تصميم وتصنيع هوائي واسع النطاق بحجم مصغر على شكل حرف **T** للتطبيقات اللاسلكية

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الملخص

تعتمد تقنية الهوائي عريض النطاق (*UWB*) على عامل فريد يرمز إلى حل النطاق العريض اللاسلكي الأكثر وضوحًا من التقنيات الأخرى، كما أن تكلفة تكاملها المنخفضة مقارنة بالمسافات الطويلة جذابة للغاية للباحثين. ستكون تقنية *UWB* هي الحل الرئيسي لأنظمة *WPAN* المستقبلية. ويرجع ذلك إلى قدرتها على تحقيق معدل بيانات مرتفع للغاية ناتج عن طيف التردد الكبير المشغول. إلى جانب ذلك، فإن مستوى انبعاث الطاقة المنخفض للغاية سيمنع أنظمة *UWB* من التسبب في تداخل شديد مع الأنظمة اللاسلكية الأخرى. أصبح تصميم وتصنيع هوائي واسع النطاق (*UWB*) مجال بحث حيوي للغاية في الآونة الأخيرة. يقدم هذا البحث هوائي *UWB* صغير الحجم على شكل *T-Slot* ، قادر على رفض الإشارة المتداخلة من شبكة المنطقة المحلية اللاسلكية (*WLAN*) وأجهزة إرسال الوصول اللاسلكي الثابت (*FWA*). في حين أن نسبة الموجة الدائمة للجهد (*VSWR*) أقل من 2 ، يبلغ حجم الهوائي 1.5 سم وعرض 1.2 سم وعرض النطاق الترددي من 3.1 إلى 10.6 جيجاهرتز. ومع ذلك ، فقد أدت الفجوة الأرضية والتصميم *T-Slot* إلى تحسين عرض النطاق الترددي ، وتم تشكيل نوع الفتحة وشريط التغذية ليكون لهما حجم رقعة هوائي مضغوط. تمت محاكاة التصميم باستخدام برنامج *Zeland Fidelity* وأنجزت القياسات على التحقق من صحة نتائج المحاكاة للحصول على مخطط إشعاع متعدد الاتجاهات.

الكلمات المفتاحية: هوائي واسع النطاق, هوائي بشكل *T-Slot*, كسب الهوائي, نمط الانتشار

دروستكردن و ديزاينكردنى هەوايى (ئەنتێناى) سنور فراوانى بچوكراو لە شێوەى پيتى **T** بۆ بەكارهێنانى وايەرلێس

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:پوختة

تەكنەلۆجياى (UWB) ئەنتێناى بەرين لەسەر بنەماى فاكتەرێكى بێ هاوتايە كە هێما دەكات بۆ چارەسەرێكى پانى بێسيمى روونتر لە تەكنەلۆجياكانى تر وتێچووى يەكخستنى كەمترى بەبەراورد بە مەودا درێژەكان زۆر سەرنجراكێشە بۆ توێژەران. تەكنەلۆجياى يو دەبليو بى دەبێتە چارەسەرێكى سەرەكى بۆ سيستەمى داهاتووى دەبليو پان. ئەمە بەهۆى تواناى ئەوەوەيە بۆ بەدەستهێنانى رێژەى داتاى زۆر بەرز كە دەرەنجامى پانتايى فراوانى گەورە كە داگيرى كردووە. لەگەڵ ئەوەشدا، ئاستى دەرچوونى هێزى زۆر نزم رێگە لە سيستەمەكانى يو دەبليو بى دەگرێت كە ببوتە هۆى دەستتێوەردانى توند لەگەڵ سيستەمى وايەرلێسى تر. بەم دواييانە ديزاين و دروستكردنى هەوايى دوور مەودا (UWB) بووە بە بوارێكى لێكۆلينە وە ى گرنگ. ئەم لێكۆلينەوەيە ئەنتێناى (UWB) نويَى شێوە T-Slot بچوكراوە دەناسێنێت, كە تواناى رەتكردنەوەى سيگنالى بێ تەلى (WLAN) هەيە هەروەها تۆرى چەسپاوى بێ تەل (FWA) , ئەمە لەكاتێكدا رێژەى (VSWR) نزمترە لە 2, قەبارەى درێژى ئەنتێناكە 1.5 سم هەروەها 1.2 پانيەتى هەروەها باندبەرينى لە نێوان 3.1 بۆ 0.6 گێگا هرتزدەبێت. لەگەڵ ئەوەشدا , بۆشايى بنچينەيى و باندبەرينى بۆتە هۆى باشتركردنى T-slot. جۆرى بۆشايەكە و شريتى پالپشتكارەكەى بە شێوەى ئەرێلێك ديزاينكراوە. ديزاينەكە بە پرۆگرامى Zeland Fidelity دروستكراوە پێوانەكان دلنيايى دەدەن لە لێكچوونى ئەنجامە راستەكانى شێوازى تيشكدانەوەى فرە ئاراستەيى.

