Progress In Electromagnetics Research M, Vol. 76, 101–111, 2018

Polarization Diversity UWB Antennas with and without Notched Bands

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Abstract—In this article, a couple of UWB antennas are presented. These antennas have the shape of two overlapped circles. The presented antennas are polarization diversity antennas with and without dual band reject filters. Measurements show that the antennas work well within the whole UWB. Antennas have practical reflection parameters S_{11} and S_{22} lower than -10 dB, practical coupling parameters S_{12} and S_{21} lower than -15 dB, an Envelope Correlation Coefficient lower than 0.015 and a diversity gain between 9.97 to 9.99 dB. Simulations of the antennas are done using the CST software.

1. INTRODUCTION

A given communication system is defined as an ultra-wideband (UWB) system when it has a very large absolute bandwidth (500 MHz or higher) or a large relative bandwidth (20% or higher) or both of them. U.S. Defense Advanced Research Projects Agency's (DARPA) considered a given communication system as a UWB system when it has a relative bandwidth (20% or higher) or a very large absolute bandwidth (500 MHz or higher) or both of them [1]. Such a large band width offers specific advantages with respect to signal robustness, information content and/or implementation simplicity. In 2002, the Federal Communications Commission (FCC) designated the (3.1–10.6) GHz band with Effective Isotropic Radiated Power (EIRP) below -41.3 dBm/MHz for UWB communications [1]. With 7.5 GHz working band, the total EIRP within the whole UWB should be lower than -2.55 dBm (-7 dBm or lower in general).

UWB antennas can be implemented as monopoles, dipoles and log-periodic directive antennas. UWB communication systems operating in (3.1–10.6) GHz share the same frequency of other communication systems and thus could be easily interfered by the nearby communication systems such as WiMAX communication system operating at 3.5 GHz band (3.3–3.7 GHz), WLAN system operating at 5.5 GHz band (5.15–5.85 GHz) and X-band downlink communication frequency operating at 7.5 GHz (7.1–7.76 GHz). The interferences of UWB systems with these wide-band communication systems can be avoided using band reject filers within the UWB transceivers. This technique will increase size, cost, and complexity of the UWB transceivers. Thus the best way to avoid interference is to utilize UWB antenna having bandnotch characteristic within itself.

To reduce the mutual interference between the UWB system and other narrow and wide band communication systems, many techniques have been proposed and implemented to get this objective. These techniques include adding parasitic strip, adding circuit stub, using meta material resonator, cutting slots of different shapes either in the microstrip feeding line, in the radiating patch or in the ground plane [2–5]. These antennas were designed with single notched band [5–9], double notched bands [10–17], triple notched bands [18–29], quad notched bands [30, 31] and even five notched bands [32, 33].

Received 27 September 2018, Accepted 12 November 2018, Scheduled 27 November 2018
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To mitigate multipath fading signals and enhance the system capacity, antenna diversity is used as an effective solution. Several types of diversity such as pattern, spatial/space, and polarization diversity have been proposed and implemented to simultaneously receive multiple transmissions [34–36]. A good UWB polarization diversity antenna should have low mutual coupling, i.e., high isolation (higher than 15 dB) between its ports. Recent articles [37–41] dealing with different aspects of UWB antennas show the continuous interest in UWB antenna design and implementation.

In this work, UWB antennas with two different configurations will be presented giving their practical performance.

The rest of the work is organized as follows. In Section 2, UWB antennas of different versions are described, and their practical performance is given. In Section 3, conclusions are addressed.

2. DESIGN AND PERFORMANCE OF THE PROPOSED UWB ANTENNAS

To have good performance UWB polarization diversity antennas, two conditions should be fulfilled. Firstly, S_{11} and S_{22} parameters should be lower than -10 dB within the UWB of (3.1–10.6) GHz. To meet this, the minimum operating frequency of the antenna should be 3.0 GHz or little bit lower to face possible degradation in performance due to the fabrication process. The minimum operating frequency corresponds to a monopole effective length of 0.24λ. Thus the antenna should be designed as a monopole that has an effective length of 0.24λ at 3 GHz or little bit lower frequency. This means that the antenna effective length should be 24 mm or little bit higher at 3 GHz. If the UWB antenna has to reject the interference of the WiMAX systems working within (3.3–3.7) GHz band without the obligation to work well at (3.1–3.3) GHz band, and the UWB monopole antenna should have an effective length of 0.24λ at 3.7 GHz (0.2λ at 3.1 GHz). The second condition that the polarization diversity antennas should meet is to have coupling parameters S_{21} and S_{12} lower than -15 dB.

