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High Gain UWB Antenna Element Design for Cognitive Radio Systems using Low Cost FR4 Substrate

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Abstract

In cognitive radio (CR) and Ultra Wideband (UWB) communication systems, one of the keys issues is designing a compact antenna while providing wideband characteristic over the entire operating band. In these systems, printed wide slot antennas have received much attention owing to their wideband matching characteristics and omnidirectional radiation patterns. In addition they present really appealing physical features, such as simple structure, small size and low cost. In this paper, a small antenna with circular radiating patch and defected ground structure for UWB applications is proposed. The proposed antenna provides a wideband frequency range from 1.17 GHz to more than 12 GHz. But, its maximum allowable gain is low and equals 2.78 dBi. In order to increase the antenna gain while maintaining the same impedance matching characteristics, a plane reflector is placed beneath the antenna at a specific distance d. The plane reflector reflects the backward radiated power again towards the antenna to be constructively added to the forward radiated power. In this case, the modified antenna radiated power is significantly increased and the maximum allowable antenna gain is also increased up to 7.67 dBi which is 2.75 times greater than the gain of the antenna without reflector. In addition, the modified antenna exhibits 51% to 95% radiation efficiency over the operating frequency range. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. The antenna is designed using the CST Microwave Studio software using low cost FR4 (lossy) substrate with $\varepsilon_r = 4.3$ and $h = 1.6\,mm$. Simulated and experimental results are presented to demonstrate the effective performance of the proposed antenna.

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* Corresponding author.

Keywords: Microstrip Antenna; Ultra Wide Band Antenna (UWBA); Cognitive radio (CR).

1. Introduction

Recently, the Ultra Wide Band (UWB) wireless technology is one of the most effective and flexible solutions for future communications issues, because it provides high data rate and excellent immunity to multi-path interferences. The federal communication commission (FFC) has arranged the use of $3.1\ GHz$ to $10.6\ GHz$ frequency band for Ultra Wide band communications [1]. The UWB antennas are widely used in several application such as high data rate Personal Area Network, cognitive radio systems, medical and radar imaging. Hence, the most common problems that obstructs while designing UWB antennas is to achieve good gain-bandwidth characteristic with reduced size and cost. Several broadband antenna designs have been recently developed [2-5]. A new design for UWB antenna with a promising result has been introduced in [6]. It exhibits a gain with maximum value of $8\ dBi$ and broad band with percentage bandwidth of 154%. The paper introduced a simple monopole antenna with circular ring patch on a glass epoxy (FR4) substrate. A hexagonal shaped ground plane is utilized. The radiating patch is fed using microstrip line. This monopole antenna can radiate at the frequency ranges 1.94 GHz to 13.84 GHz and 1.82 GHz to 12.25 GHz, respectively [6]. Also a reconfigurable UWB antenna with defected ground structure is introduced in [7]. The defected ground structure technique increases the bandwidth of the proposed antenna structure. This paper focused on reconfigurability. Ying song Li et.al, designed antenna with ultra-wide band from 3.1 GHz to 10.6 GHz for cognitive radio application [8]. In this paper, a simple UWB microstrip circular patch antenna with operating frequency range extending from 1.17 GHz to more than 12 GHz is introduced. The wide slot defected ground structure allows wideband matching characteristics and omnidirectional radiation patterns. But, it provides low antenna gains. In order to increase the antenna gain while maintaining the same impedance matching characteristics, a plane reflector is placed beneath the antenna at an optimized distance d. The plane reflector reflects the backward radiated power again towards the antenna to be constructively added to the forward radiated power. In this case, the modified antenna radiated power is significantly increased and the antenna gain is also increased.