Design and fabricate of miniaturized T-shape ultra wideband antenna for wireless application

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ABSTRACT

Ultra-wideband antenna (UWB) technology is based on a unique factor that symbolizes a clearer wireless broadband solution than other technologies, and its lower integration cost compared to long distances is very attractive to researchers. The UWB technology will be the key solution for the future WPAN systems. This is due to its ability to achieve very high data rate which results from the large frequency spectrum occupied. Besides, extremely low power emission level will prevent UWB systems from causing severe interference with other wireless systems. UWB design and fabrication have become very vital research area recently. This paper presents a novel T-Slot Shape Miniaturized UWB Antenna, which is capable of rejecting the interfered signal from Wireless Local Area Network (WLAN) and Fixed Wireless Access Transmitters (FWA). While, Voltage Standing wave Ratio (VSWR) is below 2, the antenna has a size of 1.5 cm length and 1.2cm width with bandwidth ranging from 3.1 to 10.6GHz. However, the ground gap and T-slot have improved the notching bandwidth, the slot type and feeding strip had been configured to have correspondingly a compact antenna patch size. The design simulated using Zeland Fidelity software and the measurements validate the simulation results to have an omnidirectional radiation pattern.

Keywords: Ultra Wide Band Antenna, T-slot antenna, Antinna gain, Radiation pattern

1. INTRODUCTION

Wide range of applications has made manufacturers admired by Ultra Wide Band Antennas. However, with the ubiquitous spread of Fifth generation (5G) of mobile communication expected to emerge in 2020 [1], an UWB antenna has become of necessity as a hot topic in industry and research. A narrow waves with a short time (in nanoseconds) covering short distance on a wide bandwidth of frequency domain, with low power emission is very attractive for antenna designers, and defiantly it is what we are presenting in this paper.

The use of UWB technology is made from its unique factors that are reasons why it symbolizes a more articulate solution to Wireless broadband than other technologies [1]. The low cost of integration comparing to the wide range is very attractive for researchers. Nevertheless, good power consumption accordingly we can get when we use a low power processor. Yet, complex carrier forms is no longer used as far as no modulation/demodulation process will happen in the UWB system, the mixtures, amplifiers, and filters are not required.

A superior speed which will reach to several Gbps for short range distance can be achievable with UWB antenna [2]. Nevertheless, the following antenna is incredibly attractive intended for Wireless Personal Area Network WPAN, the portability gain access to of a great services of this antenna is ubiquitous for most wireless applications. Furthermore, a fast charge and info exchange data amongst applied easily transportable devices employing UWB within a short range comparing to the present wireless technology, have made many researchers looking for ways this kind of antenna. UWB system is not affected by multipath fading, so, there will be zero inter system interference with other services because it has a frequency adaptively to adjust the frequency reuse within the range of available frequency. This property has a great benefit of avoiding sigils interfering in the same frequency segment.

Since UWB is a short range radio technology, so it has a lower probability of delectability and interconnectivity because of low power density, comparing to a higher reliability (because of wider spectrum density) than other communication technology.

It had been considered by [3] that UWB is the most protected technology against co-channel and adjacent channel interference. However, it is almost impossible for noise to penetrate the UWB short duration pulses since it has a wide range of spectrum in addition to that, the pulses still restorable after being interfered by other transmitters.

The throughput is not comparable to fiber optical communication system due to higher data rate provided by the optical communication. But due to high cost associated with the optical communication installation inside buildings, UWB remain as a best option for indoor communication.

A good resonance of antenna patch appears due to the current movement along the slot edge is well demonstrated here. However, the small gap attached with slot designed to have half wave length $\lambda/2$ structure helped to generate notched bands with the UWB characteristics. The little patches distance instead of transferring that will be employed to control the shortened and lengthen the slot span.

2. RESEARCH BACKGROUND

Designing UWB in a small size is a big challenge for many manufacturers. Sending pulses in correct sequences within the wide band range antenna efficiently is a factor of good design. By looking to previous work it had been found three types of UWB antenna system designs. First design has electromagnetic radiation to fulfill with the selected Spectrum Emission Mask (SEM) pertaining to coexistence to other systems [4]. Second design is to secure the emission pulses as a transceiver antenna which should have the optimum performance along the overall system [5]. Release energy will likely be crucial concerns for the design of source pulses and antennas in UWB systems. High effective radiation pattern and acceptable directivity with a wide bandwidth remain as a challenge for UWB antenna accordingly the dielectric lose and conductor loss should be reduced as possible. However, it must operate within 3.1GHz up to 10.6GHz frequency range [4]. A constant group delay which is calculated by derivation of unwrapped phase of each antenna is needed for UWB transmitter performance. Therefore, if the phase is usually linear in the frequency range, the group delay will be constant to that frequency collection. This characteristics has a major importance to determine wither pulses are transmitted or not. Maximizing the half power beam width and minimizing the low power profile features are preferred to have a semi-omni directional pattern to have non-line of sight connectivity [6].

