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Design of an Ultra-Wideband Semi-Circular Patch Antenna

Karim Ferroudji [1, 2], Malika Ouacifi [1, 3], Mounir Amir[4], Fouad Chebbara[3, 5]

[1]*Sciences and technologies Faculty ,Electrical engineering Dept. LARBI Tebessi University Tebessa, Algeria (karim.ferroudji@univ-tebessa.dz)*
[2]*Laboratoire d'Automatique Avancée et d'Analyse des Systèmes, Université Batna 2, Batna, Algeria*
[3]*Department of Electronic and Telecommunications, University Kasdi Merbah Ouargla, Ouargla, Algeria (malika.ouacifi@univ-tebessa.dz)*
[4]*University Mouloud MAAMRI of Tizi Ouzou Tizi Ouzou, Algeria (mounir.amir@yahoo.fr)*
[5]*Laboratory of electrical engineering (LAGE), University Kasdi Merbah Ouargla, Ouargla, Algeria (chebbara.fouad@univ-ouargla.dz)*

Abstract. This paper presents a design of an ultra-wideband (UWB) semi-circular patch antenna. The proposed UWB antenna consists of a semi-circular patch, the UWB performance is achieved using partial ground plane with a rectangular slot etched from the ground. The overall size of the antenna is 26×27×1.6 mm^3. The substrate employed is FR4 epoxy with a dielectric constant of 4.4 and a loss tangent of 0.02. The obtained results reveal that the presented UWB antenna design cover ultra-wide impedance bandwidth of around 11 GHz (120.48%), ranges from 3.63 GHz to 14.63 GHz for reflection coefficient S11<-10dB and voltage standing wave ratio VSWR<2. The results also state that the antenna has a good peak gain of 2.98 to 8.68 dB in the desired band. The proposed UWB antenna is suitable for several applications, such as 5.5 GHz WiMAX band, 5.2/5.8 GHz WLAN band, and other wireless communication applications.

Keywords and phrases: Patch antenna, ultra-wide band, slots, partial ground, circular

1 Introduction

Since the release of the law passed by the Federal Communication Commission (FCC)'s in 2002, in which FCC allocated the 3.1GHz to 10.6GHz band to be unlicensed and dedicated for commercial wireless communication [1], ultra-wideband wireless communication systems have gained increased attention. Ultra-wideband antennas were the foci of a great deal of research in

the past few years by industrial and academic researchers. Furthermore, UWB technology are widespread due to its promising features, such as high-speed communication transmission rate (more than 100 Mbps), wireless connectivity of about 10 m, and good radiation pattern performances [2].

UWB antennas have attracted increasing attention from biomedical imaging [3, 4], wearable technologies [5], wireless body area network [6, 7], 4G/5G applications [8], MIMO systems [9], and other wireless applications [10].

Several approaches can be exploited to enhance the microstrip antenna bandwidth. These techniques include incorporating parasitic element either in the patch or in the ground, increasing the substrate thickness, and modifying the shape of the radiating element by incorporating slots [11].

Some antenna designs and shapes has been proposed for UWB applications in the literature, such elliptical patch [12], circular patch [13], octagonal shaped [14], pentagonal shaped antenna loaded with slot [15], and other geometries [16]. The main challenge is to design an antenna to cover the required wide frequency range while maintaining compact size and low power consumption with sufficient radiation properties.

In this paper, a semi-circular UWB patch antenna with a partial ground plane which contains a rectangular slot is proposed. It covers a frequency range of 3.63 GHz to 14.63 GHz with a miniature size of 26×27×1.6 mm^3. The exploited substrate is FR4 epoxy with a dielectric constant of 4.4 and a loss tangent of 0.02. A parametric analysis is conducted to understand the effects of several dimensional parameter and to optimize in the same time the proposed UWB antenna's performance.