2. Proposed UWB Antenna Design

In this section, a small UWB antenna with circular radiating patch and defected ground structure for cognitive radio spectrum sensing applications is proposed. The desired wideband matching characteristic is achieved using the well-known defected ground structure DGS technique. But, the DGS provides low antenna gains. In order to increase the antenna gain, a large copper reflecting plane is mounted at a distance$d$ from the radiating patch. To clarify the basic idea behind of the proposed antenna, we start from a simple circular radiating patch with wide slot DGS as shown in Figure (1). The antenna is printed on FR4 (lossy) substrate with relative permittivity $\varepsilon_r = 4.3$, thickness $h = 1.6\ mm$, and loss tangent of $\delta = 0.025$. L, W, F, R, D, and a are the antenna dimensions whose values are reported in Table 1. The simulated scattering parameter$|S_{11}|$ of the antenna is depicted in Figure (2). It provides an ultra-wideband impedance bandwidth that extends from 1.17 GHz to more than 12 GHz where $|S_{11}|$ is below $-10dB$. Different radiation patterns of the proposed antenna without reflecting plane at various frequencies are depicted in Table 2. The radiation efficiency and total efficiency of the antenna are calculated over the operating frequency range as shown in Figure (3). Also the antenna gains are calculated over the entire bandwidth as shown in Figure (4). The simulation results revealed that the antenna has low gain. It has positive gain only in two narrow frequency ranges denoted as range 1 and range 2 as shown in Figure (4). Range 1 and range 2 extend from $1.17GHz$ to $3.6GHz$ and from $9.84GHz$ to $12\ GHz$ respectively. The maximum achievable antenna gain is $2.78\ dBi$ at $f\ = 2.1GHz$.

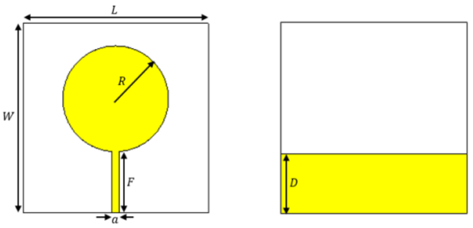


Figure 1: Configuration of the proposed UWB antenna designed using the CST microwave studio software.

Table 1: Antenna dimensions

	L	W	F	R	D	a
Dimension in mm	$84\ mm$	$86\ mm$	$27.849\ mm$	$24\ mm$	$27\ mm$	$3.08\ mm$

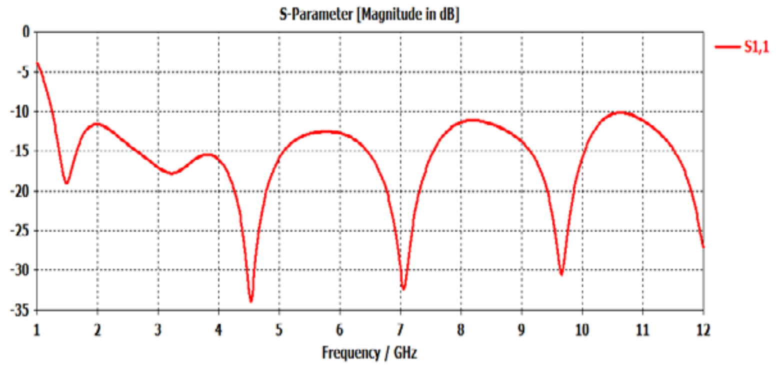


Figure 2: Simulated scattering parameter $|S_{11}|$of the traditional UWB antenna element.

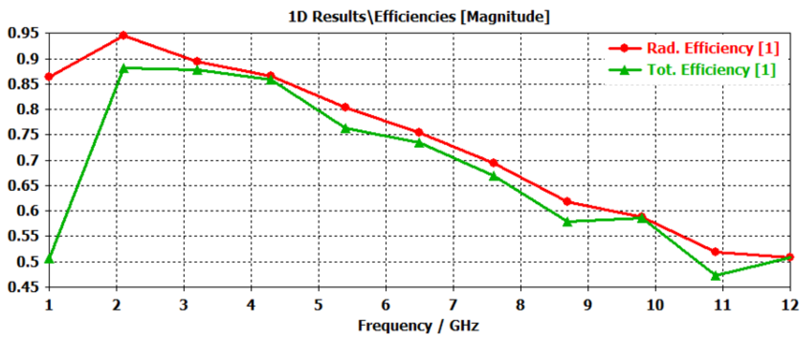


Figure 3: The simulated radiation efficiency of the proposed antenna element.

