

Design of a Planar Tri-Band Notch UWB Antenna for X-Band, WLAN, and WiMAX

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Abstract-In this work, a new ultra-wideband (UWB) antenna design with 2.08GHz to 12GHz impedance bandwidth and triple-band specifications is presented. The proposed antenna is formed by a truncated square patch, a partial ground plane, and a 50Ω microstrip line. Three different types of slots were used in order to induce notched bands. A C-shaped slot is etched on the radiating patch to obtain a notched band in 3.31-4.21GHz for WiMAX. An inverted U-shaped slot in the micro-strip line induces a second notched band in order to reduce the interference with the WLAN [5.04-6.81GHz]. Finally, two inverted L-shaped slots around the micro-ribbon line on the ground plane allow the X-band [9.13 to 10.75GHz]. The antenna has dimensions of 32×28×1.6mm³. The Ansoft software (HFSS) was used to simulate the proposed structure. The simulation results are in good agreement with the measurement results. The antenna shows an omnidirectional radiation pattern.

Keywords-UWB antenna; notched band; WiMAX; WLAN; X band

I. INTRODUCTION

The demand for higher data rates is increasing, and the available frequency bands are becoming scarce [1]. To meet the requirements, Ultra-WideBand (UWB) antenna technology (3.1GHz-10.6GHz) seems to be an effective solution. UWB technology has advantages such as the ease of manufacture, the small size, and the large bandwidth [2-3]. This bandwidth is mainly due to the fact that UWB communications use extremely narrow pulses for transmitter and receiver communication. The most popular antennas used for UWB applications are printed monopole antennas which are easily integrated with different kinds of integrated circuits like monolithic microwave ones [4, 5]. However, it should be borne in mind that the use of the UWB band frequency can be the cause of interference in applications using neighboring frequencies such as WLAN or WIMAX applications [6-7]. To avoid this, it is necessary to ensure, generally during manufacture, that the developed antenna operates on a frequency interval whose limits can be chosen by the manufacturer. One way to do this is to modify the antenna structure. The slot insertion method is the best known method for obtaining a frequency band rejected in the UWB antenna. Indeed, the presence of slots in the patches and/or the ground plane [8-11], in the parasitic elements [12-13], or in the supply

line [14-15] are effective techniques used for making a notched strip. For a given element, the shape and the dimensions of the slot allow fixing the frequency of the notch band. Usually, the slot dimensions depend on the wavelength λ on which the rejected band is centered, and is chosen to be equal to about $\lambda/2$ or $\lambda/4$ depending on the position and shape of the slot.

In [16], two frequencies (3.5GHz and 10.5GHz) were obtained when using a U slot on the radiating element. In the ground plane, the insertion of an L-shaped slot also generated a notch centered at the frequency of 5.5GHz. The bandwidth of this structure is established between 2.8GHz and 12GHz. In [17], a micro strip line-fed monopole antenna has been developed. The designed antenna (size 30×30mm²) was modified to keep the band rejection at the level of a local wireless network. For this, inverted U and II slots as well as two U-grooves in the radiating patch were used. To satisfy the need for wireless technologies, the use of UWB notch band antennas is necessary [18-19].

In this work, a 32×28×1.6mm³ triple band square patch antenna with a FR4 substrate (permittivity 4.4) was studied with an obtained bandwidth of 2.08GHz-12GHz. The tri-band specifications were achieved through engraving a C-shaped slot in the radiating patch, an inverted U-shaped slot in the micro-strip line, and an inverted L-shaped slot around the micro-ribbon line in the ground plane.

II. DESIGN PROCEDURE

All the simulations presented in this work have been performed with Ansoft's HFSS simulation software which allows simulating finite and limited ground planes. As shown in Figure 1 and Table I, the proposed antenna is made up of a 2.99mm×10.75mm microstrip feed line. The length and width of the microstrip line were chosen taking into account that the nature of the substrate and its thickness directly influence the characteristics of the microstrip feed line. With the FR4 epoxy substrate ($\epsilon_r=4.4$, thickness=1.6mm), the dimensions we used allow the microstrip feed line to have a characteristic impedance of 50Ω over a very wide frequency band. The antenna is in the form of a rectangular patch with partial ground plane. The two lower corners of the radiating element were cut to improve the band width. The dimensions of the truncated corners are 2.5×5.625mm².