Our antennas are fabricated using a TLX-9 substrate with dielectric constant of 2.5, $\tan\delta$ of 0.0019 and thickness of 0.78 mm. In this work, CST (Computer Simulation Technology) software is used to perform the simulations and optimization process.

The studied antennas have the shape of two overlapped circles. The antenna consists of the above mentioned radiating element, a feeding line and ground plane. The feeding line has a width of 2.21 mm with an impedance of almost 50 ohms.

The first minimum working frequency $f_{\min}$ (with S_{11} lower than -10 dB) of the UWB antenna is given by:

$$f_{\min}\,(\text{GHz}) = \frac{72}{l_{\mathit{eff}}\,(\text{mm})} \tag{1}$$

where l_{eff} is the effective length of the antenna.

The effective length of this antenna is given by:

$$l_{\mathit{eff}} = \sqrt[2]{\frac{\varepsilon_r + 1}{2}}\,(2R + Rc + g) \tag{2}$$

where

- ε_r is the dielectric relative permittivity, and $\frac{\varepsilon_r+1}{2}$ represents the effective permittivity.
- R is the radius of each one of the two circles that create the radiating element shown in Fig. 1.
- Rc is the effective radius of the radiating element considered as a cylinder.
- g is the gap between the radiating element and the ground plane (0.7 mm).

This antenna has an effective length of 32 mm which gives arise to a theoretical minimum working frequency of 2.25 GHz (see Equation (1)).

Figure 1 shows the geometry of the first polarization diversity antenna with its dimensions given by Table 1. Dark part of the figure represents the ground plane of the antenna.

Figure 2 shows the geometry of the polarization diversity antenna with two rejection filters that should work at the bands (5.1–6.0) GHz and (8.2–9.8) GHz, respectively. Dimensions are given in Table 2. The 5.5 GHz band reject filter consists of double U-shaped slots within the antenna feed line. The 9 GHz band reject filter consists of four L lines impressed near the antenna feeding line.

Table 1. Dimensions of the polarization diversity antenna of second type.

PARAMETER	W	L	M	Wl	R
Value (mm)	70	80	25	2.21	9.5

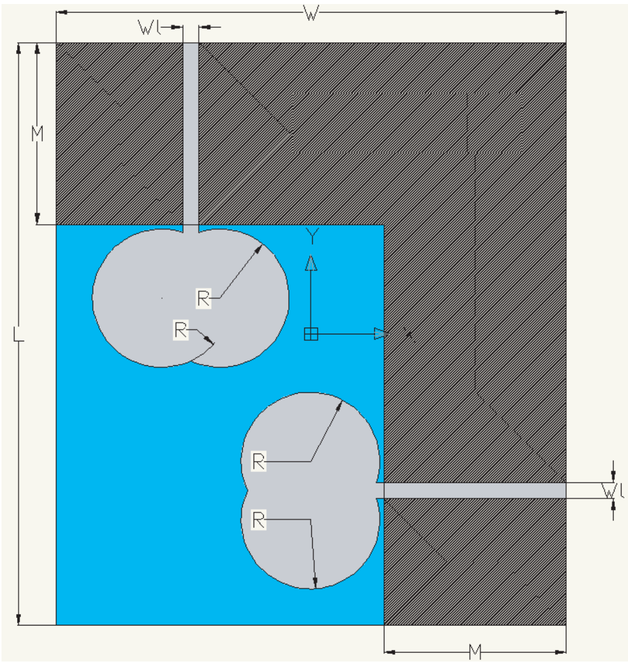


Figure 1. Geometry of the polarization diversity antenna without notched bands.