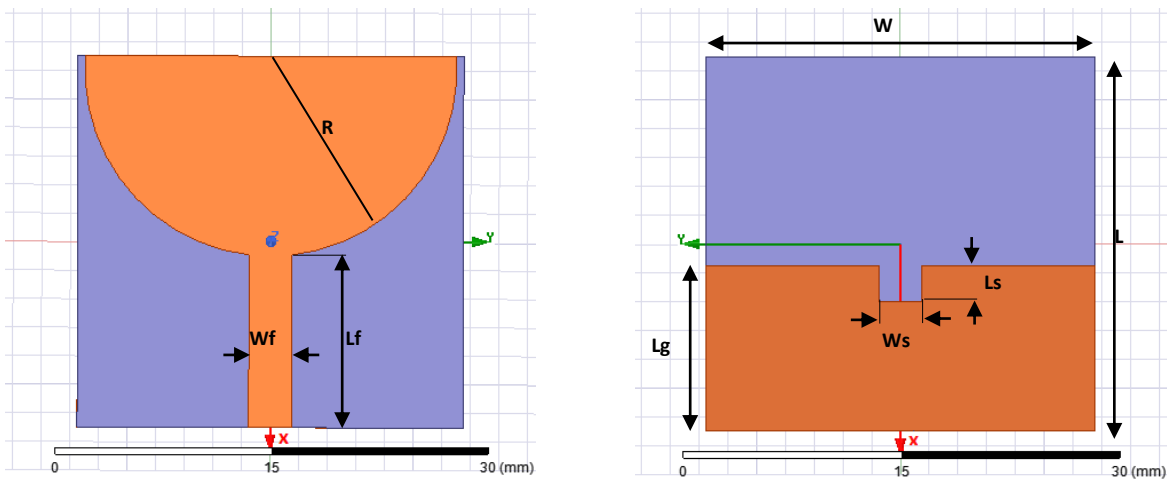
The antenna structures realized in this study are designed and simulated using High-Frequency System Simulator (HFSS) software.

This paper is organized as follows. Section II highlights the antenna design. Section III presents the simulation results in which the proposed design methodology for UWB operation with a detailed parametric analysis is provided. Section IV illustrates a comparison between the proposed antenna and recently developed UWB antennas. Section IV concludes the paper.

2 Antenna design

The UWB patch antenna geometry is illustrated in Figure 1. The form of the antenna is semi-circular of 13mm radius, using FR4 epoxy with a dielectric constant of 4.4 and a loss tangent of 0.02. It occupies an overall size of 26×27mm^2 with a thickness of 1.6 mm. A conventional

microstrip feed line connected to the radiating patch is exploited as feed structure for the proposed antenna. A modification to the ground plane structure is employed in order to create the desired ultra-wide bandwidth operation. The ground plane is truncated and a rectangular slot is centered under the feed-line as illustrated in Figure 1 (b). The upper side is shaped as shown in Figure 1 (a). The dimensions of the notched rectangular slot and the size of the truncated ground plane are modified to achieve the ultra-wide bandwidth operation. The design of the antenna is realized using HFSS software. The optimized parameters of the proposed UWB antenna are illustrated in Table 1.



(a) (b)

Figure 1: Geometry of the UWB Antenna: (a) upper view, (b) bottom view.

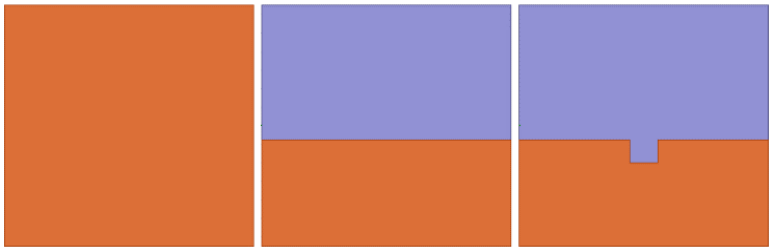
Parameter	**Value (mm)**
Radius of patch (R)	13
X position (Xp), Y position (Yp) of patch	-12 , 0
Length of substrate (L)	27
Width of substrate (W)	26
Partial ground plane (Lp)	11.5
Width feed line (Wf)	3
Length feed line (Lf)	13
Length of slot (Ls)	3
Width of slot (Ws)	4

Table 1: Parameters for the UWB patch antenna.

3 Simulation results

1. Evolution of the antenna design

The evolution of the design of the proposed ultra-wideband antenna and its corresponding reflection coefficients (S11) are illustrated in Figure 2 and Figure 3, respectively.



(a) (b) (c)

Figure 2: Design evolution of the proposed UWB: (a) Antenna I, (b) Antenna II, (c) Proposed antenna.

