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# UWB Antennas with Multiple Notched-Band Function

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**Abstract**—In this article, a monopole line-fed UWB antenna with different configurations is presented. Antennas have a shape of a big circle overlapped with four small circles. Configurations include single element antenna, single element antenna with dual band reject filters, and polarization diversity antenna version. CST software has been used in simulation process. Measurements show that all antennas work well within almost the whole UWB. The polarization diversity version has a practical port isolation ($S_{12}$ and $S_{21}$) better than $-15$ dB, an Envelope Correlation Coefficient lower than 0.019 and a diversity gain higher than 9.96 dB.

## 1. INTRODUCTION

A given communication system is considered as ultra-wideband (UWB) system when it has a large relative bandwidth (20% or higher) or a large absolute bandwidth (500 MHz or higher) or both of them. 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]. Thus, the total Effective Isotropic Radiated Power within the whole UWB should be lower than $-2.55$ dBm (typically lower than $-8$ dBm).

UWB antenna can be designed as monopoles, dipoles or even logarithmic one. UWB communication systems operating in (3.1–10.6) GHz could be easily interfered by one or more of the nearby communication systems such as WiMAX communication system operating at (3.3–3.7) GHz, WLAN system operating at the lower part or the upper part of the (5.15–5.85) GHz band and X-band downlink communication frequency operating at (7.10–7.76) GHz. The interferences of UWB systems with these communication systems can be avoided by using the band reject filers within UWB receivers. This is a problematic solution since it increases size and complexity of the UWB receiver. The optimum way to mitigate the mutual interference with other systems is to utilize UWB antenna having band reject filters within it. UWB antennas were designed and fabricated without notched band, with only single notched band or more notched bands [2–8].

To mitigate multipath fading or cross polarization, antenna diversity is used as an effective solution to this problem. Polarization diversity has been proposed and implemented [9]. A good UWB polarization diversity antenna should have low mutual coupling between its elements, i.e., high isolation (higher than 15 dB) between its ports.

In this work, various UWB antennas having dual notched bands will be presented giving their practical performance.

The rest of the work is organized as follows. In Section 2, the design of the UWB antennas is given. In Section 3 the practical performance of the UWB antennas is given. In Section 4, conclusions are addressed.

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## 2. DESIGN OF UWB ANTENNAS

UWB antenna can be implemented as monopole antenna, diploe antenna or log-periodic antenna. In this article, a monopole UWB antenna is designed and manufactured.

To have a UWB antenna with a good performance [$S_{mm}$ (where $m$ is the port index) is lower than $-10$ dB] within the UWB of (3.1–10.6) GHz, the first theoretical resonance frequency of the antenna should be 3.0 GHz or lower.

The first resonance frequency of the UWB antenna $f_r$ is given by:

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

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

Thus the monopole UWB antenna should be designed to have an effective length at least $0.24\lambda$ (24 mm) at 3 GHz. If the antenna is used to reject the interference of the WiMAX signal within the band (3.3–3.7) GHz, the UWB monopole antenna (with lower operating frequency of 3.7 GHz) should have an effective length of 19.5 mm or little bit lower. Possible $S_{11}$ of such antennas is given by Fig. 1.

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

The $S$ parameters measurement is carried out using the Vector Network Analyzer E5071C of Agilent, operating up to 20 GHz. The radiation pattern is measured using an echoic chamber with instruments that work up to 12.5 GHz.

For simple single element antennas, the parameter $S_{11}$ should be lower than $-10$ dB. In the case of the two elements polarization diversity antennas, $S_{11}$ and $S_{22}$ should be lower than $-10$ dB, and the coupling parameters $S_{21}$ and $S_{12}$ should be lower than $-15$ dB [9].

In this section, a couple of monopole line-fed UWB antennas with different versions will be presented.

Firstly a UWB antenna that consists of a big circle overlapped with 4 small circles will be studied.

