A Compact Tapered-Shape Slot UWB Antenna with WLAN Band notch characteristics

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Abstract

A new modified compact microstrip line-fed Ultra-Wide Band (UWB) tapered- shape antenna with WLAN (5.5GHz) band notch function using inverted C-slot is presented. The overall antenna dimensions are 22x24 mm^2 fabricated on FR4 substrate with a thickness h of 1.5mm and a relative permittivity ε_r of 4.5 and easily fed by a 50Ω microstrip line. A complete analysis on the inverted C-slot was simulated and measured. The modified antenna is successfully fabricated and measured. Simulation and measurements agree that the modified antenna has a stable gain, high radiation efficiency(about 90%), and near omni-directional radiation pattern within the UWB operating frequency range while a good characteristics are obtained at the specified notch with a low gain of -4.2dB and VSWR of 6.3 .

Keywords: *Ultra wide band (UWB) antenna, Microstrip fed line, Slot antenna, Notch band.*

1. Introduction

Recently, attractive characteristics of UWB antenna like low cost, low complexity, small size, and high data transmission rates have made it a potential candidate in various wireless communications [1]. The Federal Communications Commission (FCC) was dedicated the frequency band from 3.1GHz to 10.6GHz for UWB applications [2]. A suitable UWB antenna performance is required over this band including return loss less than -10 dB or a voltage standing wave ratio (VSWR) below 2. Many UWB applications exist in the frequency band like WLAN (5.15- 5.825 GHz) so; a band-notch function is required to prevent interference between the existing operating bands. Many UWB antennas with band-notch function have been reported in recent years either by using slots [3-5] or parasitic elements [6-9] or both slots and parasitic elements [10-12]. In this paper, a new compact tapered-shape antenna introduced in [1] is modified by adding an inverted C-slot in the radiating patch in order to notch the WLAN frequency band (5.15- 5.825 GHz) centered at 5.5GHz to prevent interference with other co-existing UWB applications while maintaining a flat gain through the pass band of about 3dB and a very low gain at the notch frequency 5.5GHz of about -4.3dB in addition to a near omni directional radiation pattern and a radiation efficiency around 90%. Also Measurements and simulations agree in most points in the frequency band and at the notch frequency with a VSWR of 6.4 at 5.5GHz. Also a parametric study on the inverted C-slot dimensions was done in this paper in order to find the relation between the notch frequency and each dimension in the inverted C-slot by curve fitting. The original antenna proposed in [1] is shown in Fig.1.

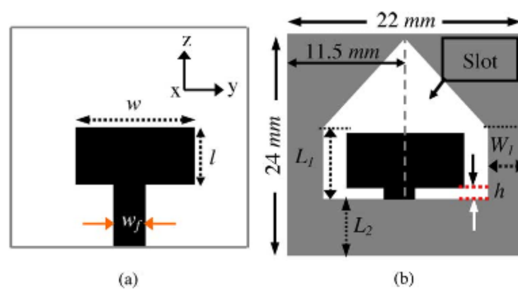


Fig.1 Original antenna (a) Top view (b) Back view

2. Design Methodology of the Modified Antenna

The modified antenna shown in Fig.2 is simulated by CST simulation software on FR4 substrate of thickness h=1.5mm and ε_r=4.5. Measurements of the antenna parameters gain, efficiency, radiation patterns, voltage standing wave ratio (VSWR) and return loss (S_{11}) was done using STARLAB 18STCE-Egypt compact multi probe antenna test station. Modified antenna configurations are shown in fig.4 and the fabricated antenna shown in Fig.12. We start simulation such that the total length of the inverted C-slot is equal to 16.4mm calculated from equation (1) such that the notch frequency located at 5.5GHz (W=7mm, c=1mm, L=2.5mm and t=0.5mm). After that, these dimensions are optimized in the CST simulation software. Optimum dimensions of the inverted C-slot (W, L, c and t) are listed in Table (1).