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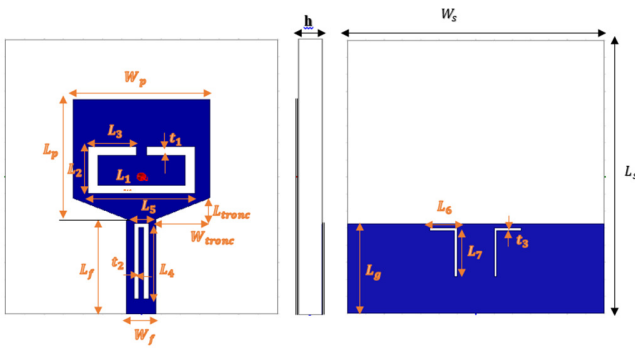


Fig. 1. Diagram of the antenna.

TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA (mm)

Parameter	L_s	W_s	L_g	h	L_p				
Value (mm)	32	28	10.7	1.6	14				
Parameter	W_p	L_f	W_f	L_{tronc}	W_{tronc}				
Value (mm)	14	10.7	2.9	2.5	5.625				
C shaped slot		Inverted U-shaped slot			Pair of inverted L-shaped slots				
L_1	L_2	L_3	t_1	L_4	L_5	t_2	L_6	L_7	t_3
10	3.5	2.5	1	6	2	0.25	3.5	4	0.25

As shown in Figure 2, this modification of the geometry of the radiating element directly influences the appearance of the return loss spectrum. After truncating the corners, we note that the antenna has a better adaptation compared to the base antenna of the same frequency band. A minimum reflection coefficient of -27dB at a frequency close to 8.5GHz is obtained for this antenna. It is also noted that the minimum in the vicinity of the 4GHz frequency is accentuated with respect to the case of the base antenna.

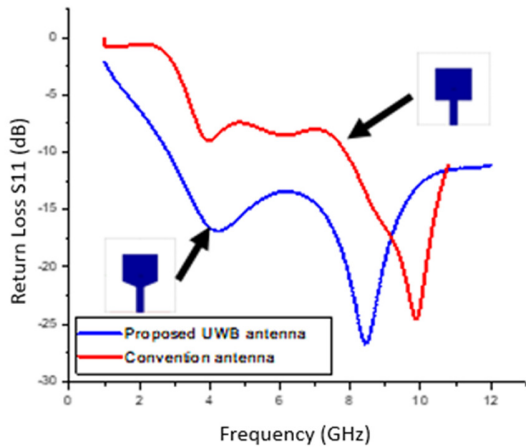


Fig. 2. The S11 of the proposed and the conventional antenna.

A. First Notched Band

As mentioned above, the presence of slots in the different elements of the antenna allows the appearance of notch at given frequencies. The arrangement of these slots, their shape and their dimensions allow control of the frequencies of the notches. To have a rejection of the WIMAX band, and to

obtain a first notched band in the range 3.31GHz-4.21GHz, a C-shape slot is introduced (Figure 3) in the radiative element [2, 4, 19-21]. To get satisfactory results and highlight the influence of each parameter, the thickness of the slit t_1 and the position in the patch noted by PF_1 vary while the length remains unchanged (proportional to the rejected frequency). As a first step, the position of the slot remains unchanged, and the values of the thickness t_1 vary ($25 \times 10^{-5}m$, $50 \times 10^{-5}m$, $100 \times 10^{-5}m$, $150 \times 10^{-5}m$, and $200 \times 10^{-5}m$).