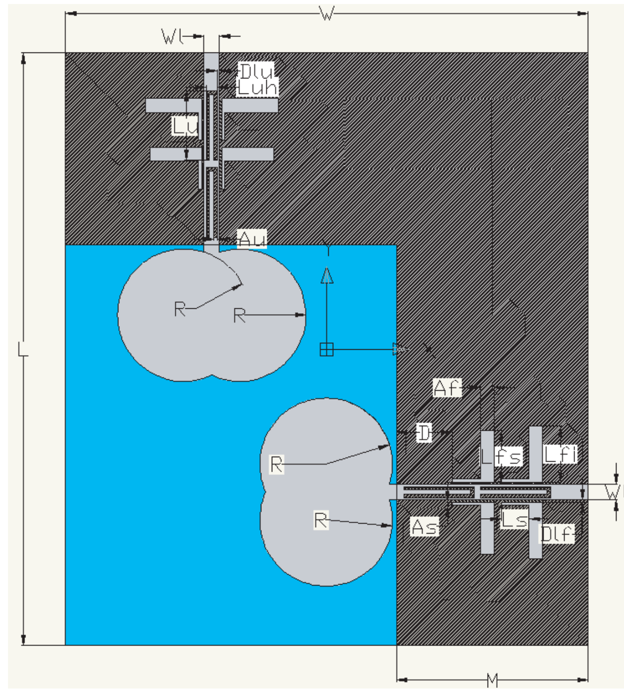


Figure 2. Geometry of the polarization diversity antenna with two rejection filters.

Table 2. Dimensions of the polarization diversity antenna with two rejection filters.

PARAMETER	W	L	M	W_l	R	D
Value (mm)	75	85	27.5	2.21	9.5	8

PARAMETER	L_{fs}	L_{f1}	L_s	A_f	A_s	L_u
Value (mm)	7.5	8.1	4	2	0.5	10

PARAMETER	L_{uh}	A_u	D_{lu}	D_{lf}
Value (mm)	1.61	0.5	0.3	0.3

The filter that rejects the (5.1–6.0) GHz band is a $\lambda_g/2$ inverted U-shaped slot within the feeding line. The effective length of the slot is given by:

$$l_{\mathit{eff}\text{-U}} = \sqrt[2]{\frac{\varepsilon_r + 1}{2}} Lt \tag{3}$$

where Lt is the total physical length of the inverted U slot. Considering a resonance frequency of 5.5 GHz, the effective length of the inverted U slot should be 27.27 mm. Thus the physical length should be 20.6 mm. The real physical length of the filter is almost $(2 * Lu + Luh - Au = 2 * 10 + 1.61 - 0.5 = 21.11\,\text{mm})$. Dark part of the figure represents the ground plane of the antenna.

Simulation shows that the degree of the overlapping influences the antenna performance in such a way that reducing it reduces the minimum operating frequency of the antenna (increases the effective length of the UWB antenna).

Figure 3 shows photographs of the fabricated first polarization diversity antenna.

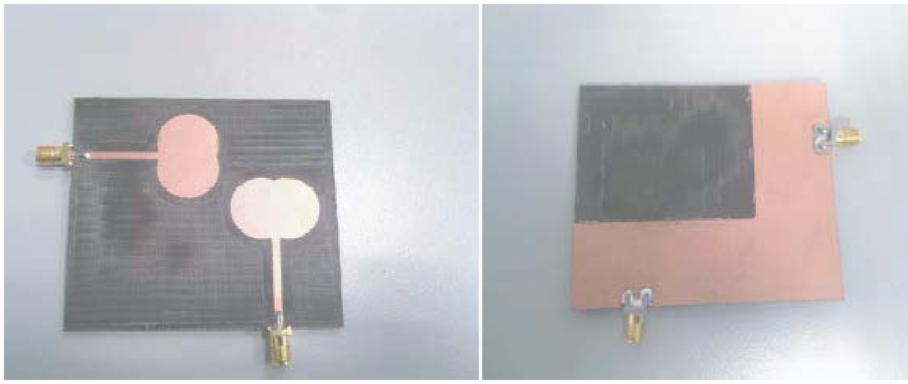


Figure 3. Photograph of the first polarization diversity antenna.

S parameters of the fabricated antennas are measured using Agilent E-5071C with maximum operating frequency of 20 GHz.

Figure 4 shows a comparison between the simulated and measured S_{11} of the antenna. It can be noticed that the fabricated antenna works well within the band (2.9–10.8) GHz, i.e., it has S_{11} lower than -10 dB in the above mentioned band.