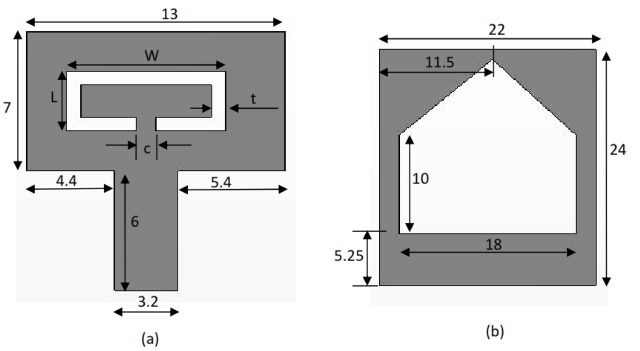


Fig.2 The modified antenna dimensions (mm)
(a) Patch (b) Ground

Table 1: Optimum C-slot dimensions

Parameter	W	L	c	t
Value (mm)	8	3	1	0.7

The inverted C-slot is designed to reject WLAN frequency band centered at 5.5GHz using the relation of [4]:

$$f_{notch} = \frac{c}{2L_{eff}\sqrt{\varepsilon_{ref}}} \quad (1)$$

Where: c =speed of light (3x10^{11}mm/s)
L_{eff} = total effective length of the C-slot
ε_{ref} = effective relative dielectric constant

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} \quad (2)$$

3. Results and Discussion

3.1 Current Densities of the Modified Antenna

As shown in Fig.3(a, c and d), current density at the operating frequencies (4GHz, 8GHz and 10GHz) flows on the patch, while at 5.5GHz (the desired notch frequency), current distribution flows around the inverted C-slot such that destructive interference for the exited surface current occurs which cause the antenna to be non respective at that frequency and the impedance nearby the feed-point changes acutely making large reflection at the desired notch frequency as shown in Fig.3 (b).

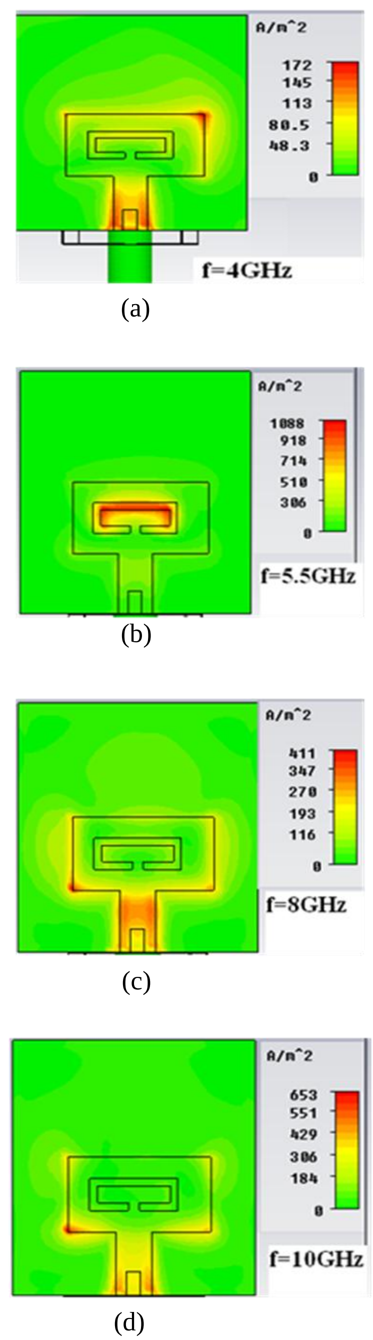
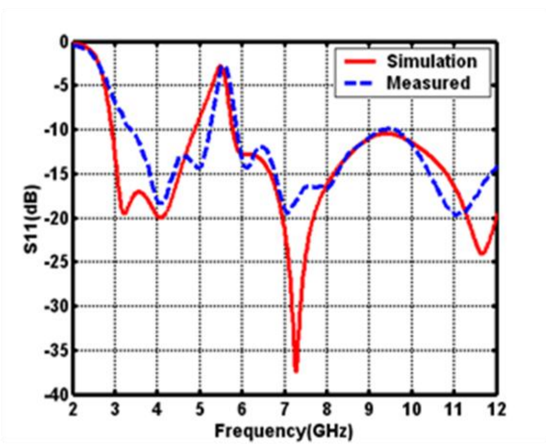