To reduce the pulse distribution along the UWB spectrum many designers focused in their researches in slots and its equivalent circuits to be distributed and matched on a planner plates to improve the bandwidth without affecting the performance of radiation pattern [7].

Having a narrow Band width from microstrip patch was difficult at the beginning, therefore, the researchers in [8] relay on dipoles and distributed slots antenna design. Accordingly, many researchers found that best way to improve the omni directional by increasing the matching impedance characteristics bandwidth ratio, therefore it was important to maximize the overall size of antenna feeder and height as in [9].

Improved matching techniques handling slots allocation had been proposed in different research papers like [10] and [11], while other researchers tried to improve the notches by adjusting the tapper below patch as in [12]. Potential demanding for a compact size with a more cost efficient is increasing for UWB system.

The limitation of bandwidth characteristics successfully removed as in [10-15] where a 90% of matching impedance was achieved by increasing the antenna overall size and feeding, in addition to using a tapper at the substrate base or using notch. There had been several proposals of planner and monopole antennas as an expecting promising technology for UWB antenna system as in [14][15], but these designs were nither small nor attractive for some applications because of high cross-polarization.

Several techniques used to introduce a notched band for rejecting the WLAN and HIPERLAN interference have been investigated, which include such as inserting a half-wavelength slot structure [16-18], slitting on the edges [19-20], utilizing fractal feeding structure [21], and parasitic quarter-wave patch [22] or parasitic open-circuit stub [23]. With the notched band antenna proposed in [16-18] characteristic, the antenna allows to reconfigurable its frequency that only responsive to other frequencies beyond the rejection bands within UWB bandwidth. Such a techniques were proposed also in slitting on the edges [19, 20], utilizing fractal feeding structure [21], and parasitic quarter-wave patch [22] or parasitic open-circuit stub [23].

The first rectangular patch of UWB antenna was mentioned in 2004 [12] a single slot on the patch and a partial ground plane was mounted, as a result researchers could get a group delay ripple less than 0.5 ns which was quite attractive at that time. This research presents an extensive investigation on the effect of slot to the impedance bandwidth has been done since this issue did not discussed in detail.

Antenna size reduction by impedance matching is the main challenge in this paper. However, reducing the size would directly affect the gain, as mentioned in [24], particularly in portable devices. All mentioned previous techniques have reached to a small required size in UWB antenna, but they couldn't have such a good performance as conducted in this research paper. In addition to that, UWB reconfigurable slotted antenna is designed and simulated in this paper in order to achieve linear phase with high radiation efficiency.

3. Antenna Charatristics and Simulation Results

It is important to consider the required VSWR and phase center of UWB Antenna, for stability across whole proposed frequency operation. Table 1 shows the proposed e UWB slotted reconfigurable antenna components parameters and specification.

Table 1. Proposed UWB antenna components parameters and specifications

Components Parameters	Specification
Impedance Bandwidth	3.1 GHZ - 10.6 GHz
Notched-Band	FWA (3.4GHz-3.7GHz) HIPERLAN (5150MHz-5350MHz) WLAN (5725MHz- 5825MHz)
Return Loss /VSWR	-10dB / VSWR<2
Radiation efficiency	High (>70%)
Phase	Nearly Linear
Radiation Pattern	Omni Directional
Directivity and Gain	Low
Physical Profile	Small (15x12mm^2)and compact

For significant impedance matching at high frequency, slots had been introduced on the patch radiator and feeder. Consecutively, to have a good impedance bandwidth, a notch had been introduced on the truncation grounded plate. And our main contribution is focusing on the various location of asymmetry couple slots design in correspondence to the equivalent circuit optimization. Figure 1 shows scenarios of T-shape slot optimization.

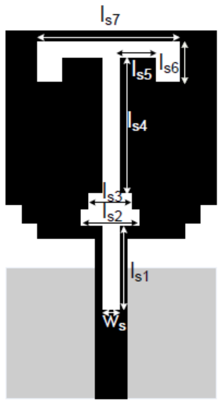


Figure 1. T-slots optimization for patch and feeding (I_{s1}= 11.5, I_{s2}=5, I_{s3}=3, I_{s4}= 7, I_{s5}= 2, I_{s6}= 3.5, I_{s7}= 6, W_s=1.5) in mm.