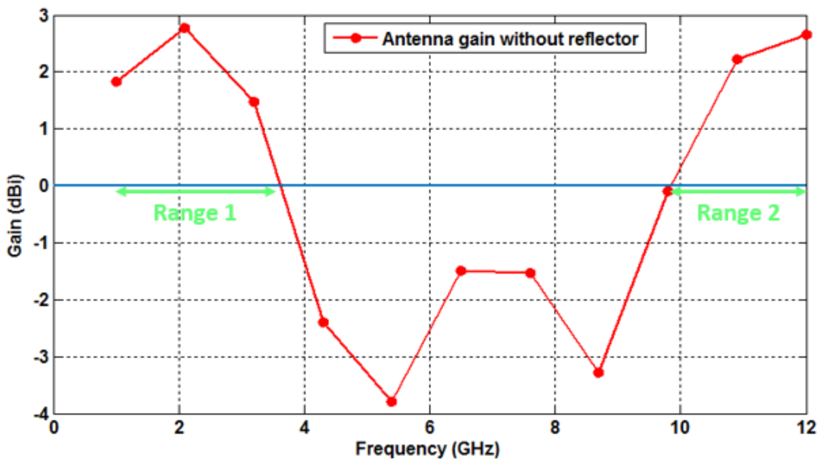


Figure 4: The calculated antenna gains of the proposed antenna without reflecting plane.

3. Modified Ultra Wide Band Circular Patch Antenna Element Design

To overcome the gain problem of the previous antenna a reflecting plane made from copper is placed at a specific distance from the antenna as shown in Figure (5). The reflecting plane reflects the backward power towards the antenna to be constructively added to the forward radiated power. In this case, the antenna radiated power is concentrated in the forward direction and the antenna gain is also increased. The reflector is made from $(172 \times 172)mm^2$ FR4 (lossy) substrate with relative permittivity $\varepsilon_r = 4.3$, thickness $h = 1.6\,mm$, and loss tangent of $\delta = 0.025$ coated with thin copper layers. Using CST Microwave studio, the optimized distance at which the reflecting plane is placed is $d = 50mm$ from the antenna element. The simulated scattering parameter $|S_{11}|$ of the modified antenna is shown in Figure (6). It provides an ultra-wideband impedance bandwidth that extends from 1.17 GHz to more than 12 GHz where $|S_{11}|$ is below $-10dB$. In addition, the modified antenna exhibits 51% to 95% radiation efficiency over the operating frequency range as shown in Figure (7). Compared to the ordinary antenna, the modified antenna provides positive gain over the entire operating frequency range as shown in Figure (8). The modified antenna radiated power is significantly increased and the maximum achievable antenna gain is also increased up to $7.67\ dBi$ which is 2.75 times greater than the gain of the antenna without reflector. To verify the reflecting plane effect on the antenna radiation pattern, different radiation patterns of the antenna with reflecting plane at various frequencies are depicted in Table 2.

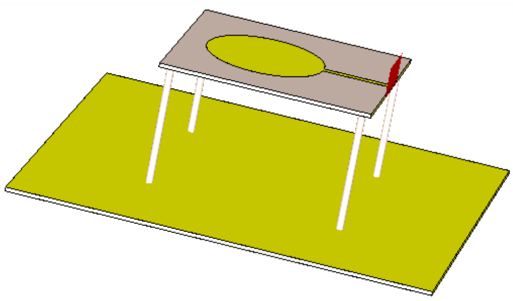


Figure 5: The design of the modified antenna element with reflecting plane placed at $d = 50mm$ from the antenna element.

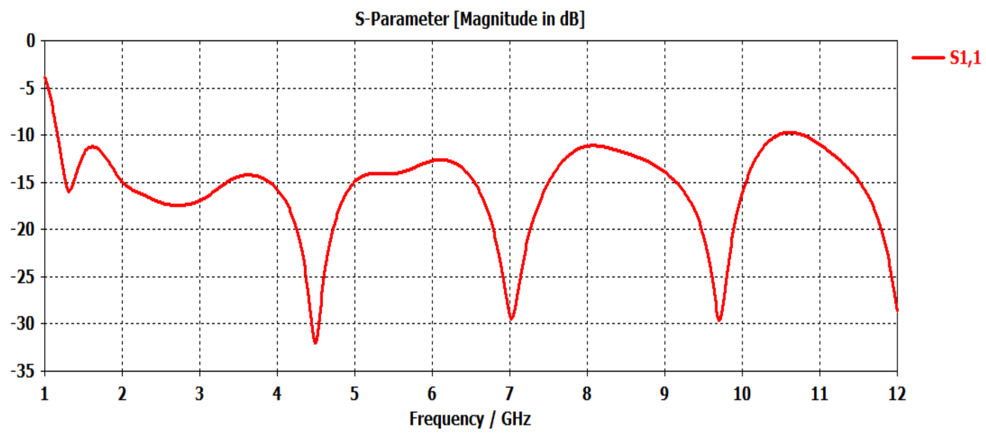


Figure 6: The scattering parameter $|S_{11}|$of the modified UWB antenna element using the CST Microwave Studio.