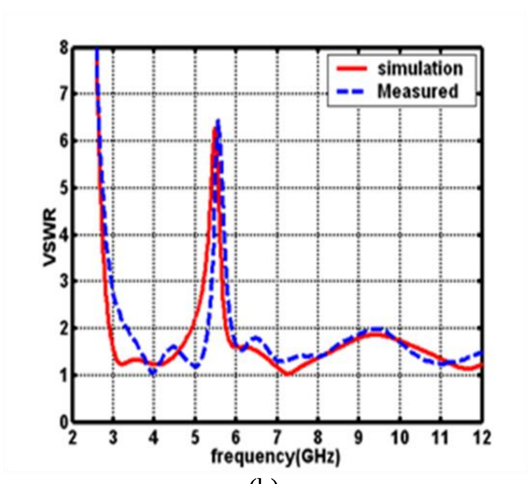
Fig.3 Current densities at different frequencies
(a) f = 4GHz (b) f = 5.5GHz
(c) f = 8GHz (d) f = 10GHz

3.2 Return Loss (S_{11}) and Voltage Standing Wave Ratio (VSWR)

As shown in Fig.4 (a), the modified antenna provides a return loss less than -10dB during the operating frequency band (3.1-10.6 GHz) and extended above 12GHz, while at the notch frequency (5.5GHz), the return loss is about -3dB and VSWR (Fig.4 (b)) is about 6.4(measured and simulated) which ensures that the inverted C-slot provides a good mismatching at the notch frequency. There is a small shift between simulation and measurement results from some few errors in manufacturing.



(a)

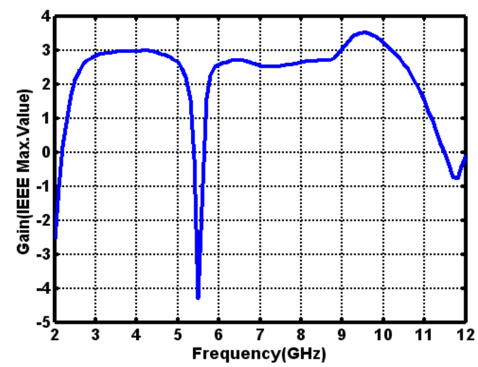


(b)

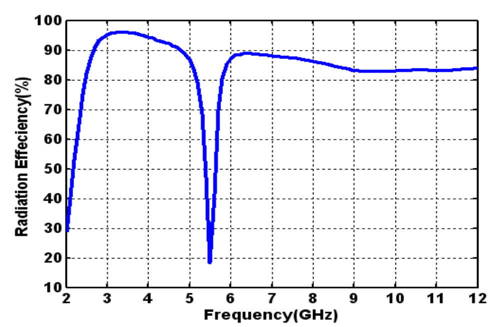
Fig.4 (a) S_{11} (dB) b) VSWR

3.3 Antenna Gain and Efficiency

As shown in Fig.5 (a), the modified antenna provides a maximum stable gain of 3dB in a part of the operating band (3-5GHz). It provides a low gain of -4.2dB at the specified WLAN frequency notch centered at 5.5GHz which means that the inverted C-slot provides a good mismatching at the notch frequency. In the remaining operating band (6-10.6GHz), the antenna provides a higher gain of about 2.5dB except for the band from 9-to-10GHz, the gain rises to 3.5dB. Thus, it can be concluded that the gain is nearly stable over the operating frequency band. Fig.5 (b) shows the radiation efficiency of the modified antenna which provides efficiency higher than 90% in the operating band 3-to-5GHz and efficiency from 85-to-90% from 6-to-10.6GHz, which means that the much of the input power are radiated in the operating frequency band. On the other hand, the efficiency drops to about 20% at the desired notch frequency (5.5GHz) which means that the much input power are reflected at this notch frequency.