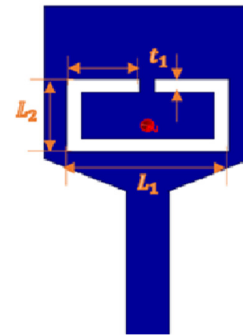


Fig. 3. Geometry of the antenna: $L_1= 10mm$, $L_2= 3.5mm$, $L_3= 3mm$, $t_1=1mm$.

The Return Loss S11 spectra (Figure 4) correspond to different values of t_1 . The antenna presents a good adaptation in the studied frequency band, with a reflection coefficient of around -10dB, except in the bands [3.5, 4.5GHz] and [9.5, 11.5GHz] where the reflection coefficient is slightly above -10dB. A minimum reflection coefficient varying from -20dB to -47.5dB, depending on the used values of t_1 , is observed between 8GHz and 9GHz.

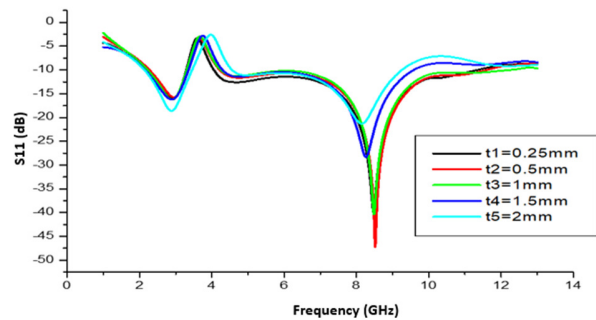


Fig. 4. Evolution of the Return Loss spectra for different values of t_1 .

Figure 5 shows the simulated VSWR of the proposed antenna. An adequate choice of parameters associated to the C slot allowed us to obtain the desired band according to (1) and (2):

$$f_{notch} = \frac{c}{2L\sqrt{\epsilon_{eff}}} \quad (1)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} \quad (2)$$

where L represents the length of form C and ϵ_{eff} the substrate dielectric constant. It is evident from the simulation results of

the VSWR, that the antenna is well suited ($VSWR \leq 2$) in the band [2.0GHz, 12.0GHz] except for the band bands [3.2GHz, 4.0GHz] where $VSWR > 2$ with a $VSWR = 9$ obtained in the vicinity of 3.8GHz.

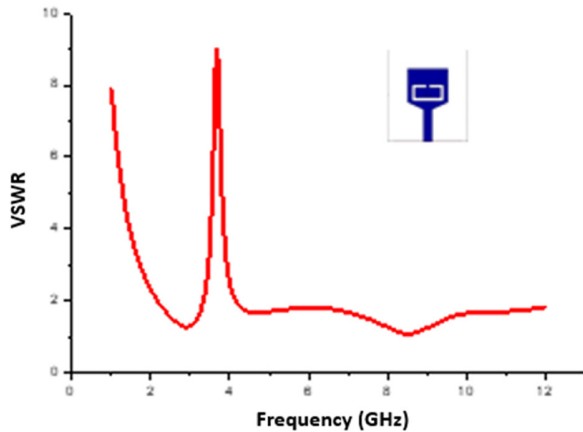


Fig. 5. The antenna VSWR.

B. Second Notched Band

Due to the wide frequency range of UWB technology, it is essential to avoid interference with WLAN technology in order to reduce its impact on the UWB system. In order to obtain a second notched band in the range 5.04GHz-6.81GHz, a second slot was embedded in the micro-strip line [22-24]. The inverted U shape of this slot (Figure 6) has the following characteristics: The $\lambda c/4$ length chosen for this slot allows the rejection of the band centered at $f_c=5.5$ GHz. The other geometric parameters are not modified comparing to the base antenna's.

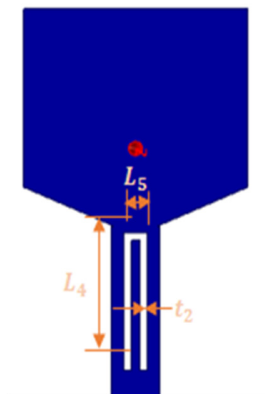


Fig. 6. Insertion of the second slot for WLAN rejection.