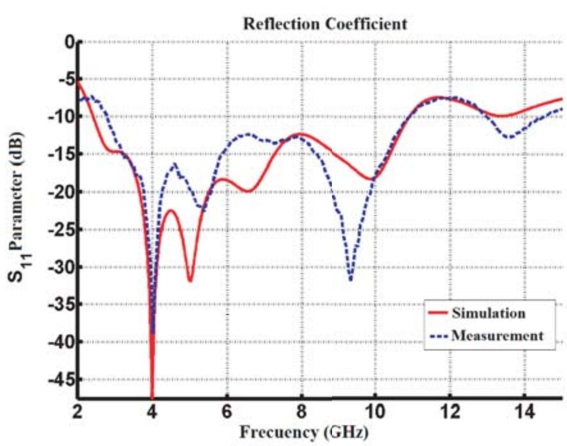


Figure 4. S_{11} of the first polarization diversity antenna.

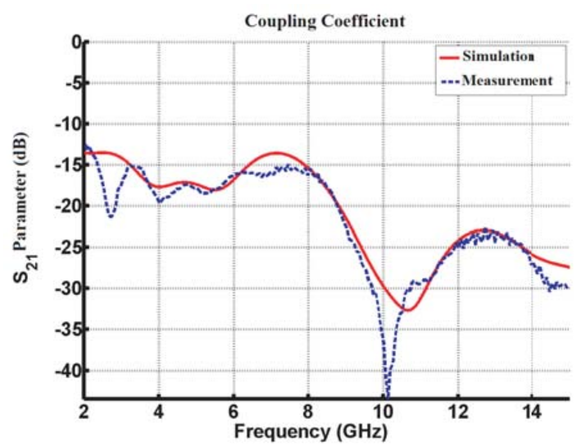


Figure 5. S_{21} of the first polarization diversity antenna.

Figure 5 shows a comparison between the simulated and measured S_{21} of the antenna. It can be noticed that the fabricated antenna works well (with an isolation higher than 15 dB) within the band (2.5–15.0) GHz.

The Envelope Correlation Coefficient (ECC) ρ of the MIMO antenna is given by:

$$\rho = \frac{|S_{11} * S_{12} + S_{21} * S_{22}|^2}{(1 - (|S_{11}|^2 + |S_{21}|^2))\,(1 - (|S_{12}|^2 + |S_{22}|^2))} \tag{4}$$

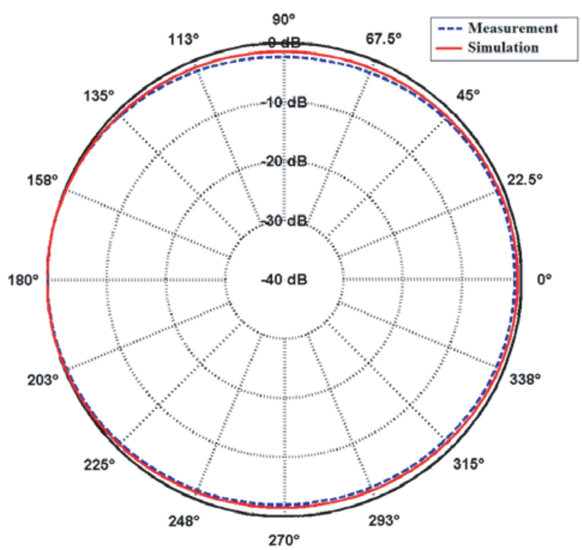
For $S_{11} = -10$ dB, $S_{22} = -10$ dB, $S_{21} = -15$ dB and $S_{12} = -15$ dB, worst case ECC is 0.0167.

In the band (3.1–10.6) GHz, the ECC is lower than 0.02, and the diversity gain is higher than 9.96 dB.

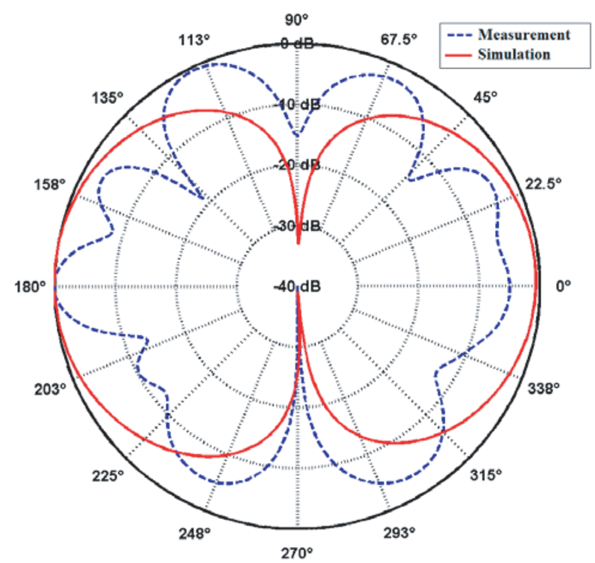
Radiation pattern of the UWB antennas has been measured using the anechoic chamber of the RFCAS group that works with a maximum frequency of 20 GHz.

