A New Compact Small Circular Patch Antenna for UWB Communication

Soufian Lakrit, Hassan Ammor, Jaouad Terhzaz, Mohamed Chaïbi, and À. Mediavilla Sànchez

***Abstract*—A new small circular patch antenna for ultra-wideband (UWB) applications is presented. By studying this structure, it is shown that the insertion of a slot with the desired length and width in the ground plane, can lead to a large bandwidth. Our antenna, whose dimensions are 18×12×1.58 mm^3, was fed by an SMA female connector with characteristic impedance of 50Ω in order to measure the return loss and VSWR and to compare them with the simulation results. The bandwidth obtained from measurements ranges from 3.52 to 13.67 GHz for VSWR < 2 and from 3.26 GHzto14.23GHz for VSWR < 3. The radiation pattern is omnidirectional on most of the operating band. High Frequency Structure Simulator (HFSS) was used for simulation whose results are in good agreement with the measured parameters.**

***Index Terms*— Compact, Microstrip, SMA female connector, Ultra-wideband (UWB), Return loss, VSWR, HFSS**

I. Introduction

Modern mobile communications systems require miniature and wideband antennas for their terminal stations. In fact, both 3G and 4G technologies need high bit rates to transmit their different data types (sound, video…) from small equipment. Also, the scientific community has produced many publications in this sense [1,2]. However, since February 2002, when the FCC has authorized to civilian applications to use the UWB, many researchers in this domain have begun to develop antennas in accordance with specificities of this part of the spectrum [3]. This last is defined as any frequency band of more than 500MHz, or having a relative bandwidth of more than 20%. Before this date, this domain was dedicated to military applications. In addition to mobile applications, short-range applications also use UWB antennas. This is the case of Ground penetrating radars, medical imaging, high data rate wireless local area networks WLAN (5.15–5.35 and 5.725–5.825 GHz), downlink of X-band satellite communication systems (7.25–7.75 GHz).

The enhancement of the antenna bandwidth leaded to the development of many design and manufacturing techniques. This is particularly true for microstrip antennas that are characterized by a narrow band [4]. These techniques have been discussed in the literature, for instance, U-slot stacked patch antenna [5], triangle Circular fractal antenna [6], H-slot antenna [7], E-shaped patch antenna [8]. Other techniques employed to increase the bandwidth of antennas include meandered ground plane [9], slot loading [10], meandering slots [11], tulip-shaped monopole antenna [12] and T-slot in the radiating element [13]. In fact, many circular patch antennas has been studied in the literature but we observed that the compactness and miniaturisation problems must be analysed more deeply [14-17].

In this paper, we study a compact miniature circular planar UWB antenna having a simple structure with low geometric complexity. In fact, due to its excellent characteristics like single layer, small size, and large bandwidth, this antenna is a good candidate for miniature UWB equipment. The measured results show that the antenna has a bandwidth ranging from 3.26 to 14.23 GHz for S11< -6 dB [1] and from 3.52 to 13.67 GHz for S11< -10dB. Also, the radiation pattern keeps approximately the same shape over the frequency bandwidth. Details of the proposed design are presented and discussed in this paper. The Ansoft High Frequency Structure Simulator (HFSS) was used in the design process. The present work is a more detailed study of our previous papers [18, 19].

II. Antenna Geometry and Design

Figure 1 illustrates the configuration of the proposed antenna, which consists of a circular patch, a partial ground plane and a T-shaped slot on the ground plane. This compact antenna, which has a radius a = 5mm, is printed in the front of an FR4 substrate having a thickness 1.58mm with relative permittivity of 4.4 and 0.02 for loss tangent. The dimensions of the partial ground plane, which is printed in the bottom side of the substrate, are chosen to be 12×3.5mm2 in this study. The patch is fed by a 50Ω coaxial probe from the side of the antenna through a 50Ω microstrip line. The microstrip line was etched on the same side of the substrate as the radiating element.

Fig. 2 shows the succession of steps followed to arrive to the final shape that makes the frequency band wide. As shown in Fig. 3, the bandwidth obtained by the T slot is wider than that obtained by the rectangular one. Figure 4 shows the variation of S11 with frequency for different values of the radius ‘a’. The optimal result is obtained for a value of 5mm.

Manuscript received October 23, 2015; revised December 16, 2015.

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The analysis of the antenna for different physical parameters has been carried out by varying one of them and keeping the others constant. The final optimal parameter values are listed in Table 1.

In our view, the relationship between this structure and the wideband characteristic can be explained by the cavity model. With a total ground plane, the structure behaves like a cavity having a single resonant frequency and narrow bandwidth. When the ground plane becomes partial, the cavity behavior is removed and the band is wider like the case of a monopole antenna. Finally, if we add a slot to the ground plane, the structure becomes more complex and its behavior is equivalent to many simple antennas that contributes to the wideband. More the slot is complex, more the band is wide.