The first version of the UWB antenna shown in Fig. 1 is a single element antenna. Its optimum physical dimensions are given in Table 1.

**Table 1.** Dimensions of the single element UWB antenna.

| PARAMETER | $L$ | $W$ | $M$ | $W_l$ | $R_e$ | $R_s$ | $R_1$ |
|---|---|---|---|---|---|---|---|
| VALUE (mm) | 41.67 | 30 | 15 | 2 | 9.5 | 3 | 2 |

The antenna consists of a radiating element, feeding line and ground plane. The feeding line has a width of 2 mm with an impedance of almost 50 ohms.

The effective length of this antenna is given by:

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

where

- $\varepsilon_r$ is the permittivity of the dielectric material used to fabricate the antenna.
- $Re$ is a dimension shown in Fig. 1.
- $R$ is the effective radius of the radiating element when it is considered as a cylinder.
- $G$ is the gap between the radiating element and the ground plane (0.7 mm).

The four small circles increase the effective radius of radiating element. The calculated effective length of the antenna is 29 mm, which gives a theoretical first resonance frequency of 2.5 GHz.

Figure 2 shows the single element antenna with two rejection filters designed to work at the bands (5.1–5.9) GHz and (8.2–10.0) GHz, respectively. Physical dimensions of this antenna are given in Table 2.

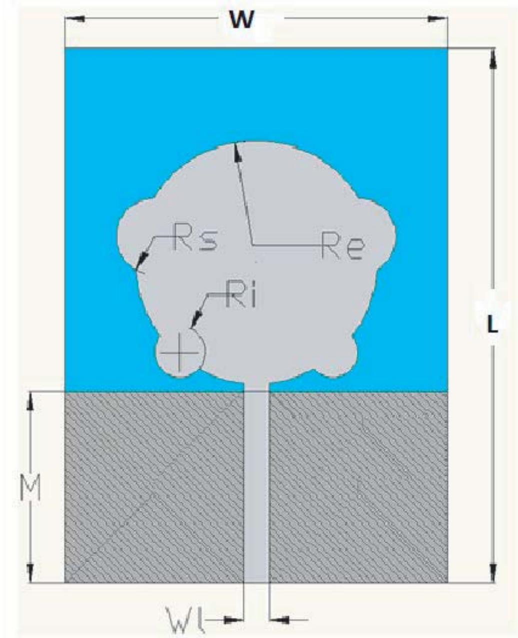



**Figure 1.** Geometry of the single element UWB antenna.

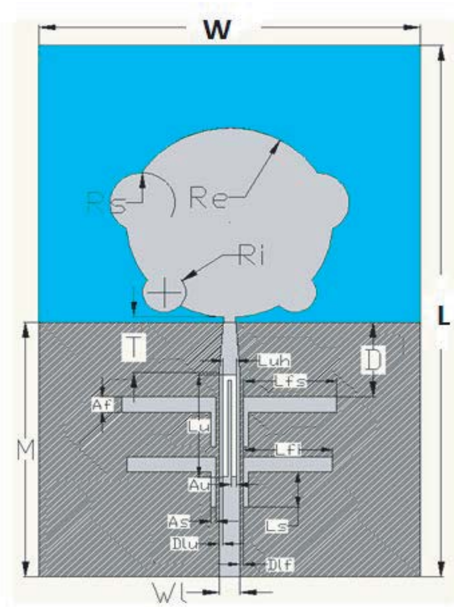



**Figure 2.** Geometry of the single element UWB antenna with dual band reject filter.

**Table 2.** Dimensions of the single element UWB antenna with dual band reject filters.

| PARAMETER | $L$ | $W$ | $M$ | $W_l$ | $R_e$ | $R_s$ | $R_i$ | $T$ | $D$ |
|---|---|---|---|---|---|---|---|---|---|
| VALUE (mm) | 53.25 | 35 | 25.5 | 1.9 | 9.5 | 3 | 2 | 6 | 17.5 |

| PARAMETER | $L_{fs}$ | $L_{fi}$ | $A_f$ | $A_s$ | $L_u$ | $L_{uh}$ | $A_u$ | $D_{lu}$ | $D_{lf}$ |
|---|---|---|---|---|---|---|---|---|---|
| VALUE (mm) | 8.6 | 8.2 | 3.5 | 0.5 | 10.2 | 1.3 | 0.5 | 0.3 | 0.3 |