(a)



(b)

Fig.5 (a) Antenna gain (b) Radiation efficiency

3.4 Antenna Radiation Patterns

The radiation patterns for the modified antenna (simulation and measured values) are shown in Fig.6 in the H-plane (Phi=0) and E-plane (Phi=90) at different operating frequencies. In most cases, the antenna seems to have near omni-directional radiation with a small shift between the measured and simulated values due to some few manufacturing errors.

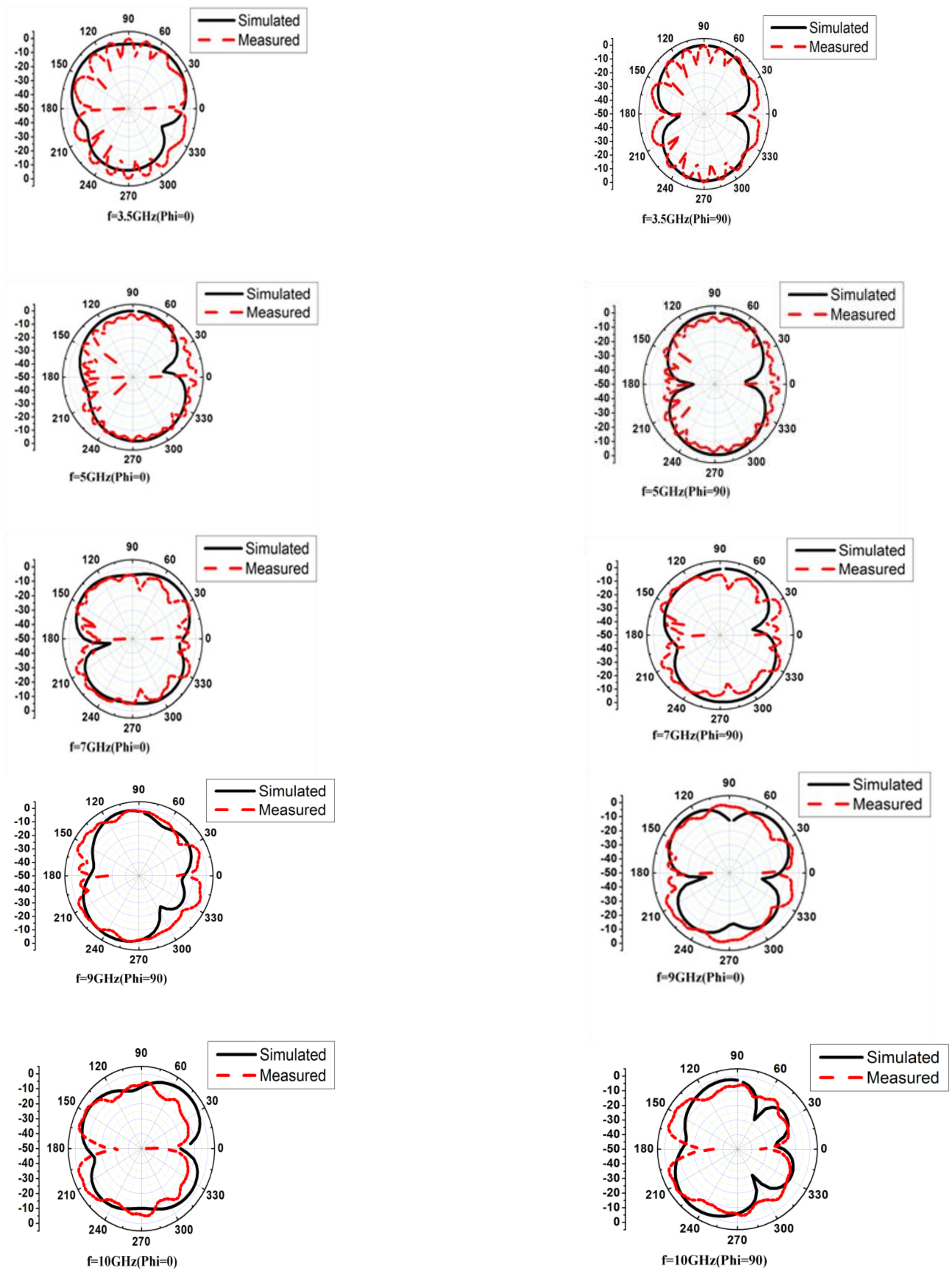
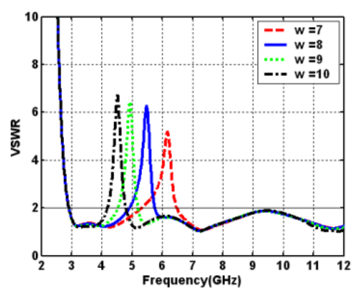