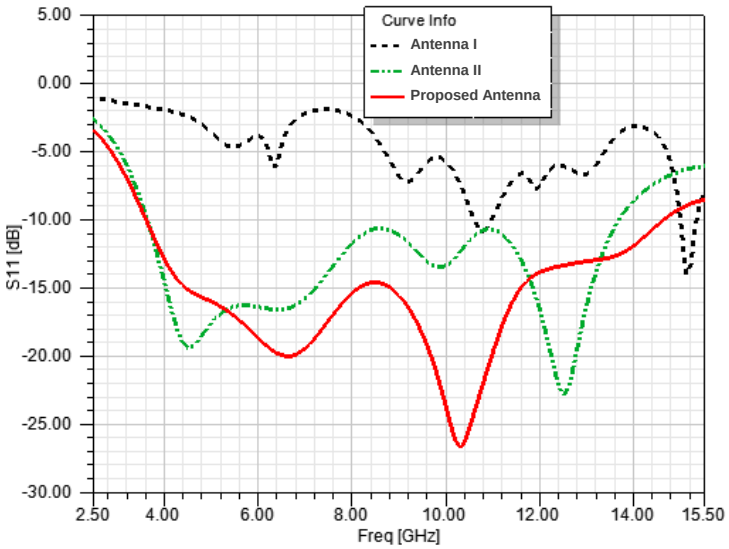


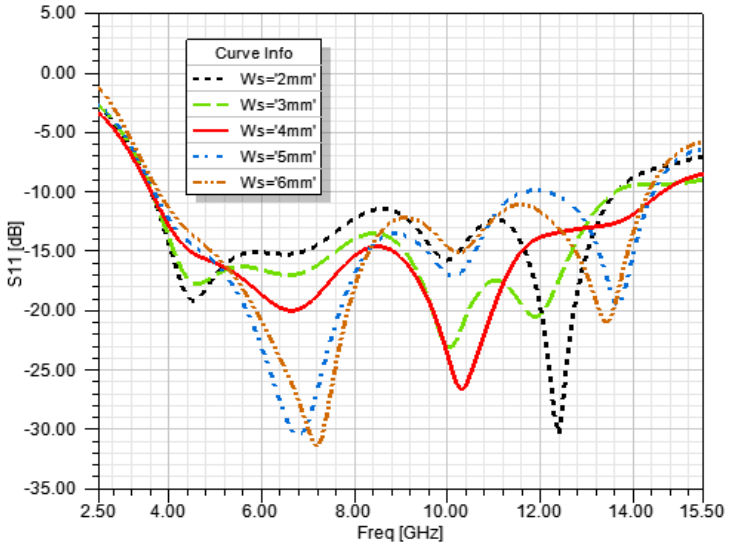
Figure 3: Return loss of Antenna I, Antenna II, and Proposed antenna.

Antenna I: This antenna is designed to resonate at 10.8 GHz and 15.1 GHz, refer to Figure 3.

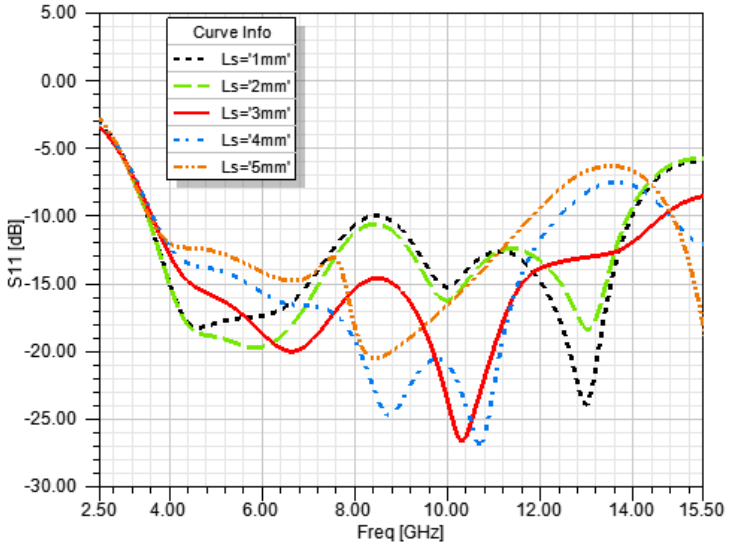
Antenna II: The ground plane is truncated as shown in Figure 2. An UWB behavior that covers 3.7 GHz to 13.7 GHz is observed (refer to Figure 3).

Proposed Antenna: In order to enhance the antenna bandwidth as well as the reflection coefficients, a rectangular slot is etched from the ground plane and it is centered under the feed-line as illustrated in Figure 2. From the obtained results, shown in Figure 3, the proposed UWB antenna bandwidth ranges from 3.63 GHz to 14.63 GHz.