To analyze the influence of the parameters of the slot, the thickness of the slot t_2 and the position in the patch noted by PF_2 varied, whereas the length of the slot was kept unchanged. In the first step, the position of the slot remained fixed, and the thickness values varied ($25 \times 10^{-5}m$, $50 \times 10^{-5}m$, $75 \times 10^{-5}m$, $100 \times 10^{-5}m$, and $125 \times 10^{-5}m$). Figure 7 shows the evolution of the Return Loss S11 according to the slot thickness variation. A clear evolution of the frequency and value of the minima can be observed.

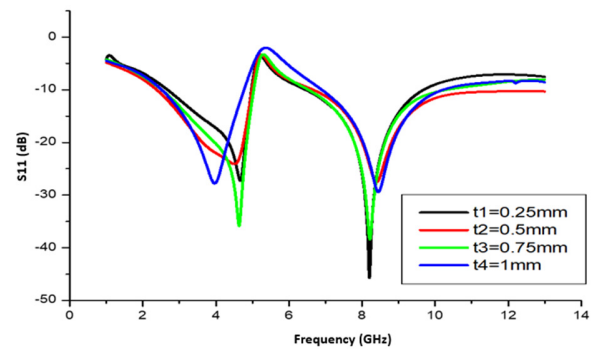


Fig. 7. S11 versus the variation of the thickness t_2 .

By adjusting the main parameters, the length of this slot is chosen to be 13.5mm. The desired rejected WLAN band is accomplished, and the antenna is well suited as shown in Figure 8.

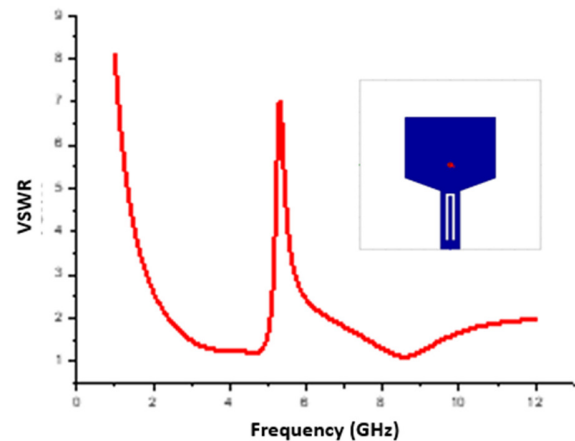


Fig. 8. VSWR spectra with U-shaped slot.

C. Third Notched Band

Another type of slot was used to attenuate interference signals over the frequency range of 9.13 to 10.75GHz for the X-band, an inverted L-shaped slot (PF_3) is etched around the micro-ribbon line on the ground plane [25-27]. The geometry of the obtained antenna is shown in Figure 9. The total length of the slot is 8.5mm, or about $\lambda c/4$ when considering the frequency $f_c=10$ GHz which corresponds to the center of the rejected band. No modifications were made to the other antenna parameters. The position of the PF_3 varied whereas the thickness of the slot remained fixed. The position PF_3 was calculated according to the center of the ground plane. According to the evolution of the shape of spectra in Figure 10, corresponding to different positions of the slot, it can be seen clearly that when the slot moves upwardly with an increase of the antenna bandwidth. At the position $PF_3=0$ mm the antenna is adapted in the band [3.1GHz, 10.6GHz] with the rejection of the central frequency band of 10GHz [9.33GHz, 10.54 GHz]. The band we wanted to reject was obtained by adjusting the parameters of L_6 and L_7 (Figure 11).