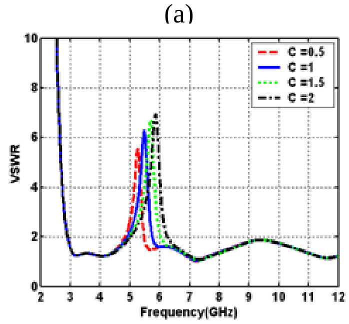
Fig.6 Radiation patterns at different frequencies

3.5 Parametric Study

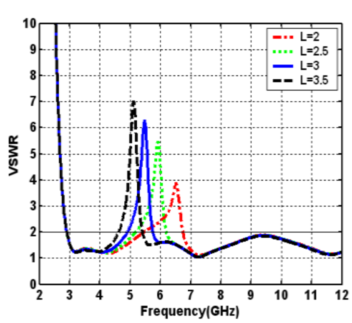
As shown from eqn.(1), the notch frequency is a function of the total effective length of the inverted C-slot (L_{eff}) which is controlled by the dimensions W,L,c and the thickness of the slot (t). Fig.7 (a) and Fig.7(c) show that the notch frequency is inversely proportional to width (W) and vertical length (L) of the inverted C-clot while the VSWR is directly proportional to both W and L. Fig.7 (b) and Fig.7 (d) show that both notch frequency and VSWR are directly proportional to the gap(c) and the slot thickness (t). For example, it can be seen that at W=7mm, VSWR=5.1 and f_{notch}= 6.2GHz, while at W=10, VSWR= 6.4 and f_{notch} = 4.5GHz. Also, it can be concluded that when the thickness of the slot (t) increased from 0.2mm to 0.9mm i.e. 350% w.r.t. the starting point(0.2mm), VSWR increased from 3.2 to 6.5 i.e. 103.125% w.r.t. the starting point(3.2) and the notch frequency increased from 4.7GHz to 5.87GHz i.e. 23.4% w.r.t. the starting point(4.7GHz).



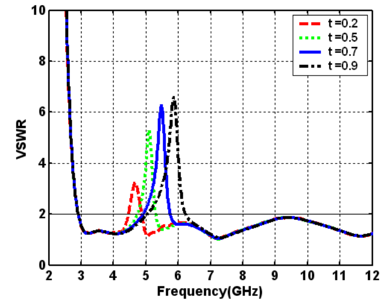
(a)



(b)



(c)



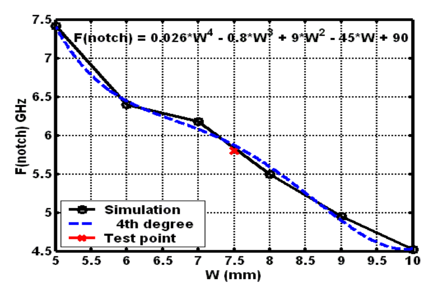
(d)