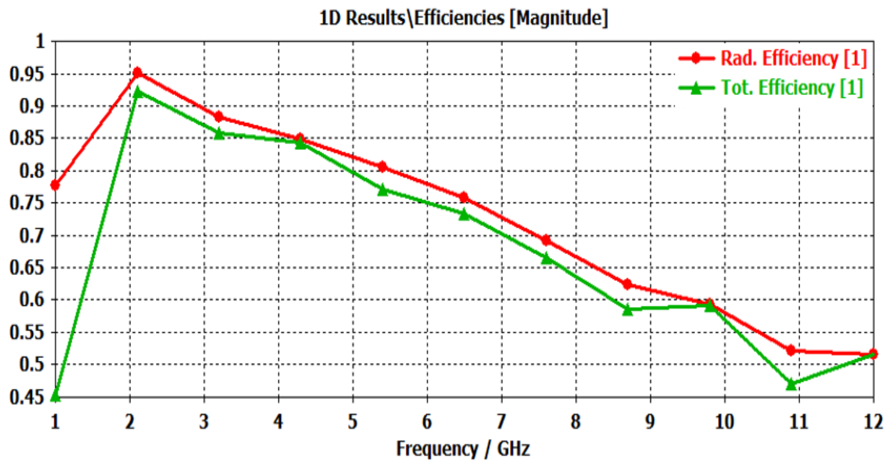


Figure 7: The radiation efficiency of the modified UWB antenna element using the CST Microwave Studio.