The filter that rejects the (5.1–5.9) GHz band is a $\lambda_g/2$ inverted U-shaped slot within the feeding line. The effective length of the slot is given by:

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

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. A parametric study of this filter is done. Its resonant frequency as a function of its physical length is shown in Fig. 4.

The filter that rejects the (8.2–10.0) GHz band consists of four L-shaped lines near the antenna feeding line. Due to the capacitance created between the filters and the antenna feed line, $L_{fs}$ and $L_{fi}$ should have a length longer than $\lambda/4$. It can be noticed that the lengths $L_{fs}$ and $L_{fi}$ are little bit different. This has been done to have two little bit different resonance frequencies getting larger operating bandwidth of the second filter.

Figure 3 shows the polarization diversity antenna. Dimensions are given in Table 3.

Figure 4 shows the polarization diversity antenna with two rejection filters designed to work at the bands (5.1–5.9) GHz and (8.2–10.0) GHz, respectively. The (5.1–5.9) GHz filter consists of dual U-shaped slots. Physical dimensions of the antenna are given in Table 4.

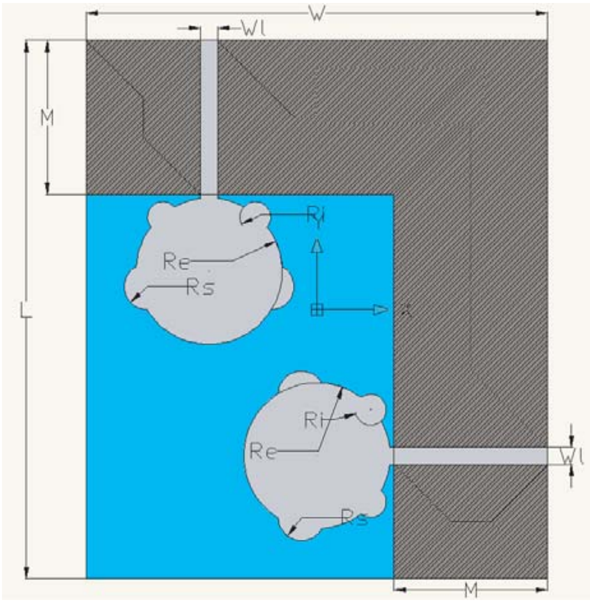



**Figure 3.** Geometry of the polarization diversity UWB antenna.

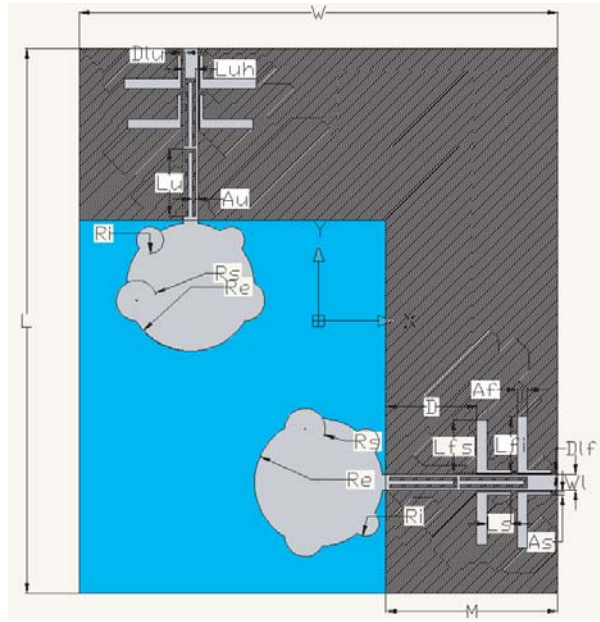



**Figure 4.** Geometry of the polarization diversity UWB antenna with dual band reject filter.

**Table 3.** Dimensions of the polarization diversity UWB antenna.

| PARAMETER | $W$ | $L$ | $M$ | $W_l$ | $R_e$ | $R_s$ | $R_i$ |
|---|---|---|---|---|---|---|---|
| Value (mm) | 60 | 70 | 20 | 2.21 | 9.5 | 3 | 2 |