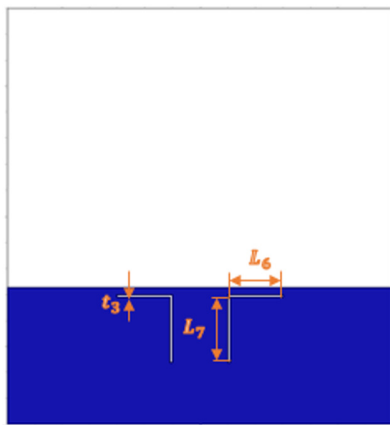


Fig. 9. Geometry of the proposed antenna: $L_6=2.5\text{mm}$, $L_7=6\text{mm}$, $t_3=0.5\text{mm}$.

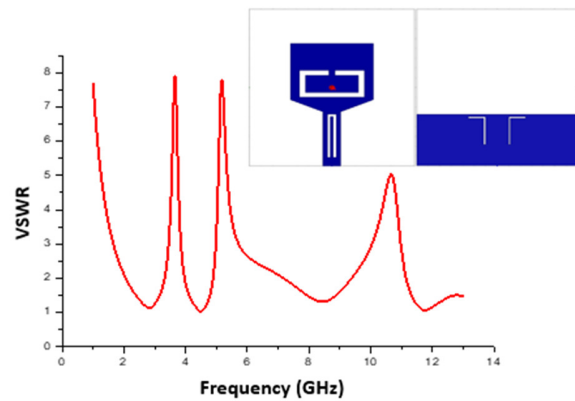


Fig. 12. Triple-band-notched VSWR spectrum of the proposed antenna.

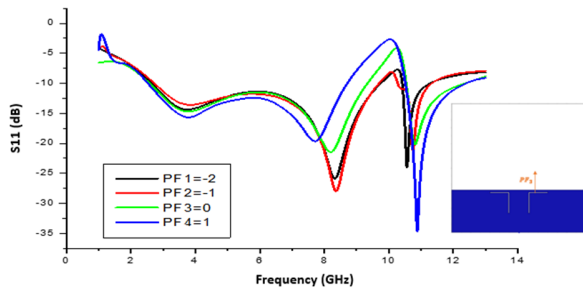


Fig. 10. Variation of the position PF3.

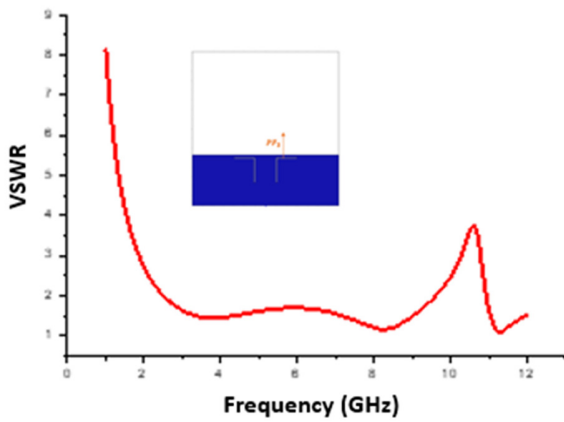


Fig. 11. VSWR spectrum of the antenna after inserting an L-shaped slot.

III. RESULTS AND DISCUSSION

The VSWR spectrum of the proposed UWB antenna is presented in Figure 12. We notice a bandwidth ranging from 2.08GHz to 12GHz, which covers the frequency band of the UWB. The three notched bands are: 3.28 to 3.91GHz (VSWR=8 at 3.59GHz), 4.9 to 7.15GHz (VSWR=7.73 at 5.18GHz) and 9.21 to 10.94GHz (VSWR=5 at 10.27GHz). Figure 13 shows the antenna radiation directional dependence obtained at three different frequencies. These patterns are omnidirectional at the considered frequencies. On the other hand, there is a deterioration of the radiation pattern at the 10GHz frequency.