The T slot antenna shape is a result of vertical and horizontal slot collaboration. However, on feeding strip T-slot generate more straight current that helps to enhance the matching impedance at higher frequency. T-Slot length on feeding strip designed to have 2 λ at 10 GHz and above, whereas the │S11│ attain 29dB. In the lower resonance of 5GHz, best slot of ring was within open angle of 90^o and 0.3 cm radios, good improvement had been noticed as well as for the upper resonance 0f 10GHz. Surrounding 1.9cm was the ring slot Arc length; meanwhile overall ring and vertical slots were equal to 1λ at 10 GHz. At the right upper side of the Antenna is resonance at 7.2GHz, with 1.1 cm slot length. The other two slots at the left side resonance at 3 to 11 GHz frequency range. Meanwhile a multiple resonances are produced by the rectangular patch.

3.1 Feed Gap and Slotted Ground Plane

In the measurements of crucial effect factor in response to the impedance bandwidth, the ground plane act as an impedance matching in order to control its bandwidth. Different S11 (Return loss) simulation results for slotted T-Shape antenna appeared in Figure 2 for different feeding method (h: feed gap in mm) between ground plane and the feed gaps.

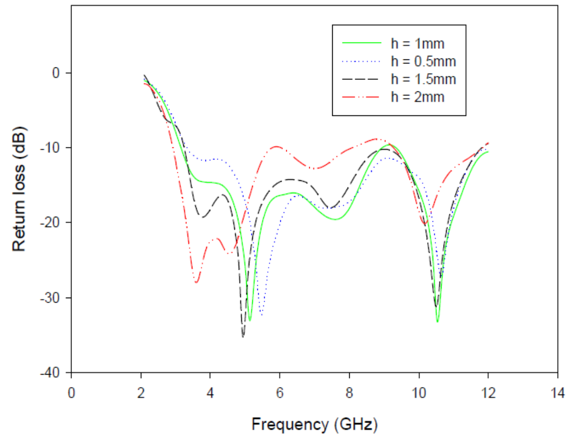


Figure 2. Different h (feed gap) simulation for T-Shape slotted antenna.

From Figure 2, it was found that optimum gap feeding was 1mm to provide a fractional with a bandwidth of 115% (3.1 GHZ - 10.3 GHz). It is obviously depict that real part (Re) is varying tardily at 50 Ohms while the current is low across wide frequency bandwidth, at 0.1cm to 0.15cm height. These characteristics are combatable with the UWB antenna requirements.

A various slots length (N) in mm and width were simulated respectively to produce different Return loss results as shown in Figure 3. Apparently, the best option is to have feed gap of 1mm above ground plane

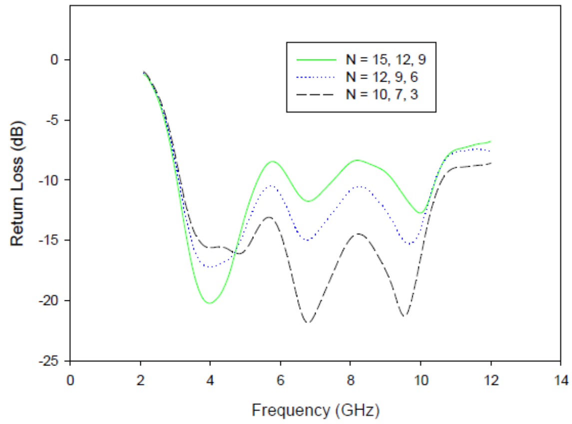


Figure 3. The T- Slot antenna effected by different length of slots ground plane.

As shown in Figure 3 the lengths were 10, 7, and 3mm for N1, N2, and N3 respectively. It shows that slot length decreasing proportionally with increasing the impedance bandwidth.

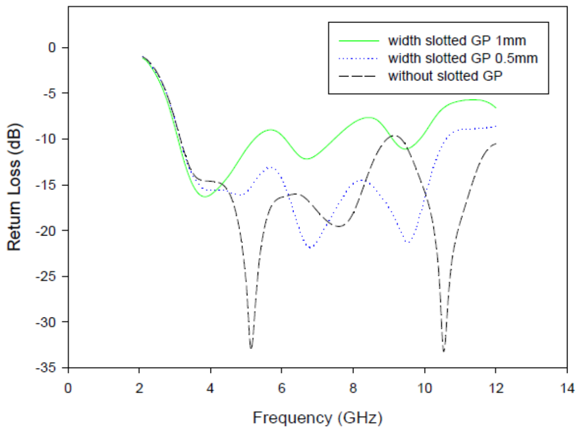


Figure 4. T-Slot antenna performance with different slots width design.

Figure 4 shows different slots width effects on T shape antenna performance. However, 1 mm gape in plane has degraded the antenna return loss above -10 dB.

3.2 Permittivity and Thickness of Substrate

Resonance frequency, characteristic impedance, and phase velocity are directly affected by the Substrate Permittivity and Thickness. As a permittivity of εr=2.2 εr=4.6 were considered for T shape microstrip design, respectively, we have got a different return loss results. The FR4 with εr=4.6 was used in the fabrication, due to the low cost and availability.