- Effects of varying slot and ground dimensions on the designed antenna



(a)



(b)

Figure 4: Variation of slot dimensions for design optimization: (a). width of Slot, (b). Length of Slot.

A parametric study is conducted for proper optimization of the antenna design. Slot and ground dimensions are modified within tolerable limits as shown in Figure 4 and Figure 5, in which the width and the length of the slot as well as the size of the ground are changed, respectively. The results that met the required specification for the antenna to achieve the best UWB behavior in terms of length of the bandwidth and reflection coefficient are obtained using the following parameters:

Ws=4 mm, refer to Figure 4 .(a), Ls=3 mm, refer to Figure 4 .(b), and Lg=11.5 mm, refer to Figure 5.

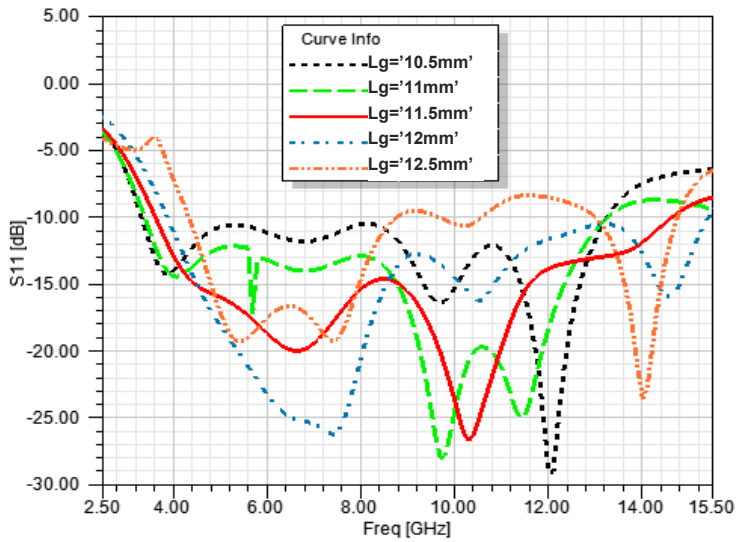


Figure 5: Variation of ground dimensions for design optimization.

2. Proposed UWB antenna

The performance of the proposed UWB antenna are evaluated throughout simulation verification for several antenna parameters, such as reflection coefficient, voltage standing wave ratio (VSWR), maximum gain, radiation patterns, and group delay using HFSS software.

- S-Parameter characteristics:

The simulated |S11| performance for the proposed UWB antenna is illustrated in Figure 6. It is observed that the reflection coefficient curve has several resonance frequencies close to 6.7 GHz and 10.3 GHz delivering reflection coefficient values of -19.96 dB and -26.64 dB, respectively. Moreover, the measured bandwidth of the proposed UWB antenna for |S11|≤-10 dB is 11 GHz (3.63-14.63 GHz), constituting 120.48% fractional bandwidth.

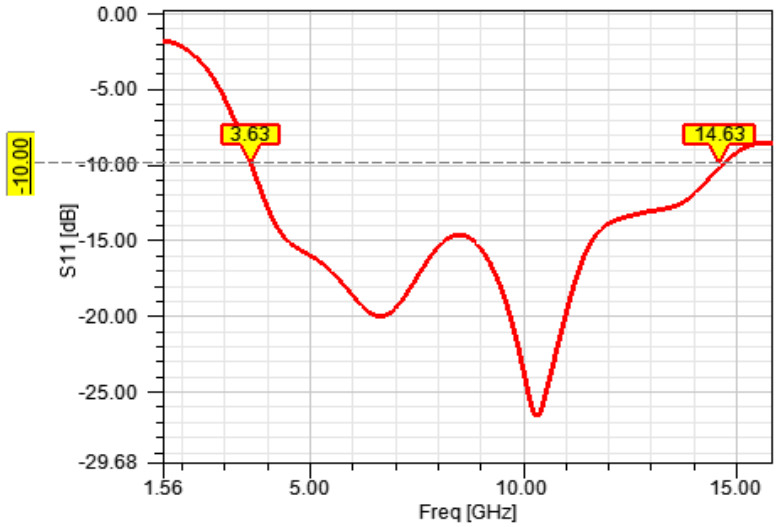


Figure 6: Return loss of the proposed UWB antenna.