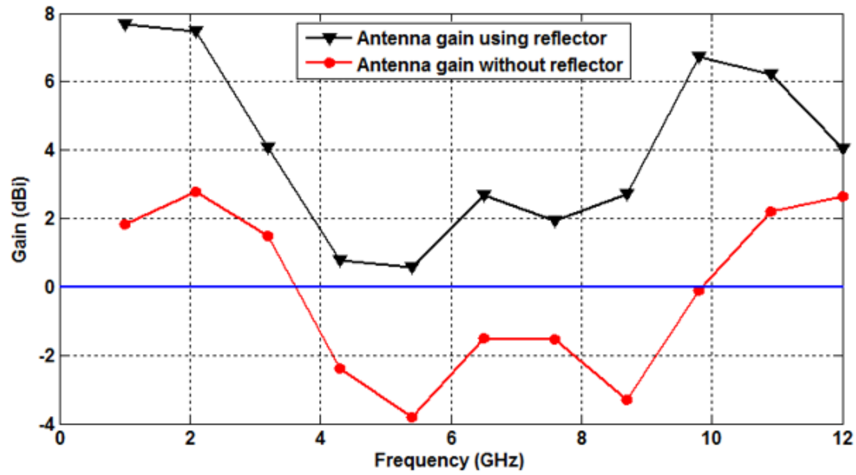
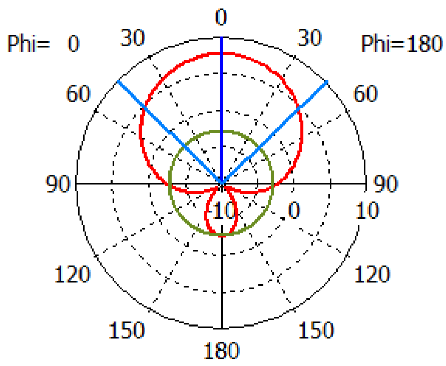
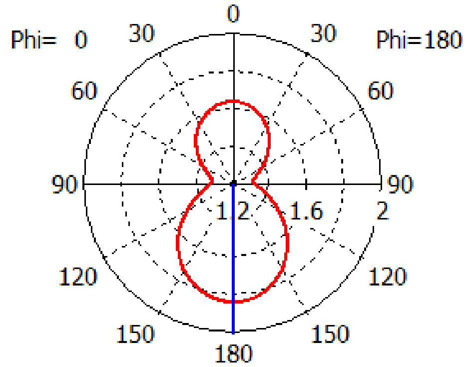
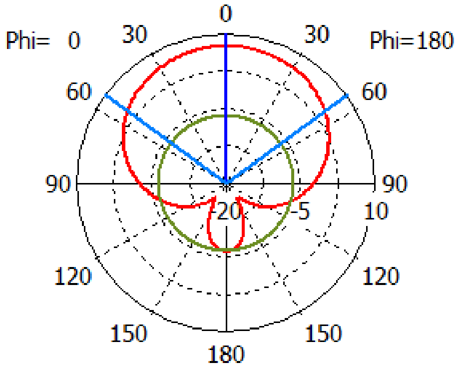
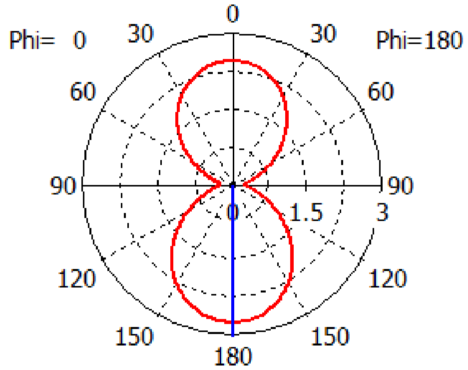
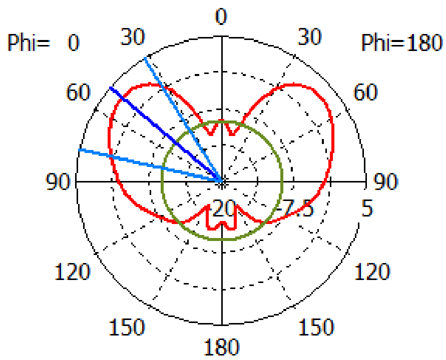
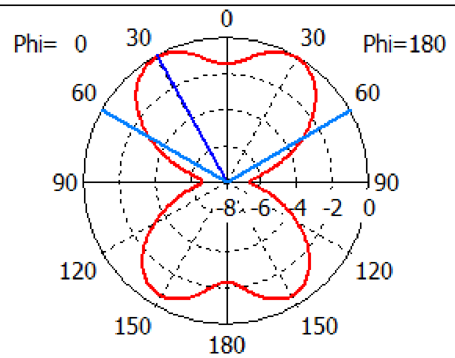
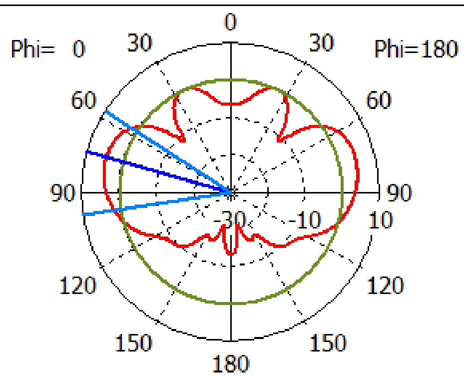
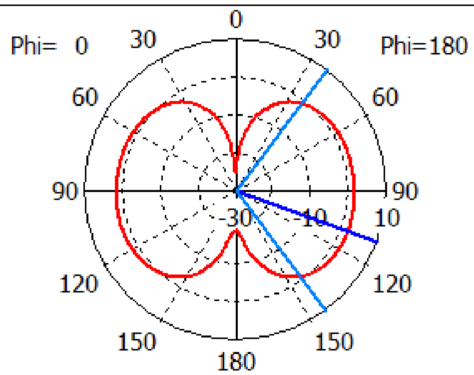


Figure 8: Comparison between the calculated antenna gains for the proposed antenna with and without reflecting plane.