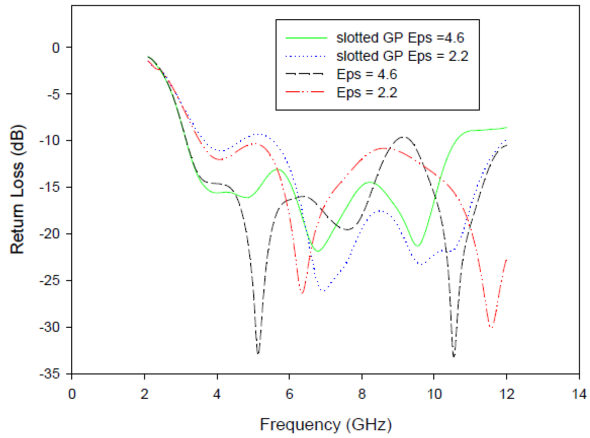


Figure 5. T slotted antenna return loss for different scenarios of substrate permittivity.

Simulation results shows good radiation and antenna efficiency within UWB frequency range which exceed 70% except at 11.9 GHz.

4. T-Shape Antenna Fabrication for UWB Application

The slot dimensions for T-Shape model have been employed in Figure 6 to give the optimum feed gap for T slotted with slotted ground plane.

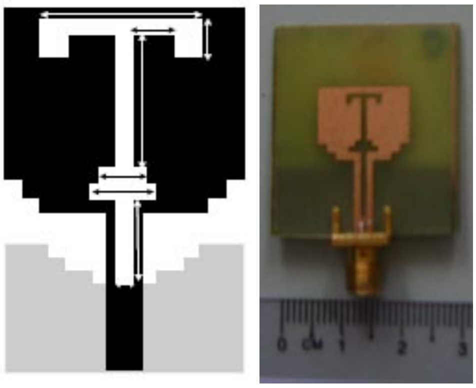


Figure 6. The fabricated prototype of T-shape UWB antennas (dimention are given in Figure 1).

As demonstrated before, prototype is printed in the front of substrate FR4 of thickness 0.16 cm and relative permittivity (εr) 4.6. The return losses were measured by using Agilent network analyzer. The return loss measurement setup is demonstrated by Figure 7, where a Network Analyzer is used. As a matter of fact, same testbed could be used to evaluate the VSWR and phase distortion.

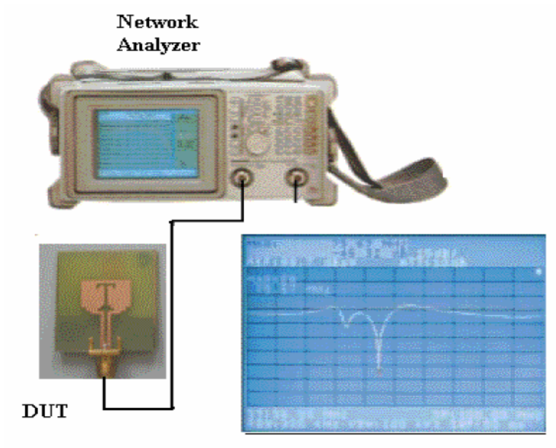


Figure 7. Return loss Laboratory test and measurements.

Return loss measurement shows a good matching and excellent result in both cases slotted and without slot T-shape antenna. Figure 8 and Figure 9 depicted that both antennas produced a good resonance for UWB frequency applications. In Figure 8 at a reference of -10dB, we noticed that frequency range started at 3.1GHz to 10.2GHz. In Figure 9, the antenna without slotted ground shows a return loss less than 10dB for a frequency range starting at 2.4GHz to 10.2GHz.
High accuracy in alignment between the slotted ground plane and patch on both sided of substrate is required throughout fabrication process. Measurements show that antenna without slots have better resonance and respond more effectively for S11.

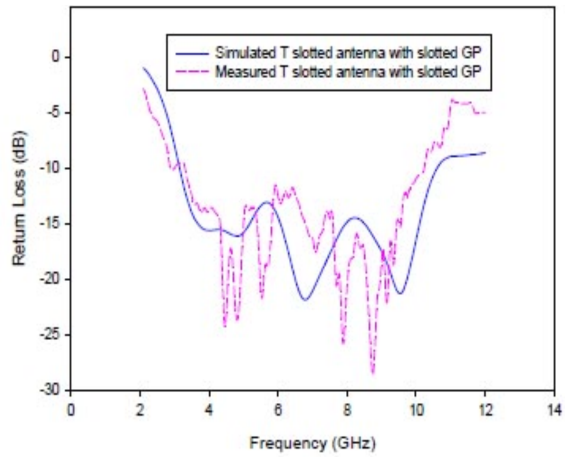


Figure 8. The measured return loss for T-shape antenna with slotted ground plane.