- Voltage Standing Wave Ratio (VSWR):

Figure 7 illustrates the voltage standing wave ratio (VSWR) characteristic of the UWB antenna. It is observed from the figure that the operating bandwidth of the proposed UWB antenna has a minimum VSWR value of around 1.09 and it remains less than 2 over the entire bandwidth of 3.63 GHz to 14.63 GHz. The obtained results demonstrate that the antenna satisfies the VSWR<2 requirement and resonates within the allowable limit of VSWR which is between 1 and 2. This indicates that a good impedance matching between antenna feed line and radiating patch is obtained.

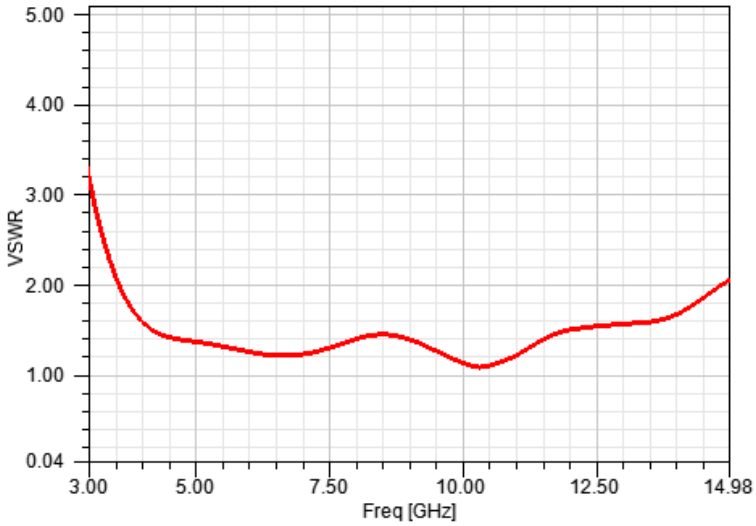


Figure 7: Voltage standing wave ratio (VSWR) of the UWB antenna.

- Gain:

Figure 8 illustrates the measured peak gain vs. frequency of desired band of 3.63 GHz to 14.63GHz. It is observed that the UWB antenna offers a good proper gain over the entire band. It is above 2.98 dB in the whole operating bandwidth. The peak gain achieves a maximum value of around 8.68 dBi at 3.63 GHz. The measured peak gains range between 8.68 and 2.98 dB within the working band. Consequently, due to the good gain in the entire band, the proposed UWB antenna is a good candidate for several wireless communication applications, such as WIMAX, WLAN, …etc.

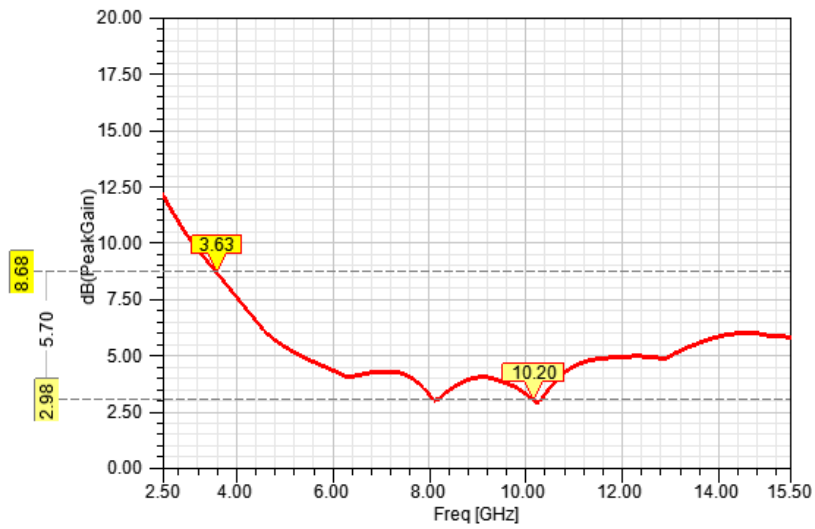
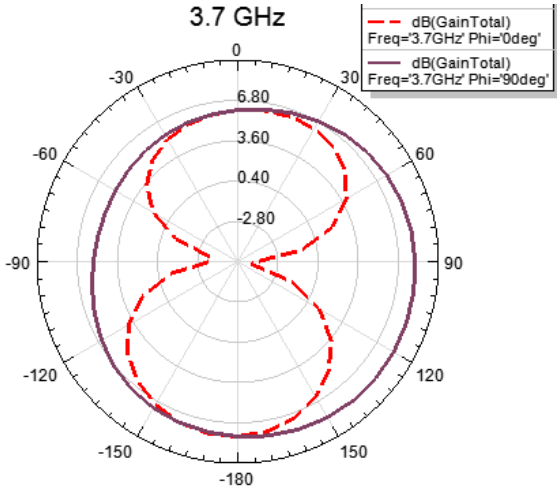