Figure 6 shows the radiation pattern of the fabricated antenna at three frequencies. It can be noticed that that for the first frequency (4.0 GHz), the H-plane radiation pattern of the antenna is almost omnidirectional; meanwhile, it is not the case for the two higher frequencies (6.5 GHz and 9 GHz). This is because increasing the frequency will increase the relative width of the antenna (0.27λ, 0.44λ and 0.62λ at 4.0 GHz, 6.5 GHz and 9.0 GHz, respectively) and consequently the directivity of the antenna in the directions 0° and 180°. Only antennas with a cylindrical shape could have an omnidirectional radiation pattern in the H-plane. For the E-plane radiation pattern it can be noticed that the maximum points are almost at 0 and 180 degrees except the case of 6.5 GHz where one of the simulated maxima shifts to 22.5°.

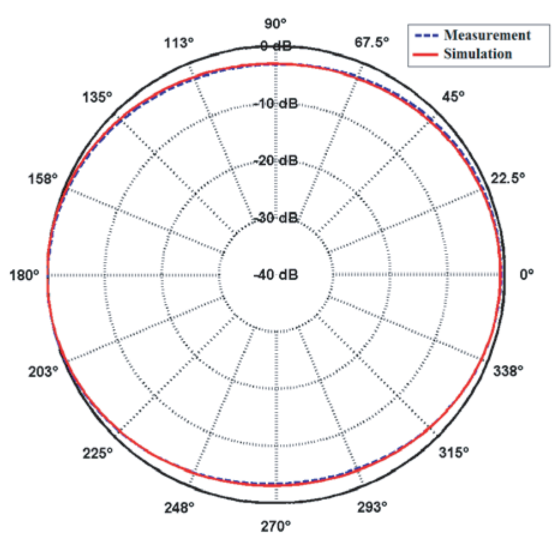
Figure 7 shows photographs of the fabricated polarization diversity antenna with two rejection filters.