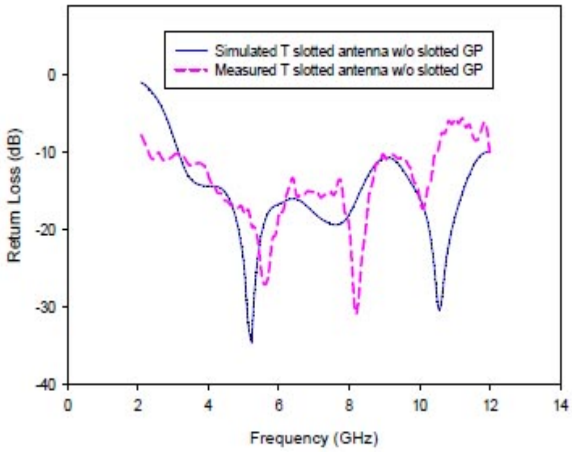


Figure 9. The measured return loss for T-shape antenna without slotted ground plane

A good agreement between Simulation and measurements results appeared in this section. However, the VSWR is well under 2:1 by tapering the base of FR4 plate and well adjusting the gap to ground plane. The Simulated T-Shape antenna gain versus directivity is highlighted in Figure 10 in comparing to gain of horn antenna. Where the gain was 1.6 to 5.5dBi and the directivity had better results varying between 2.5 and 7.2 dBi.

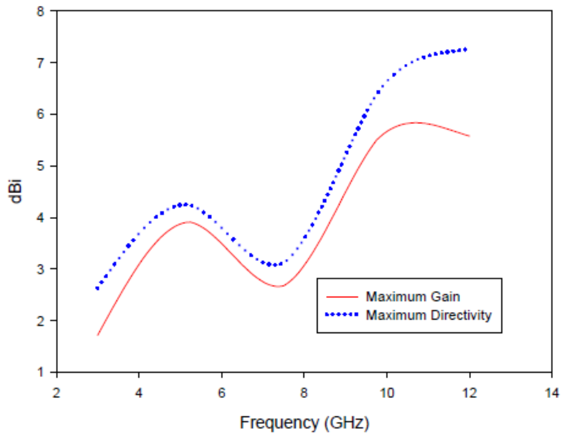


Figure 10. The gain versus directivity of slotted ground T-shape UWB Antenna.

Due to the coaxial cable feeds disturbing the T-shape design symmetry, as frequency increases the radiation pattern starts degrading. Whereas, efficiency reached to 90% at 5GHz and stay fix varying around 67% in the rest of frequencies bands. The optimum width of T-shape antenna was found to be 0.1cm

Different slot arrangements were considered to have the best design, as show in Figure 11, Return loss was developed with the best resonance broadly below -15dB.

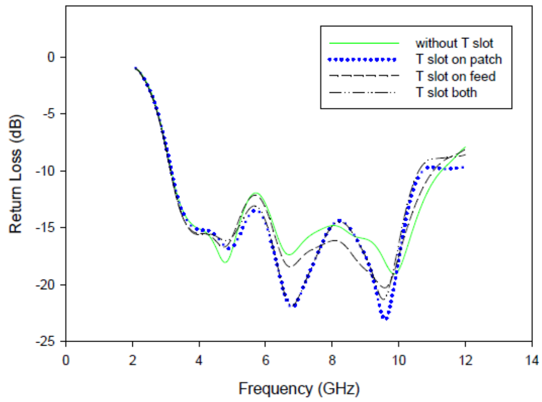


Figure 11. Different slots arrangement for T-Shape antenna to have the best return loss results.

Eventually, a three Models of Slotted T-Shape UWB antenna produced with an applicability of different services as shown in Figure 12.

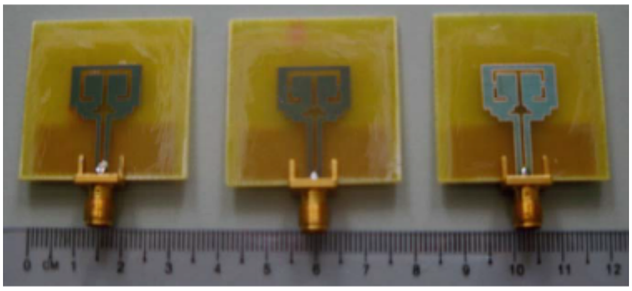
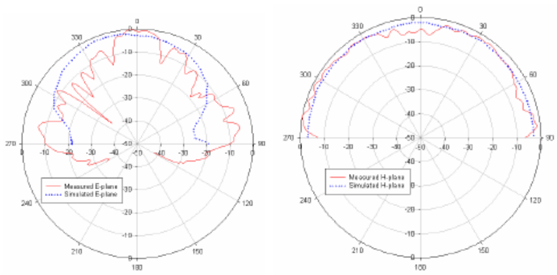


Figure 12. Fabricated slotted T-Shape designs, from left to right: 1- Operating frequency compatible with FWA Services, 2- Notch band is functional with HIPERLAN, and 3- for WLAN application.