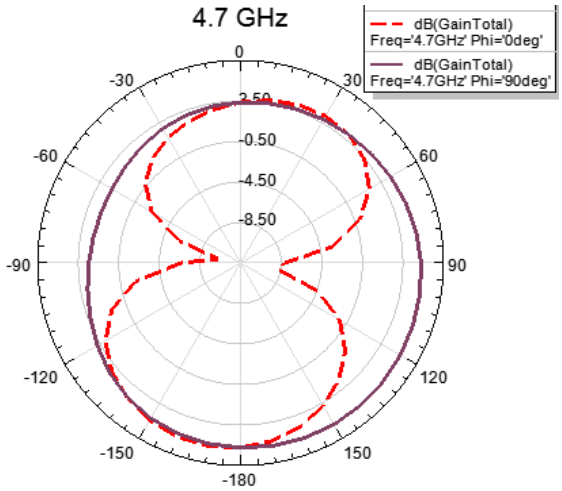
Figure 8: Simulated peak gain of the proposed UWB antenna.

- Radiation Patterns:

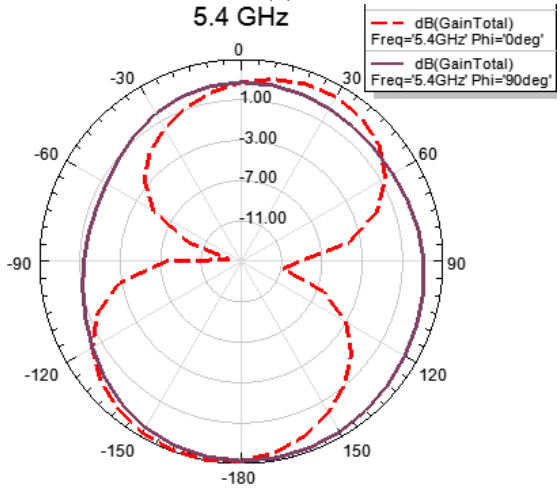
Figure 9 shows the 2-D simulated radiation pattern in E-Plane (Φ = 0°) and H-Plane (Φ = 90°) for several operating frequencies of 3.7, 4.7, 5.4, 6.7, 8, 10.3, 12.5, and 14.5 GHz. These figures illustrate that the radiation patterns of the UWB antenna have almost omnidirectional behavior, however they became more directive at higher frequencies.


3.7 GHz
dB(GainTotal)
Freq='3.7GHz' Phi='0deg'
dB(GainTotal)
Freq='3.7GHz' Phi='90deg'
6.80
3.60
0.40
-2.80

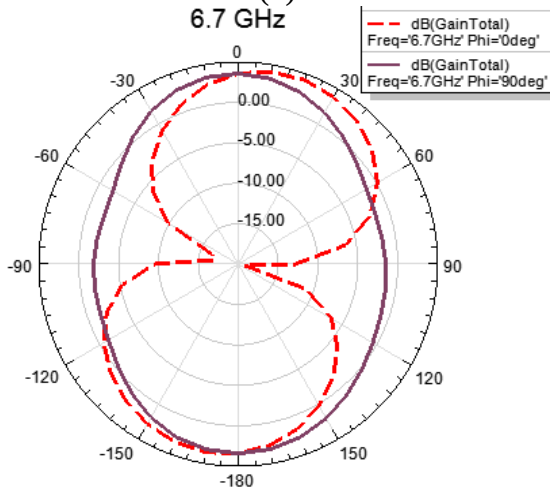
(a)