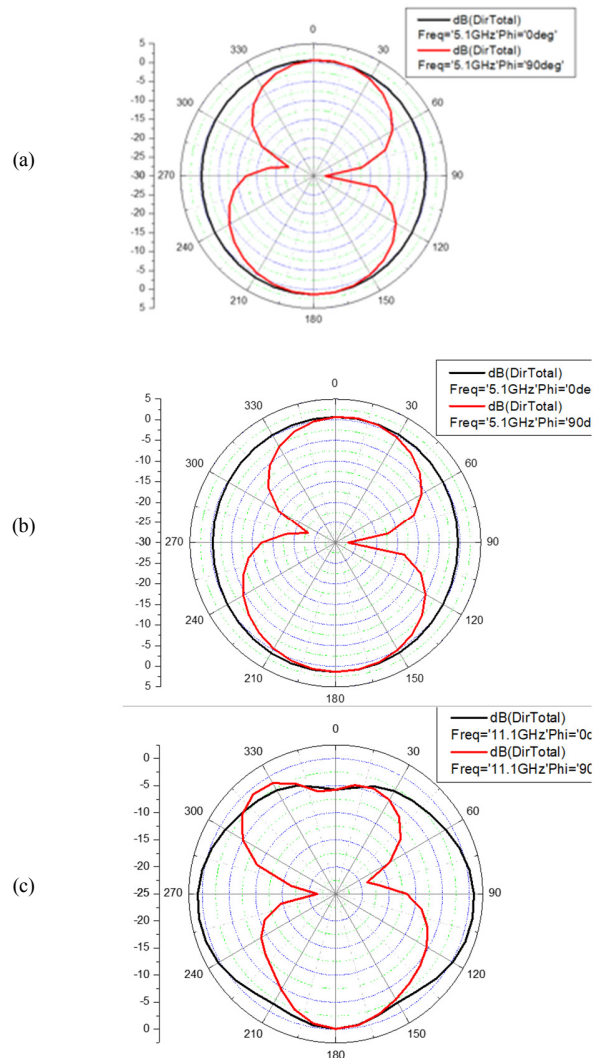


Fig. 13. Radiation patterns corresponding to three different frequencies.

The antenna current distributions at the three frequencies are shown in Figure 14. We can observe that for frequencies

5.18GHz and 10.27GHz, the surface currents are localized on the feed line. On the other hand, at 3.59GHz, the surface currents increase in the patch around the slot.

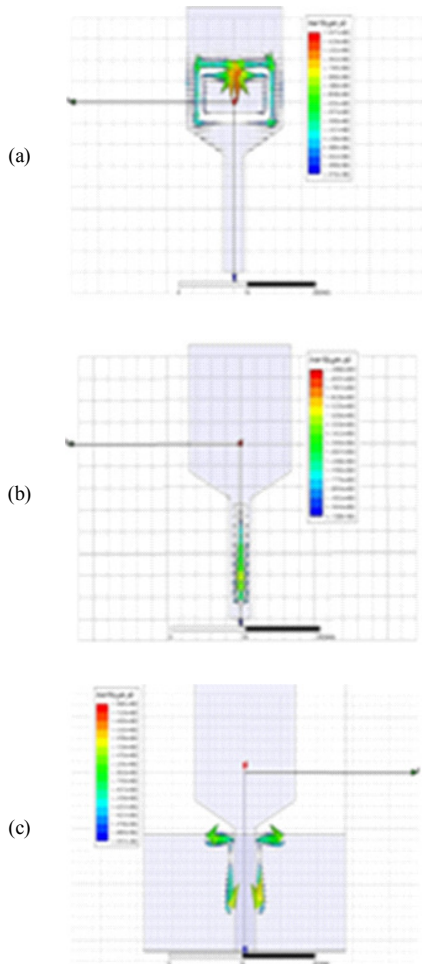


Fig. 14. Antenna surface current distribution associated to the frequencies of (a) 3.59GHz, (b) 5.18GHz, and (c) 10.27GHz.

To validate the design of our notched triple band UWB antenna, we have manufactured (Figure 15) and tested it in an anechoic chamber (Figure 16).