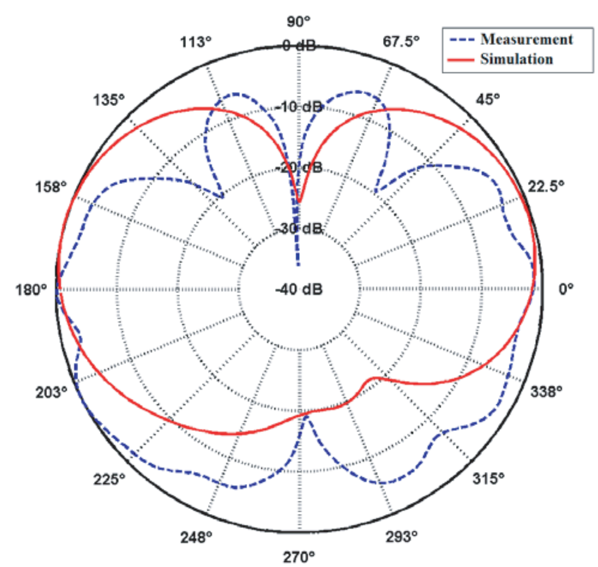
H-plane radiation pattern at 4.0 GHz



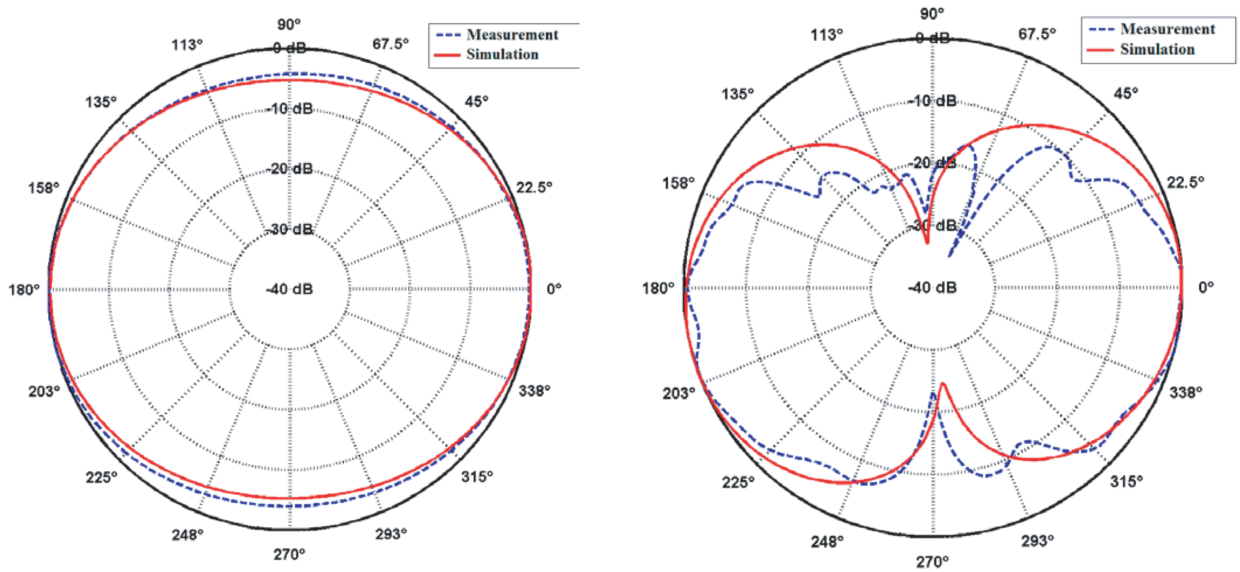
E-plane radiation pattern at 4.0 GHz



H-plane radiation pattern at 6.5 GHz



E-plane radiation pattern at 6.5 GHz



H-plane radiation pattern at 9.0 GHz

E-plane radiation pattern at 9.0 GHz

Figure 6. *H*-plane and *E*-plane radiation pattern at different frequencies.

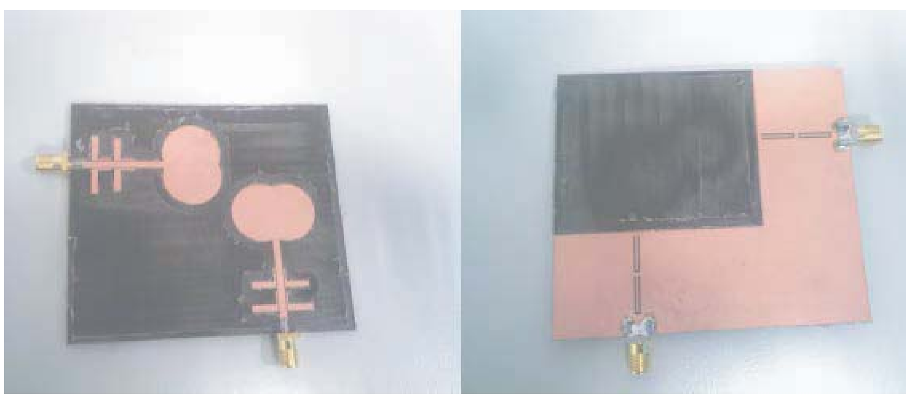


Figure 7. Photograph of the polarization diversity antenna with dual rejection filters.

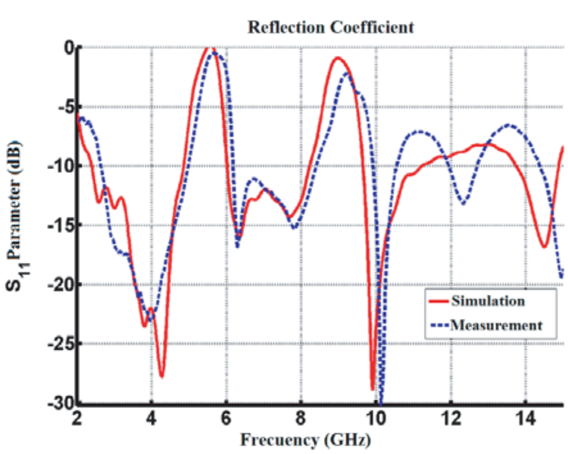


Figure 8. S_{11} of the polarization diversity antenna with two rejection filters.