4.7 GHz
dB(GainTotal)
Freq='4.7GHz' Phi='0deg'
dB(GainTotal)
Freq='4.7GHz' Phi='90deg'
-0.50
-4.50
-8.50

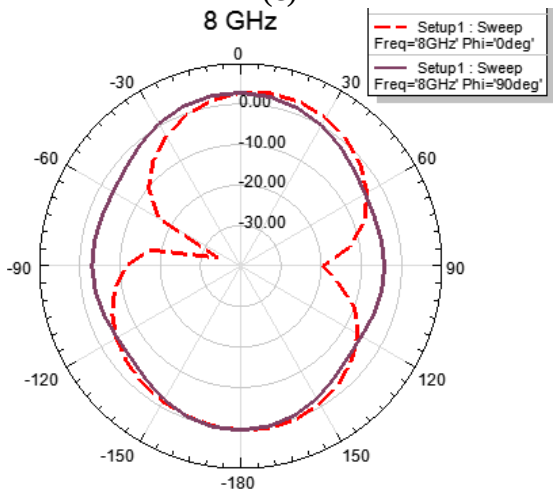
(b)


5.4 GHz
dB(GainTotal)
Freq='5.4GHz' Phi='0deg'
dB(GainTotal)
Freq='5.4GHz' Phi='90deg'
1.00
-3.00
-7.00
-11.00

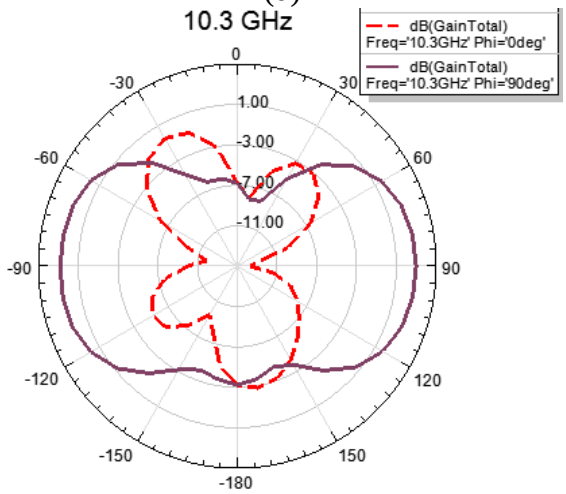
(c)


6.7 GHz
dB(GainTotal)
Freq='6.7GHz' Phi='0deg'
dB(GainTotal)
Freq='6.7GHz' Phi='90deg'
0.00
-5.00
-10.00
-15.00

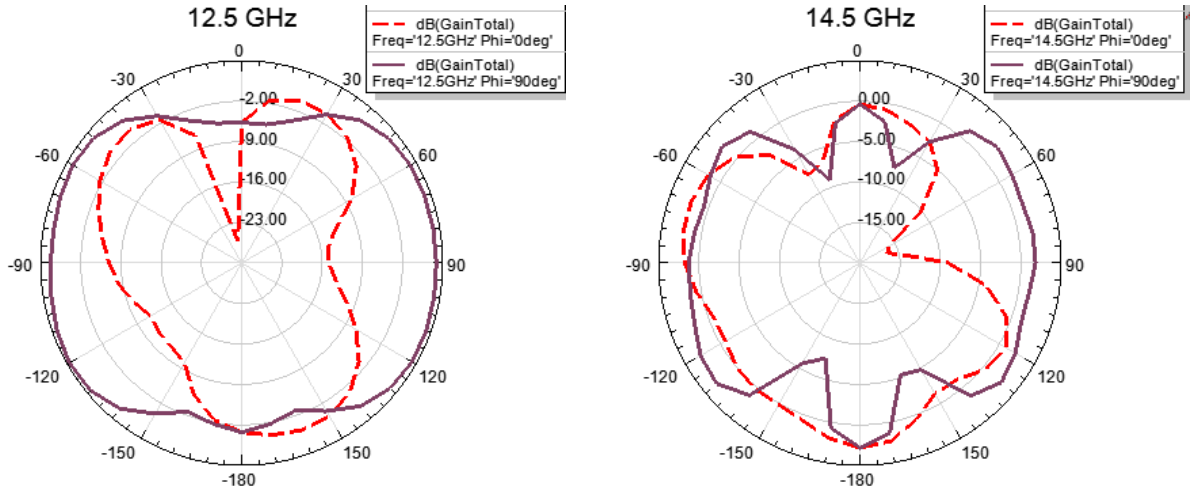
(d)


8 GHz
Setup1 : Sweep
Freq='8GHz' Phi='0deg'
Setup1 : Sweep
Freq='8GHz' Phi='90deg'
0.00
-10.00
-20.00
-30.00

(e)


10.3 GHz
dB(GainTotal)
Freq='10.3GHz' Phi='0deg'
dB(GainTotal)
Freq='10.3GHz' Phi='90deg'
1.00
-3.00
-7.00
-11.00

(f)



(g) (h)

Figure 9: Simulated peak gain of the proposed UWB antenna.