**Table 4.** Dimensions of the polarization diversity UWB antenna with dual band reject filter.

| PARAMETER | $W$ | $L$ | $M$ | $W_l$ | $R_e$ | $R_s$ | $R_i$ |
|---|---|---|---|---|---|---|---|
| Value (mm) | 71 | 81 | 25.5 | 2.21 | 9.5 | 3 | 2 |

| PARAMETER | $D$ | $L_{fs}$ | $L_{fi}$ | $L_s$ | $A_f$ | $A_s$ | $L_u$ |
|---|---|---|---|---|---|---|---|
| Value (mm) | 13.5 | 7.9 | 8.4 | 3.5 | 1.5 | 0.5 | 10 |

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

## 3. RESULTS

Figure 5 shows the fabricated single element UWB antenna.

Examining the simulated and measured $S_{11}$ depicted in Fig. 6, it can be noticed that the fabricated antenna has an impedance band (band with $S_{11}$ better than $-10$ dB) of (3.7–10.7) GHz; meanwhile, the simulated antenna has a working band of (2.9–11.2) GHz.

The radiation pattern of the fabricated antenna at three frequencies is given by Fig. 7. It can be seen that the horizontal ($H$-plane) radiation pattern of the antenna at 4 GHz is almost omnidirectional while it is not for the two higher frequencies. This is because increasing the operating frequency will increase the directivity of the UWB monopole antenna in the 0° and 180° directions (vertical to the antenna plane). Deviation between simulated and measured patterns is very small. The vertical ($E$-plane) radiation pattern has a shape of 8 with maximum points almost at 0 and 180 degrees. Deviation between the simulated and measured $E$-plane radiation patterns is due to the measurement system including the feeding rigid cable connected to the SMA connector.

Cutting the external parts of the fabricated antenna to get an antenna with a width of 24 mm and length of 36 mm has a very small effect on its practical performance.

Figure 8 shows the fabricated single element antenna with two rejection filters.

Figure 9 depicts the simulated and measured $S_{11}$ of the antenna. It can be seen that the fabricated antenna work well within the band (3.1–11.2) GHz. It can be noticed that the center frequency of the band reject filters has a mall frequency shift to higher frequencies. The frequency shift of the rejected band may be because the dielectric constant decreases a little bit with the increment of the frequency. Increasing the length of the band reject filters a little bit will make them work in the desired bands. The frequency of the simulated first point of operation is 2.4 GHz; meanwhile, the practical one is 3.1 GHz.

Here also, cutting the external parts of the fabricated antenna to get an antenna with a width of 24 mm and length of 40 mm has a very small effect on its practical performance.

Figure 10 shows the single element antenna gain with and without notch filters. It can be noticed that the filter reduces the gain by 7 dB while the second filter has 6.2 dB gain reduction effect.

Table 5 shows a comparison among our presented UWB antenna and some other reported two band notched UWB antennas. It can be noticed that our second antenna is one of the best UWB antennas.