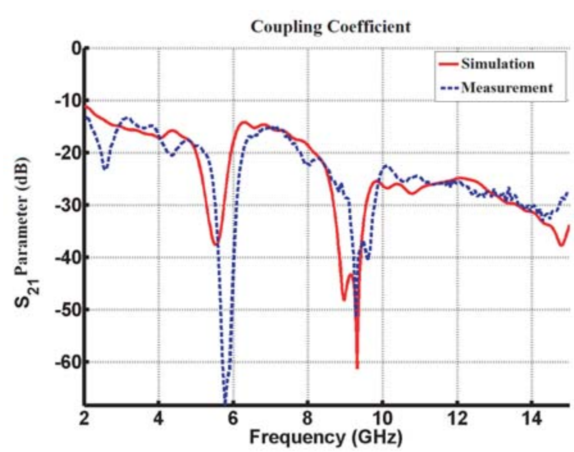


Figure 9. S_{21} of the polarization diversity antenna with two rejection filters.

Figure 8 shows a comparison between the simulated and measured S_{11} of the antenna. It can be noticed that the fabricated antenna works well within the band (2.8–10.6) GHz. Filters bands are shifted to higher frequencies. Increasing the length of the band reject filters a little bit makes them work in the desired bands.

Figure 9 shows a comparison between the simulated and measured S_{21} of the antenna. It can be noticed that the fabricated antenna works well (with an isolation higher than 15 dB) within almost the whole UWB.

Figure 10 shows the antenna gain with and without notch filters. Two notches can be noticed around 5.5 GHz and 9.2 GHz.

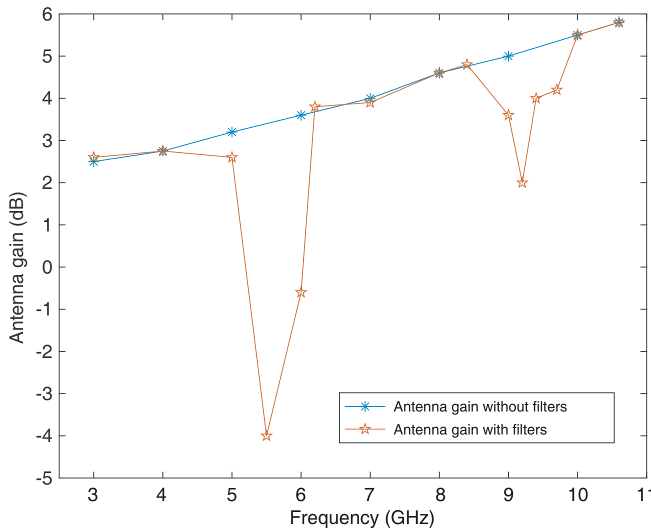


Figure 10. Antenna gain with and without the notch filters.

Table 3 shows a comparison of the proposed antenna with antennas given in references. Our antenna has isolation higher than 15 dB and two notched bands.

Table 3. Comparison of the proposed antenna with antennas given in references.

Reference	Dimensions (mm ∗ mm)	Notched bands	Isolation (dB)
[42]	22 ∗ 30	(5–6) GHz	> 15
[43]	20 ∗ 29	(3.3–3.6) GHz (5.15-5.85) GHz	− − −−
[44]	23 ∗ 30	(3.3–4.08) GHz (5.04–6.03) GHz	− − −−
[45]	40 ∗ 40	− − −−	− − −−
[46]	42 ∗ 50	(3.3–3.8) GHz (5.15–5.825) GHz (7.1–7.9) GHz	− − −−
[47]	26 ∗ 30	(3.3–3.6) GHz (5.1–5.8) GHz (7.25–7.75) GHz	− − −−
[48]	46 ∗ 27.2	− − −−	> 18
This work	70 ∗ 80	(5.0–6.1) GHz (8.4–9.9) GHz	> 15

3. CONCLUSIONS

In this work, a couple of UWB polarization diversity antennas have been presented. These antennas include a polarization diversity antenna without notched bands and polarization diversity versions with double bands reject filters. They work well within the whole UWB, i.e., (3.1–10.6) GHz band with reflection scattering parameters S_{11} and S_{22} lower than -10 dB and coupling scattering parameters S_{21} and S_{12} lower than -15 dB. The Envelope Correlation Coefficient is lower than 0.015.