- Group Delay:

Group delay is one of the important criterion while discussing wide and ultra wide-band antennas. It measures the phase distortion of the pulse with the variations of radiated amplitudes and phases over frequency. The antenna should be able to transmit the electrical pulse with minimal distortion (i.e. group delay variation less than 1 ns) to receive the correct UWB pulse. The group delay results in Figure 10 show that over the whole frequency band from 3.63 to 14.63 GHz the variation is less than 0.7 ns which indicates that the proposed antenna has low-impulse distortion, therefore it is appropriate for UWB applications.

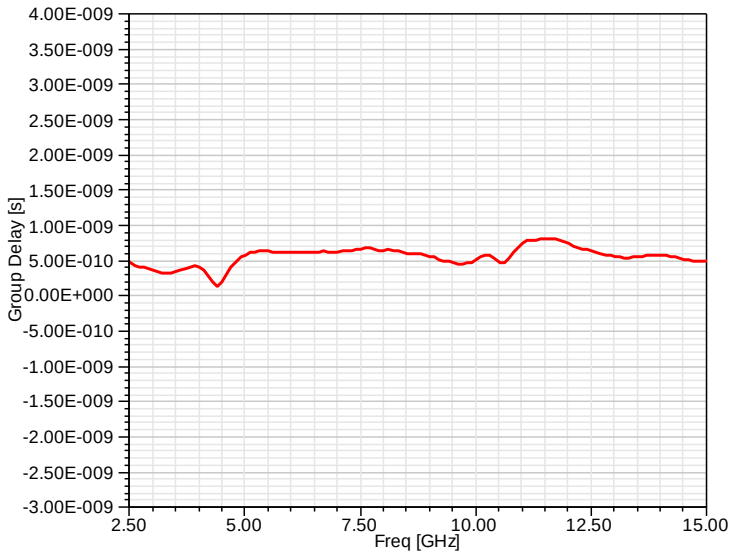


Figure 10: Group Delay of the UWB antenna.

4 Comparison between recently developed UWB antennas

Table 2 presents a comparison between the proposed antenna and recently developed UWB antennas. The comparison is conducted in terms of antenna size, bandwidth, and gain. The proposed antenna provides good impedance bandwidth from 3.63–14.63GHz (S11 < −10 dB) with an acceptable gain characteristic. Furthermore, the proposed UWB antenna is smaller and occupies minimum area compared to other works in [9, 17-19, 20, 21]. The proposed geometry covers WiMAX (3.7GHz, 5–5.5 GHz) WLAN (5.1–5.3GHz and 5.7–5.8GHz), and X band (8–12 GHz) applications.

Antenna	**Antenna size mm^2**	**Bandwidth (GHz)**	**Gain (dB)**
Proposed	26 × 27	3.63–14.63	2.98–8.68
[9]	28 × 56	2.0–13.3	1.4–6.6
[17]	35 × 24	3.1–12.3	2–6.8
[18]	47 × 93	3.1–10.6	2.4–3.5
[19]	35 × 36	3.0–9.0	1.7–5.5
[20]	26 × 26	2.9–11.6	0–6
[21]	50 × 35	3.0–11	4–6
[22]	45 × 25	3.0–12	1.8–5.4

Table 2: Comparison between recently published UWB antennas.

5 Conclusion

In this paper, an UWB semi-circular antenna, fed by a microstrip line, is designed. The proposed antenna occupies an area of 26×27 mm^2, and presents an ultra-wide bandwidth corresponding to an impedance bandwidth of 11 GHz (3.63–14.63 GHz) for VSWR<2 and S11≤-10 dB, constituting 120.48% fractional bandwidth. To obtain and to improve the UWB behavior of the antenna, two modifications are incorporated. The first one is to truncate the ground plane, the second modification is to incorporate a rectangular slot, which is centered under the feed-line, in the ground. The antenna shows a stable radiation patterns and a peak gain ranges from 2.98 to 8.68 dB with a group delay variation less than 0.7 ns. Due to its very wide bandwidth and small size, the proposed antenna can be considered as a potential candidate for several UWB communication systems, such as WiMAX, WLAN, and X bands.

At lower frequencies the radiation patterns are almost omnidirectional, however they became more directive at higher frequencies. Further modification can be introduced into the antenna design in order to enhance the radiation patterns of higher frequencies.

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