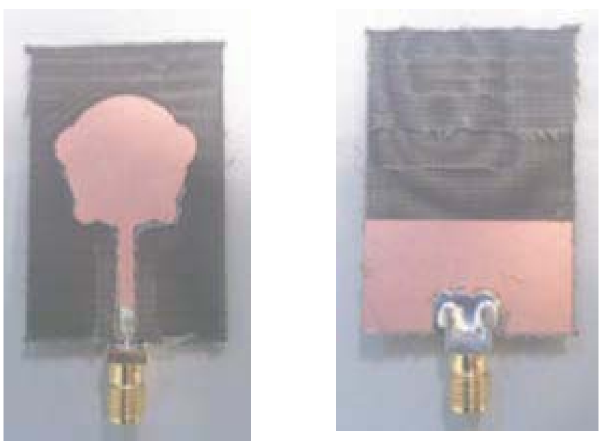


**Figure 5.** Photograph of the fabricated single element UWB antenna.

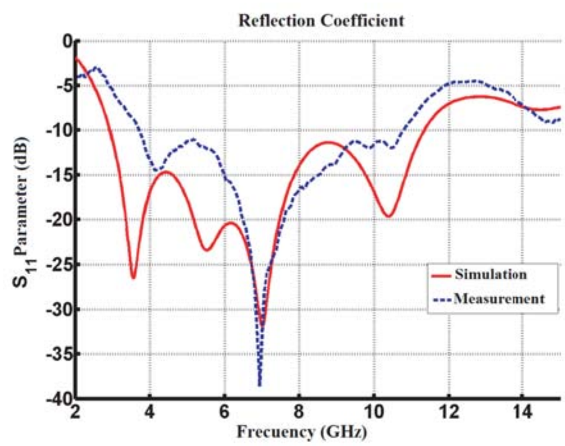
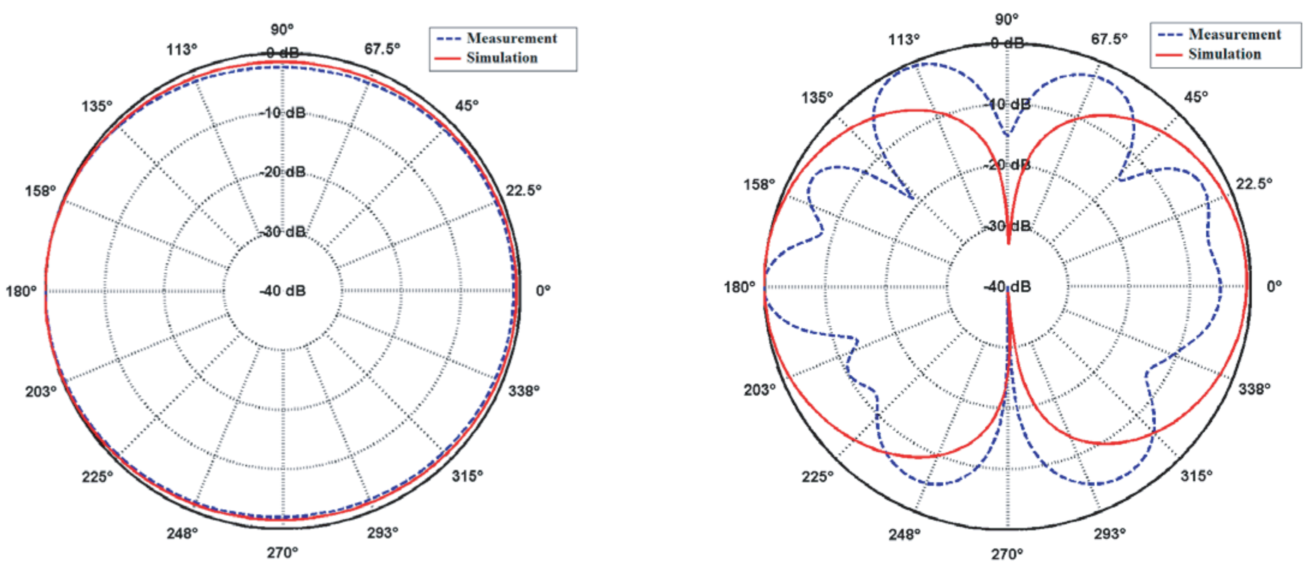
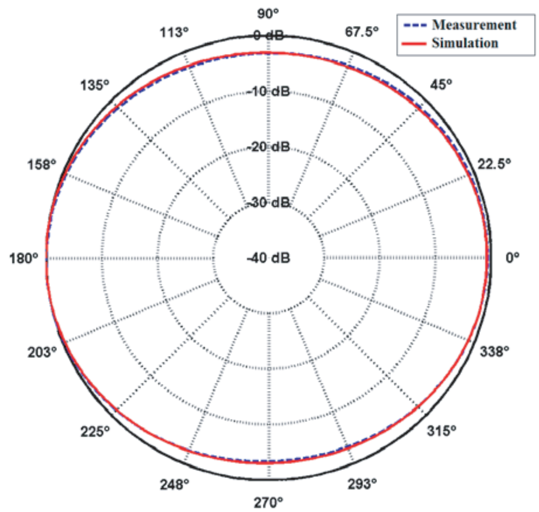