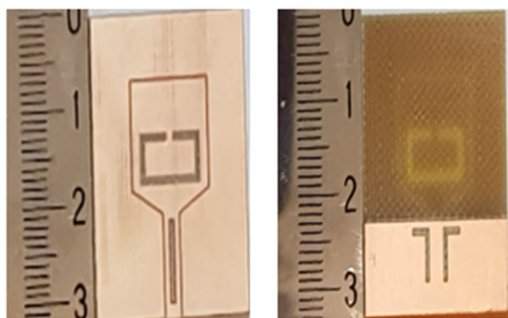


Fig. 15. Photo of the manufactured tri-band UWB antenna.

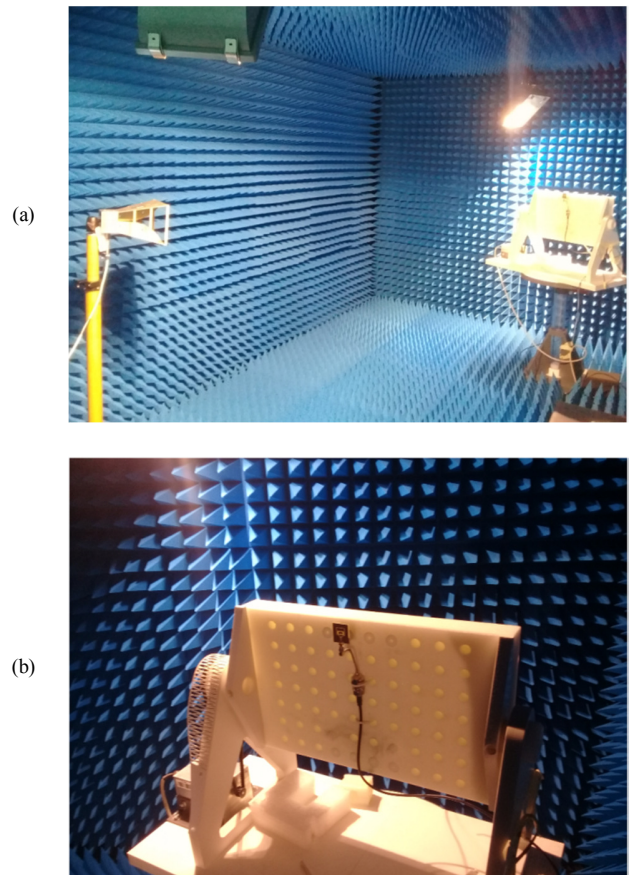


Fig. 16. Photos of the measurement procedure.

The numerically obtained results of the reflection coefficients with those obtained experimentally are represented in Figure 17. The comparison of the two curves shows a good agreement between the experimental and the simulation results.

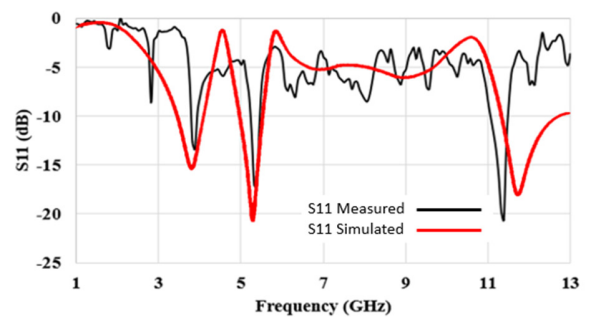


Fig. 17. Comparison of simulated and measured S11.

IV. CONCLUSION

A new ultra-wideband planar antenna with triple band notch characteristics is proposed in this work. The first notch at 3.59GHz is achieved by inserting a C-shaped slot in the radiating patch, the second notch at 5.18GHz is realized by etching a U-shaped slot in the micro-strip line, and the third

notch at 10.27GHz is accomplished by using an L-shaped slot on the ground plane. An almost 10GHz large operating band frequency is obtained (2.08GHz-12GHz) with three rejected bands (3.28-3.91GHz, 4.9-7.15GHz, and 9.21-10.94GHz). It also presents an omnidirectional radiation pattern which allows minimizing the interference from technologies such as WiMAX, WLAN and applications in the X band.

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