APPENDIX A. UWB ANTENNA DESIGN CRITERIA

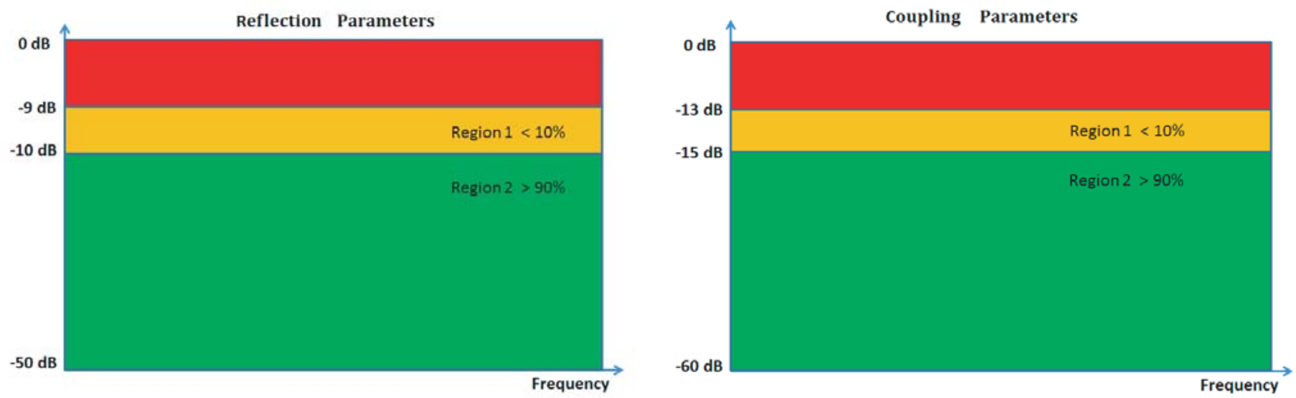


Figure A1.

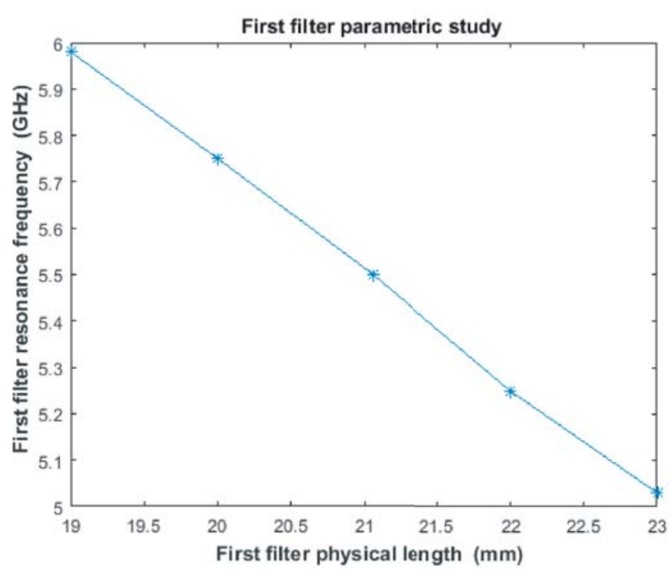


Figure A2. Parametric study of the first filter.

Table A1. Classes of polarization diversity antenna.

Class	Maximum S_{11} and S_{22}	Maximum S_{21} and S_{12}
First	< -10 dB	< -25 dB
Second	< -10 dB	< -20 dB
Third	< -10 dB	< -15 dB

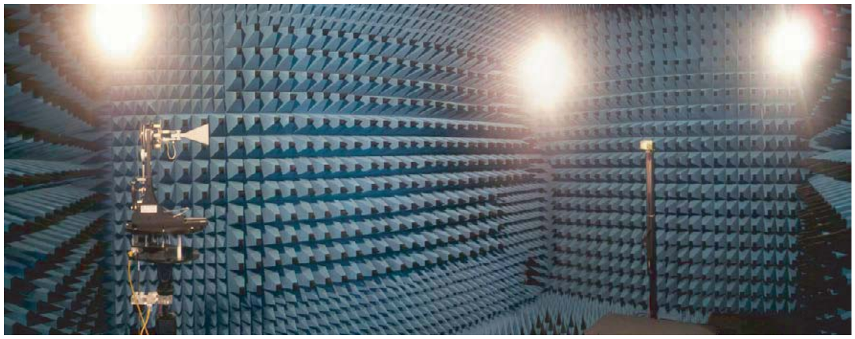


Figure A3. RFCAS group anechoic chamber.

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