Table 2: Radiation patterns of the proposed antennas with and without reflecting plane at various frequencies

Frequency (GHz)	Field pattern at $\Phi = 0^{\circ}$ using reflector	Field pattern at $\Phi = 0^{\circ}$ without reflector
1		
2.1		
3.2		
4.3		

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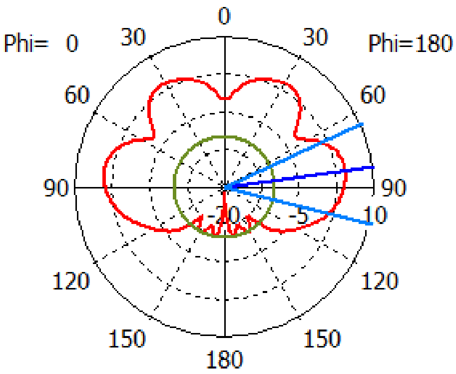
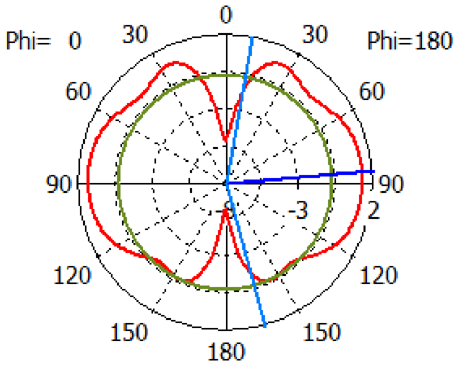
<table>
<tr><th>Frequency (GHz)</th><th>Field pattern at $\Phi = 0^{\circ}$
Using reflector</th><th>Field pattern at $\Phi = 0^{\circ}$
Without reflector</th></tr>
<tr><td>5.4</td><td>
</td><td>
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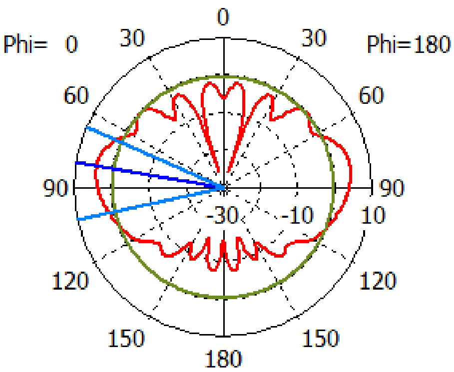
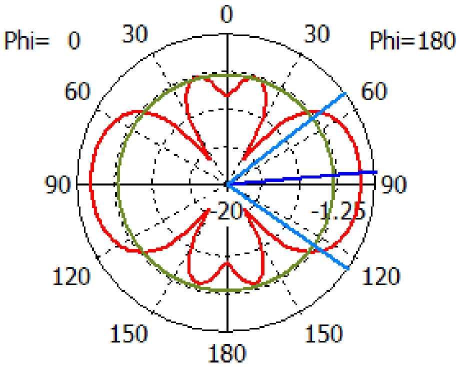
<tr><td>6.5</td><td>
</td><td>