Fig.7 Effect of C-slot dimensions on VSWR and notch frequency

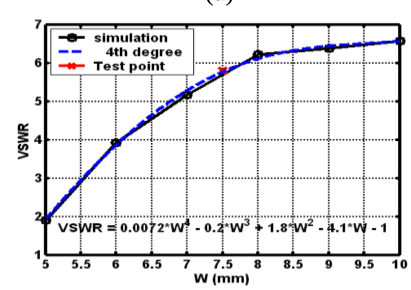
3.6 Curve Fitting

The relation between each dimension in the inverted C-slot and the notch frequency and the value of the VSWR is studied and shown in Fig.8, Fig,9, Fig.10 and Fig.11 (a and b). Then, two equations are derived for each dimension. The first equation (3, 5, 7, and 9) clears the impact of each dimension (W, L, c and t) on the notch frequency. The second equation (4, 6, 8 and 10) defines the influence of each dimension on the VSWR. These equations have been checked by taking a test point for each curve and it is found that the result values from these equations are matched with simulation. By using these equations, it can be easy to select the best dimensions at a specific notch frequency with the highest VSWR for good mismatching at the notch frequency.

3.6.1 W-Fitting



(a)



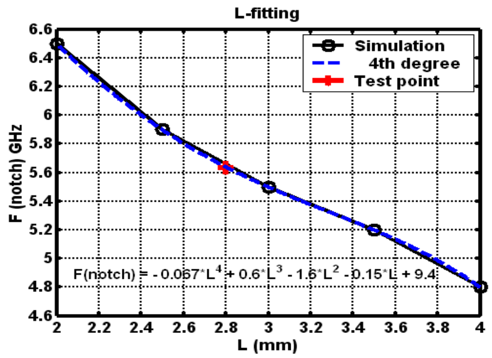
(b)

Fig.8 Effect of C-slot width (W) on
(a) Notch frequency (b) VSWR

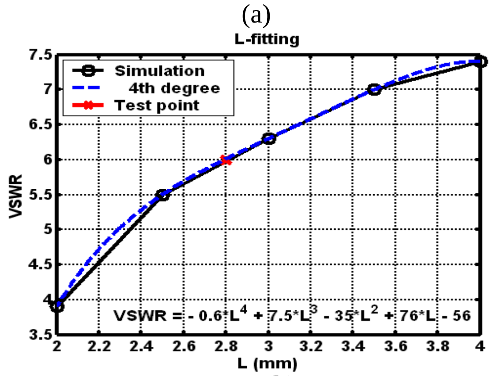
$$f_{notch} = 0.026*w^4 - 0.8*w^3 + 9*w^2 - 45*w + 90 \text{ GHz} \quad (3)$$

$$VSWR = 0.0072*w^4 - 0.2*w^3 + 1.8*w^2 - 4.1*w - 1 \quad (4)$$

3.6.2 L-Fitting



(a)



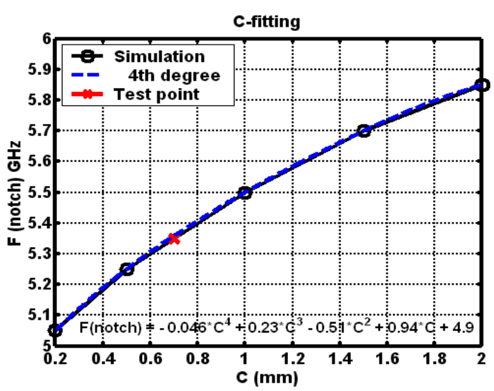
(b)