**Figure 6.** $S_{11}$ of the UWB antenna (single element version of first type).

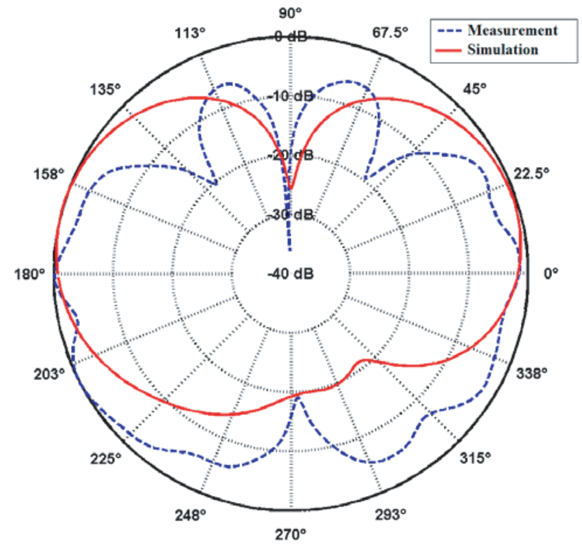



Azimuth radiation pattern at 4.0 GHz

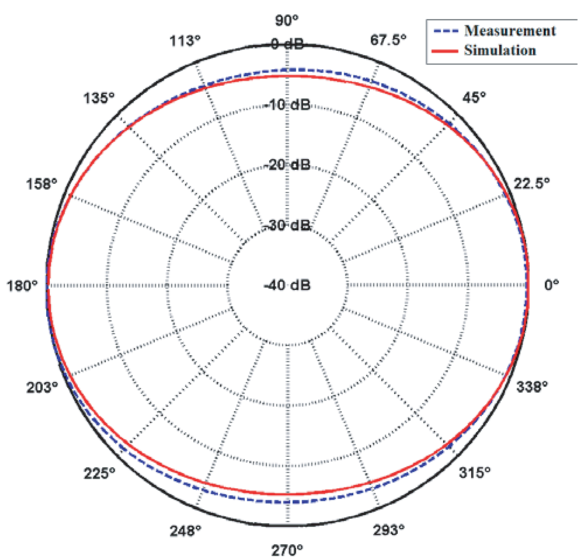
Elevation radiation pattern at 4.0 GHz



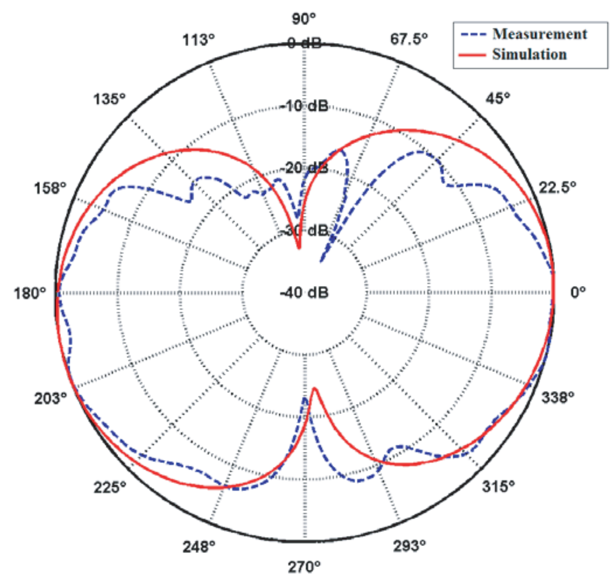

Azimuth radiation pattern at 6.5 GHz




Elevation radiation pattern at 6.5 GHz




Azimuth radiation pattern at 9.0 GHz




Elevation radiation pattern at 9.0 GHz

**Figure 7.** Azimuth and elevation radiation pattern at three different frequencies.

**Table 5.** Comparison of UWB antennas.

| Work | Working band (GHz) | Notched bands (GHz) | Dimensions (mm) |
|---|---|---|---|
| REF. [10] | 2.8–9.0 | 3.5 and 5.5 | $35 * 26$ |
| REF. [11] | 3.1–10.6 | 3.5 and 5.5 | $36 * 36$ |
| REF. [12] | 2.9–10.2 | 3.5 and 5.5 | $35.5 * 30$ |
| REF. [13] | 3–11 | 3.6 and 5.5 | $31 * 31$ |
| Our work | 3.1–11.2 | 5.5 and 9 GHz | $53.25 * 35$ |
| Our work | 3.1–11.0 | 5.5 and 9 GHz | 36*24 |