5. Radiation Pattern Measurments:

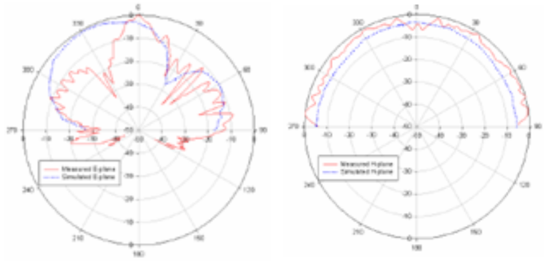
During the measurements process an essential steps should be considered to perform the measurements setup inside an anechoic chamber. However, the pattern accuracy relay on several thing like probe position, field test, distortion elements, and probe type. In this research the antennal elevation pattern was evaluated at the E-plane (φ = 900, xy-plane) which measured in a continuing feed plane and H-plane (φ = 00, yz-plane) which is orthogonal to the E-plane. Simulated results for both planes are shown in figure 13(a) and 13(b) respectively, for three operating frequencies 4 GHz, 5.8 GHz and 10.6 GHz.



(a) (b)

Figure 13. The measured and simulated radiation pattern at 4 GHz: (a) E-planes measured and simulated and (b) H-planes measured and simulated

Figure 13 (a) and (b) definitely shows that both E and H Planes are broad, which means that radiation is fare in all directions. According to the Radiation pattern measurements, at the lower end of operating frequency we have a nice flow of current distribution along the antenna patch plate, and the pattern is almost omnidirectional. Conversely, at the higher end of operating frequency, the current is gathered around the slots, which force the radiation through slots only.



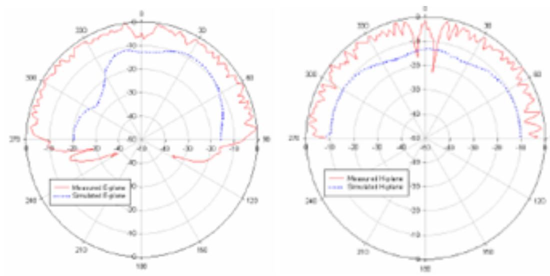
(b) (b)

Figure 14. The measured and simulated E and H planes at 5.8 GHz: (a) measured and simulated E-planes and (b) measured and simulated H-planes

It is also noted from Figure 14 that with increasing frequency to 5.8 GHz, the E-plane patterns become smaller.

Many ripples occurred in this frequency. The dips also present for various different angles.

Even though the measured radiation patterns are slightly difference to the simulated ones, since their patterns are nearly omni directional and their return losses are less than -10 dB, this proposed antenna meets the UWB requirements.



(a) (b)

Figure 15. The measured and simulated E and H planes at 10.6 GHz: (a) measured and simulated E-planes and (b) measured and simulated H-planes

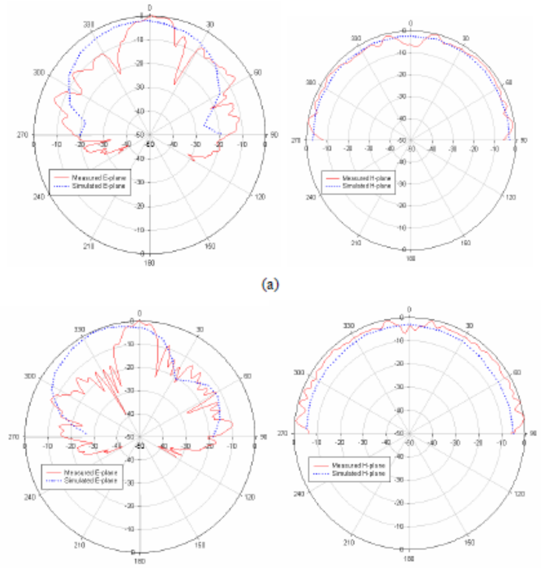
Figure 15 shows the E and H-planes for simulated and measured results. Slightly degradation at boresight occurs in measured H-plane. It is shown from both figures that both measured planes are wider than both simulated planes. The E-plane pattern seems tend to omnidirectional, which is similar to the H-plane. The degradation at boresight is due to misalignment of the AUT.

5.1 Radiation Patterns of Reconfigurable T slotted UWB Antenna

This part will inspect the effect of frequency notched to the radiation pattern at 4 GHz and 5.8 GHz. Figure 16 presents the measured and simulated radiation patterns for antenna having frequency notched at FWA.