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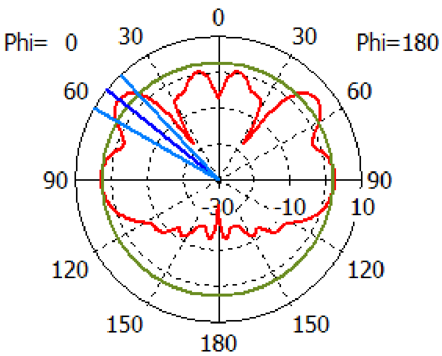
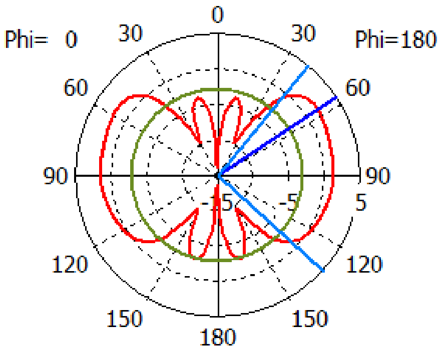
<tr><td>7.6</td><td>
</td><td>
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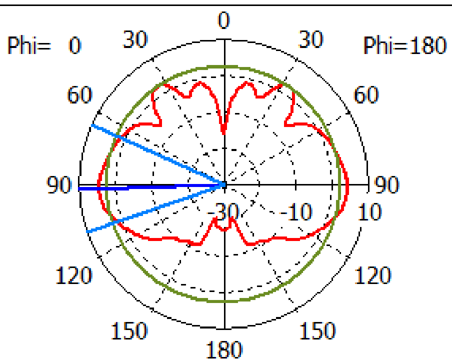
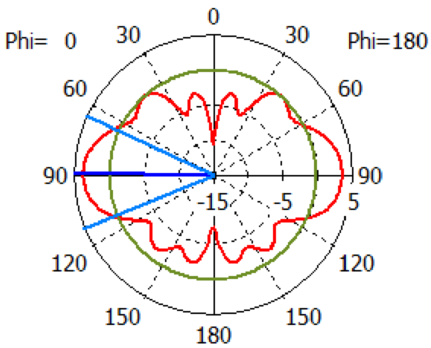
<tr><td>8.7</td><td>
</td><td>
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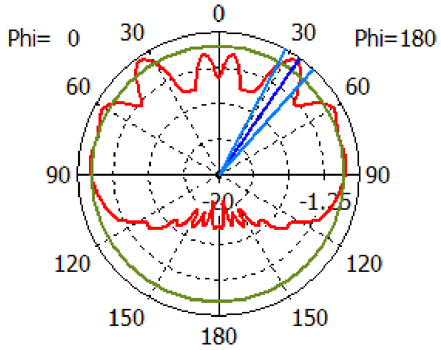
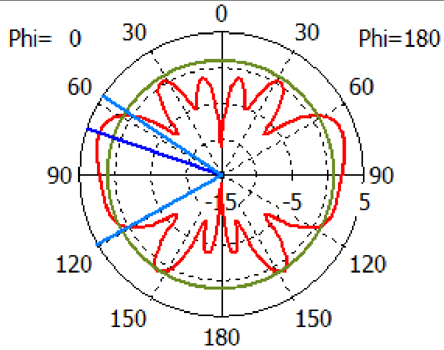
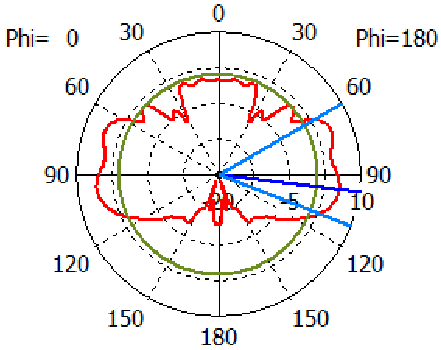
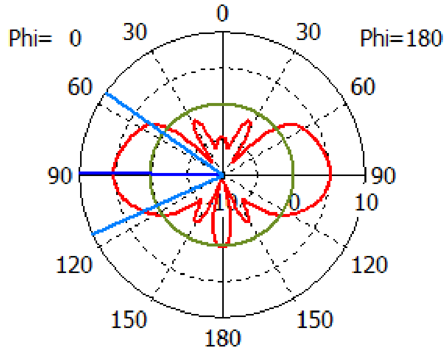
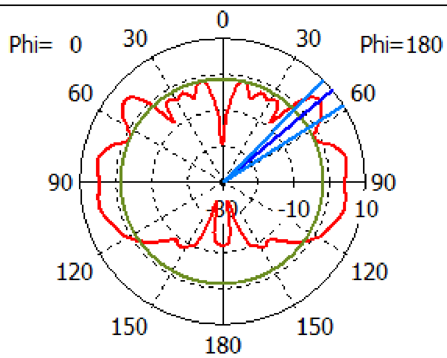
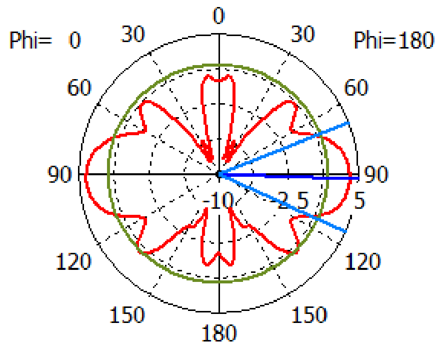
Frequency (GHz)	Field pattern at $\Phi = 0^{\circ}$ Using reflector	Field pattern at $\Phi = 0^{\circ}$ Without reflector
9.8		
10.9		
12		

