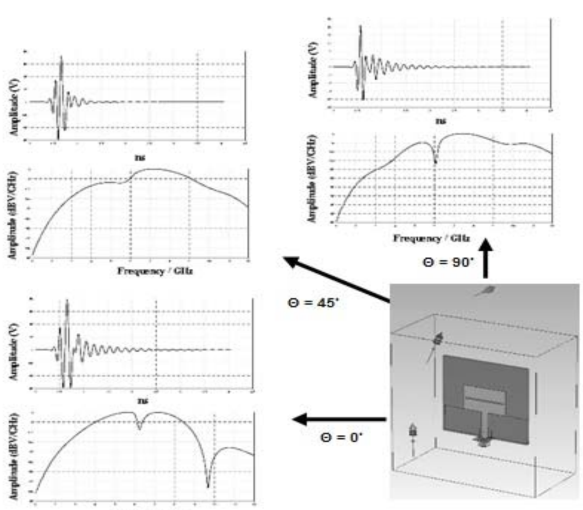

Figure-10. The signal seen by virtual probe and respective power spectra density.

Experimental results

The optimum design from simulation model has been fabricated on PCB and the antenna prototype is shown in Figure-11. The comparisons plot between the two different numerical technique analysis and measured results of return loss (dB) using constructed antenna prototype are shown in Figure-12. The measurement result show similarity between simulated results further verifies the performance of the antenna.

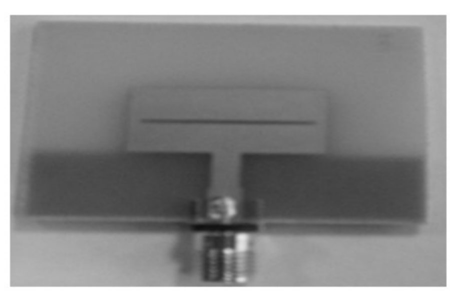

Figure-11. Fabricated notched rectangular patch antenna on FR4 PCB.

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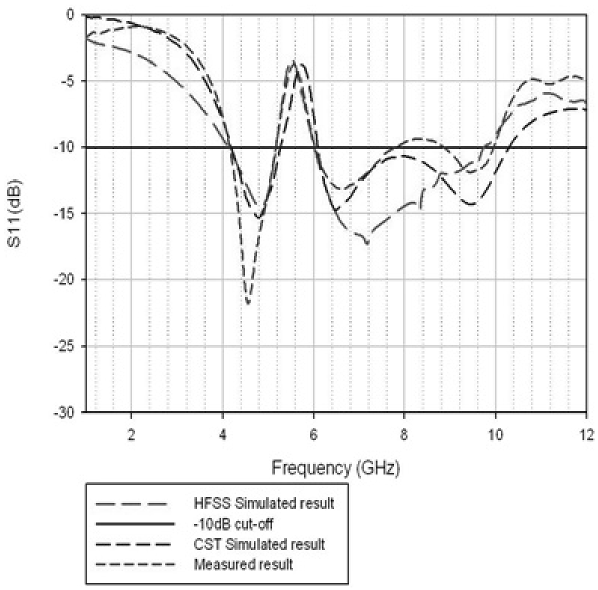

Figure-12. Measured return loss (S11) using Vector Network Analyzer and with CST and HFSS simulation results.

Table-2. The measured and simulation results.

Return Loss results from	Operating Band	Notched Band
Ansoft HFSS	4.2 - 9.8GHz BW = 5.6GHz	5.0 – 6.0GHz BW = 1.0GHz
CST Microwave Studio	4.2 - 10.4GHz BW = 6.2GHz	5.1 – 6.1GHz BW = 1.0GHz
Measured	4.2 – 10.0 GHz BW = 5.8GHz	5.0 – 6.0GHz BW = 1.0GHz

Table-2 represents the measured and simulated operating frequencies with their operating bandwidths and notch band for comparison purpose. The proposed antenna demonstrates the capability to operate between 4.2GHz to 10.0GHz and stop band capability from 5.0GHz to 6.0GHz. The antenna can be considered as ultra-wideband antenna since the operating bandwidth is 5.8GHz and it is based on FCC rules where the fractional bandwidth must be more than 500MHz or 20% from the center frequency.

CONCLUSIONS

In this paper, have proposed band notch UWB antenna which can support large bandwidth excited by a time domain pulse base signal to ensure the UWB signal is transmitted and received effectively. By variation on the size of the ground patch at bottom layer, the optimization on return loss has been realized and the potential as the key parameter on return loss improvement has been demonstrated. Furthermore, stepped impedance matching technique applied on the microstrip feed line is proved to provide further enhancement of the antenna performance in term of impedance bandwidth. By inserting slot on radiating patch, the proposed antenna can provide stop band at approximately 5.0GHz to 6.0GHz range of frequency. The simulation based fabricated band notch characteristic antenna, capable to reducing potential interference between UWB and WLAN or HYPERLAN/2 communication system when the signals of two radio systems are collided.

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