Fig.9 Effect of C-slot length (L) on
(a) Notch frequency (b) VSWR

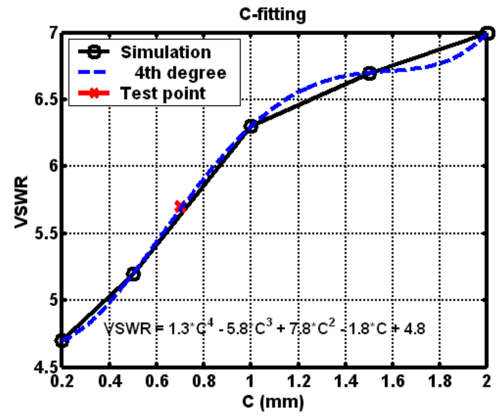
$$f_{notch} = -0.067*L^4 + 0.6*L^3 - 1.6*L^2 - 0.15*L + 9.4 \text{ GHz} \quad (5)$$

$$VSWR = -0.6*L^4 + 7.5*L^3 - 35*L^2 + 76*L - 56 \quad (6)$$

3.6.3 C-Fitting



(a)



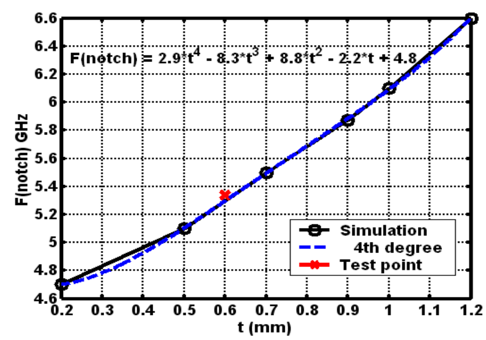
(b)

Fig.10 Effect of C-slot gap(c) on
(a) Notch frequency (b) VSWR

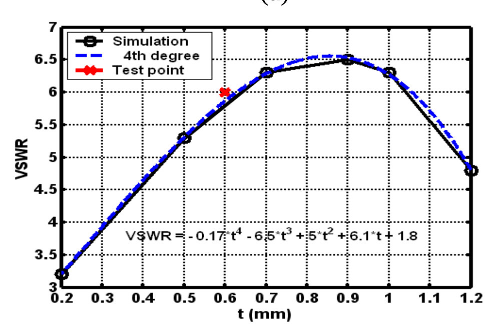
$$f_{notch} = -0.046*C^4 + 0.23*C^3 - 0.51*C^2 + 0.94*C + 4.9 \text{ GHz} \quad (7)$$

$$VSWR = 1.3*C^4 - 5.8*C^3 + 7.8*C^2 - 1.8*C + 4.8 \quad (8)$$

3.6.4 t-Fitting



(a)



(b)

Fig.11 Effect of C-slot thickness (t) on
(a) Notch frequency (b) VSWR

$$f_{notch} = 2.9*t^4 - 8.3*t^3 + 8.8*t^2 - 2.2*t + 4.8 \text{ GHz} \quad (9)$$

$$VSWR = -0.17*t^4 - 6.5*t^3 + 5*t^2 + 6.1*t + 1.8 \quad (10)$$

4. Conclusions

A new modified UWB antenna with WLAN notch using inverted C-slot has been designed, manufacured and measured. A new design equations are derived that helps the designer to determine the best dimenstions for a specific notch frequency with a good band notch characteristics. The modified antenna has a high radiation effeciency (avarage of 90%) and gain (average of 3dB) during the operating frequency band, while it provides a low effeciency (about 20%) and low gain (less than -4dB) at the WLAN (5.5GHz) desired notch frequency. Measurements also show that the modified antenna has a near omni-directional radiation patterns through the operating frequency band of UWB applications,while a good reflection characteristics at the WLAN desired notch frequency.

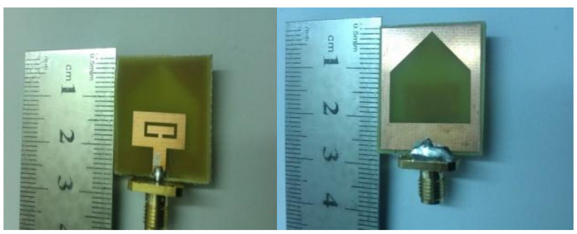


Fig.12 Photograph of the fabricated antenna

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