4. Fabrication and Measurement of the Proposed Antenna

In this section, the fabrication and measurements of the proposed antenna are introduced. The antenna is fabricated on the aforementioned substrate and reflecting plane as shown in Figure (9).

The scattering parameter $|S_{11}|$of the fabricated antenna is measured using Rohde & Schwarz ZVL20 Network Analyzer as shown in Figure (10). Also, Figure (10) shows a comparison between the simulated and measured scattering parameters for the proposed antenna. The results revealed that the simulated and measured parameters are highly coincided.

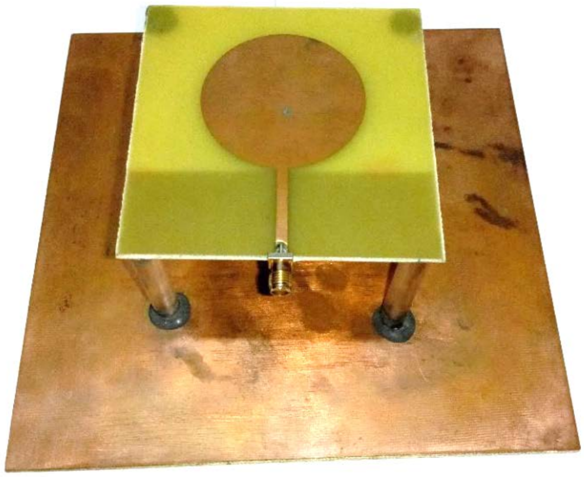


Figure 9: The fabricated UWB antenna.

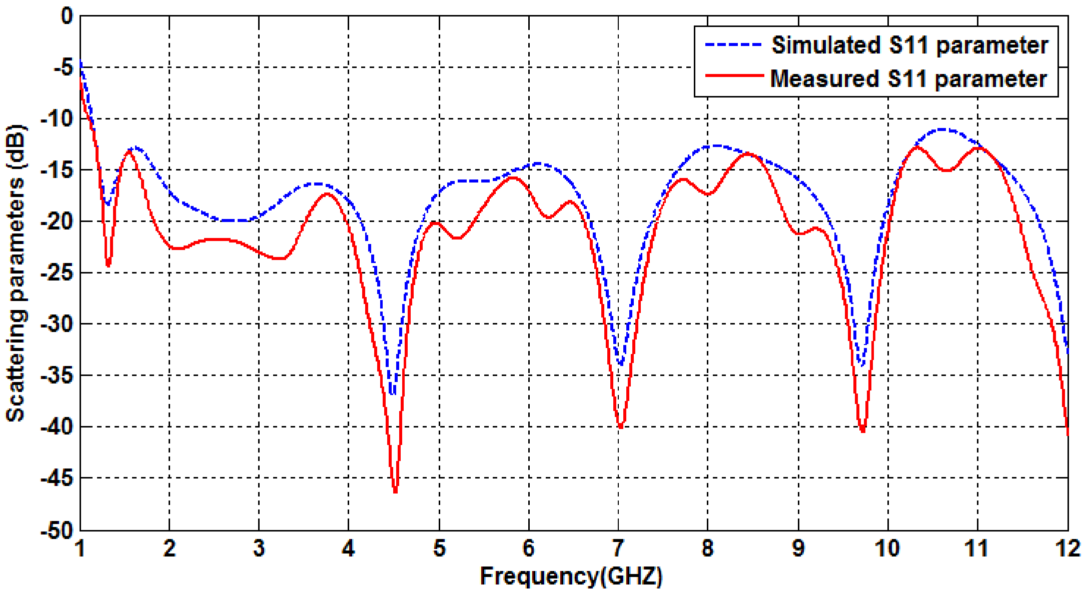


Figure 10: Comparison between the measured and simulated scattering parameter $|S_{11}|$ of the modified UWB antenna element.

5. Conclusion

In this paper, a small antenna with circular radiating patch and defected ground structure for UWB applications is introduced to overcome the gain problem of the traditional wide slot defected ground antenna by placing a large reflecting plane at a specific distance from the antenna. The proposed antenna provides UWB frequency range from 1.17 GHz to more than 12 GHz. The antenna is designed using the CST Microwave Studio software using low cost FR4 (lossy) substrate with $\varepsilon_r = 4.3$ and $h = 1.6\ mm$. Compared to the ordinary antenna, the modified antenna provides positive gain over the entire operating frequency range. The simulation results and measurements revealed that the proposed UWB antenna has achieved good gain-bandwidth characteristics.

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