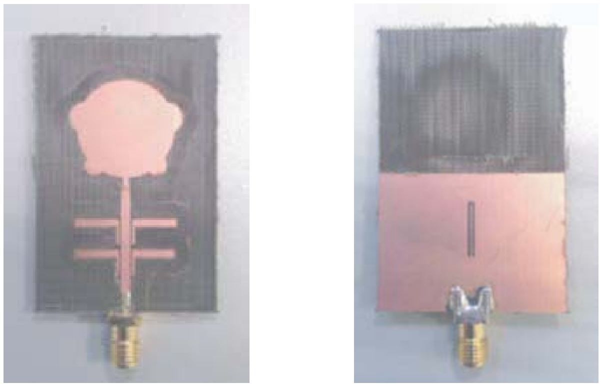


**Figure 8.** Photograph of the fabricated single element UWB antenna with dual band reject filters.

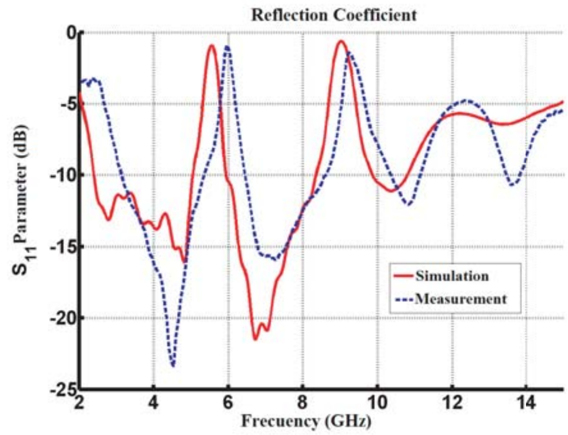



**Figure 9.** $S_{11}$ of the fabricated single element UWB antenna with dual band reject filters.

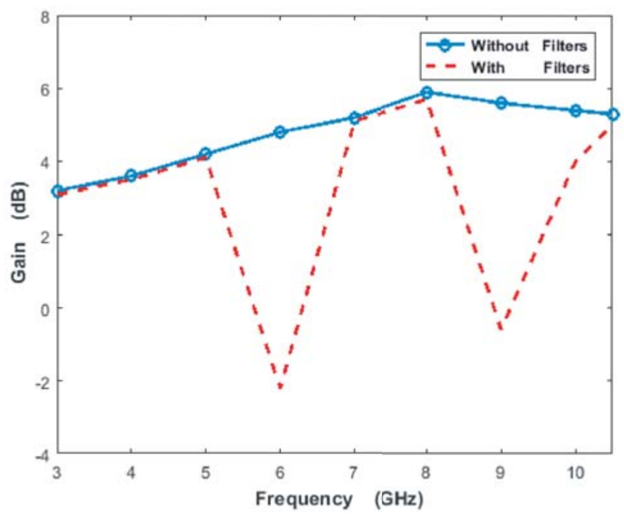



**Figure 10.** Single element antenna gain with and without notch filters.

**Figure 11.** Photograph of the polarization diversity UWB antenna.

Figure 11 shows the fabricated polarization diversity antenna of the first type of antenna.

Figure 12 shows the simulated and measured $S_{11}$ of the antennas. It can be noticed that the fabricated antenna works well within the band (3.5–10.5) GHz.

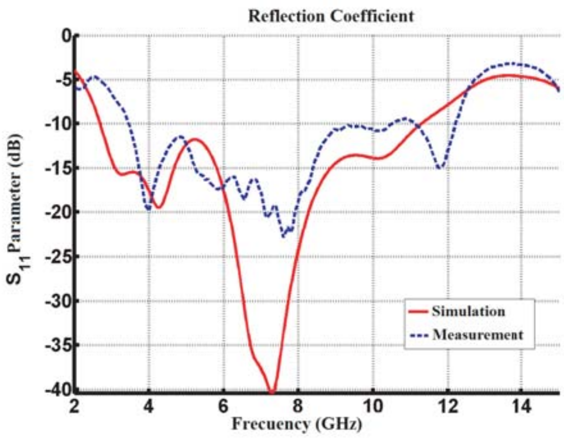



**Figure 12.** $S_{11}$ of the polarization diversity UWB antenna.

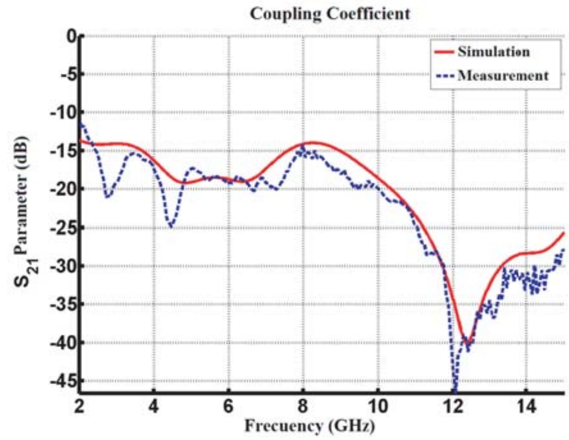



**Figure 13.** $S_{21}$ of the polarization diversity UWB antenna.

Figure 13 shows the simulated and measured $S_{21}$ of the antenna. It can be seen that the fabricated antenna works well (with an isolation higher than 15 dB) within the band (2.5–15) GHz.

The Envelope Correlation Coefficient $\rho$ of the MIMO antenna is given by:

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

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

For the band (3.5–10.6) GHz, the ECC is lower than 0.019, and the diversity gain is higher than 9.96 dB. It is believed that introducing a metallic line between the radiating elements of the antenna will increase isolation up to 20 dB, i.e., $S_{21}$ lower than $-20$ dB.

## 4. CONCLUSIONS

In this article, a monopole line-fed UWB antenna with different configurations is presented. Antennas have a shape of a big circle overlapped with four small circles. Configurations include single element antenna, single element antenna with dual band reject filters, and polarization diversity antenna version. Measurements show that all antennas work well within almost the whole UWB. The polarization diversity version has a practical port isolation ($S_{12}$ and $S_{21}$) better than $-15$ dB, an Envelope Correlation Coefficient lower than 0.019 and a diversity gain higher than 9.96 dB.

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