Comparison between the reconfigurable modified T slot antenna and UWB T slotted antenna without frequency notch function, in terms of radiation patterns, have been done. It is found that the radiation pattern at 4 GHz of notched band at FWA has a dip towards null at 300 in E plane. This dip is smaller than the dip occurs at 490 for antenna without notch function. For radiation pattern at 5.8 GHz, more distortions occur for the E-plane rather than the E-plane pattern of previous frequency.

Both the E planes for both frequencies are relative broad. The measured H planes for both frequencies are remaining omnidirectional behaviors. The E plane at 5.8 GHz has a dip to null at -300.



(a)

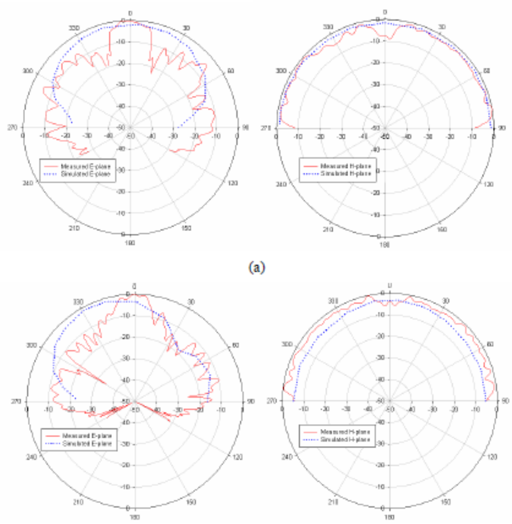
(b)

Figure 16. The measured and simulated E and H-planes for T slotted antenna.

Notched at FWA: (a) 4 GHz and (b) 5.8 GHz.

Figure 17 shows the measured and simulated radiation pattern for antenna with notched band at HIPERLAN band. It is observed that the E-pattern of 5.8 GHz is smaller than E-pattern of 4 GHz, while both H-planes are omnidirectional. On the otherhand, figure 18 shows antenna with notched band at WLAN band.

It is noticed that the notched band does not affect to the radiation pattern. This is investigated by comparing between these characteristic patterns with the previous characteristics without notched function. Both characteristics are mostly similar each other. A dip occurs at -600 for E-plane of 5.8 GHz pattern. E-plane pattern of 4GHz has no dip toward null, it is broad and the ripples still occur in the pattern due to the uncertainties. The uncertainties of the far-field patterns caused by any errors, as mentioned in previous chapter, contribute to the radiation pattern degradation.



(a)

(b)

Figure 17. The measured and simulated E and H planes for T slotted antenna

Notched at HIPERLAN: (a) 4 GHz and (b) 5.8 GHz

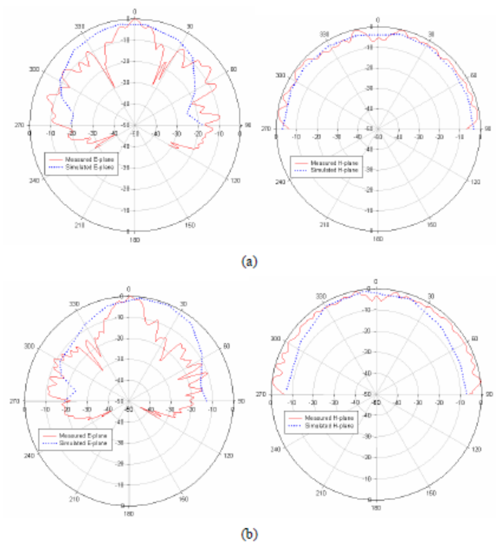


Figure 18. The measured and simulated E and H planes for T slotted antenna

Notched at WLAN: (a) 4 GHz and (b) 5.8 GHz

6. CONCLUSIONS

The UWB technology will be the key solution for the future WPAN systems. This is due to its ability to achieve very high data rate which results from the large frequency spectrum occupied. Besides, extremely low power emission level will prevent UWB systems from causing severe interference with other wireless systems.

Rectangular planar monopole antenna is chosen as conventional structure, this is due to a simple structure, low profile, easy to fabricate and UWB characteristics with nearly omni-directional radiation patterns. T slotted antenna originate from a conventional rectangular monopole by modifying the bottom patch with beveling and notches. The T slotted antenna with slotted ground plane has shown the return loss varies from -15 dB to -20 dB. However, during fabrication process, the slightly shifted impedance bandwidth has occurred. This is due to the antenna with slotted ground plane need very accuracy in alignment between the slotted ground plane and patch on both sided of substrate. The distance of patch to the ground plane is also very small of 0.5 mm, where is this distance as the impedance matching.

Interference rejection in an advantage of current UWB antenna especially the adjacent and co-channel interfered signal coming from Wireless Local Area Network (WLAN) and Fixed Wireless Access (FWA) during the same communication channel at the same environment of propagated signals. In addition to that, the S11 (return loss) and radiation develop measurements presented a good binding agreement with the simulation results. Also, validation shows that proposed T-Slot shape antenna was smaller size than others listed in the references.

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