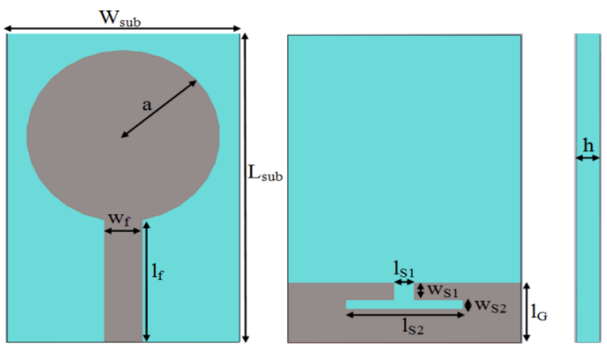


Fig. 1. Geometry of the proposed antenna

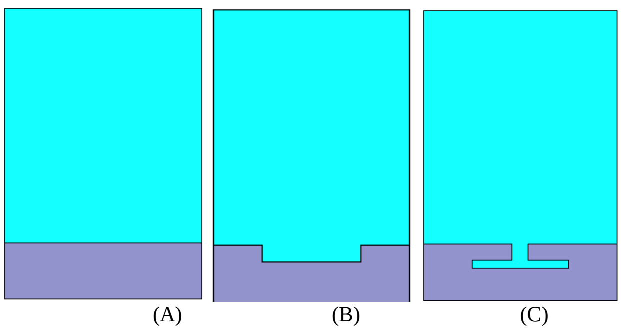


Fig. 2. The different geometric shapes of the partial ground plane: (A) partial ground plane without slot, (B) a rectangular slot in the ground plane and (C) an inverted T-shaped slot in the ground plane

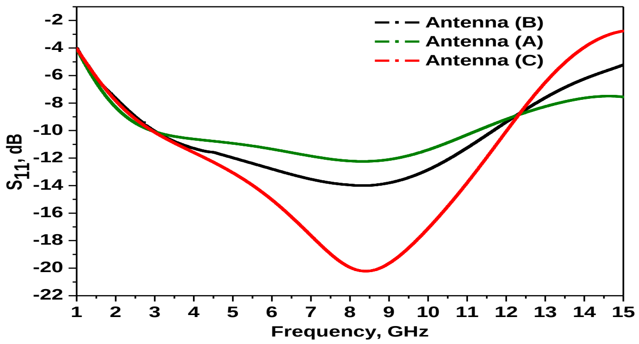


Fig. 3. The simulated S_{11} curves for the antennas shown in Fig. 2.

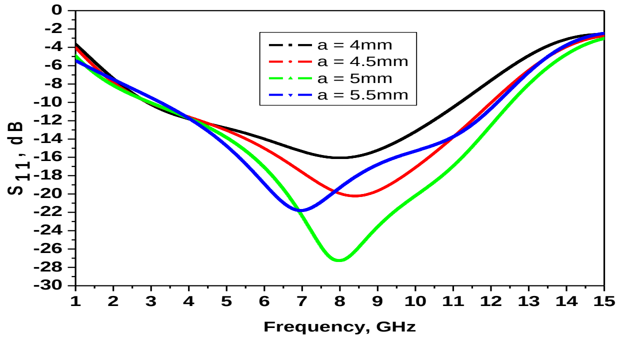


Fig. 4. S_{11} variation vs frequency for different values of the radius

TABLE 1
THE OPTIMAL DIMENSIONS OF THE PROPOSED ANTENNA

Elements	**Dimensions**
FR4 substrate	h=1.58mm, L_{Sub}=18mm, W_{Sub}=12mm
Microstrip line	L_f=7mm, W_f= 2mm
Slots	w_{S1}=l_{S1}=1mm w_{S2}=0.5mm, l_{S2}=6mm.
Circular patch	a = 5mm
Ground plane	L_G = 3.5mm, W_G=W_{Sub} =12mm

III. RESULTS AND DISCUSSION

In this section, we begin by evaluating the performance of our antenna by simulation using HFSS. This same tool was used to optimize the microwave structure for the best impedance bandwidth. HFSS is the main design tool of our research team. However, the results of simulation must be compared to other results. Before realization of our antenna, we compared the results with CST software. This last is not used in the present study because the antenna is fabricated and measured to validate the HFSS design. In fact, one of our goals is to evaluate, practically, the performance of this tool without studying analytically the numerical algorithm it uses (finite element method). So, our observations were focused on the bandwidth not on the complete similitude between the tools. After fabrication, HFSS results are verified by measurements.

Since our main goal is to design an UWB antenna, we need to apply techniques that will improve the impedance bandwidth. One way is to use a partial ground plane with rectangular slots. This increases the bandwidth, especially at the upper frequencies.

Figure 5 presents the optimal curve separately. This result shows the presence of a resonance frequency at 8GHz with a level of S11 parameter at -27.30 dB. The bandwidth measured at -10dB ranges from 2.72GHz to 12.61GHz, and it has a width of 9.89GHz.

The simulation results in Fig. 6 show the real and imaginary parts of the antenna input impedance. Across the matching band, the real part is approximately 50 Ω and the imaginary part varies close to the zero value. This is a result of the equilibrium between the capacitive and inductive effects. This result means that the antenna will have near linear phase characteristics.

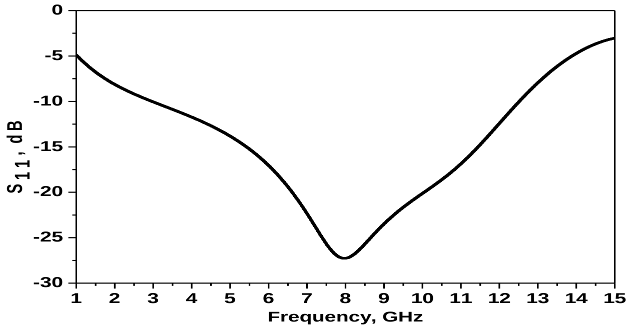


Fig. 5. Return loss versus frequency of the proposed antenna

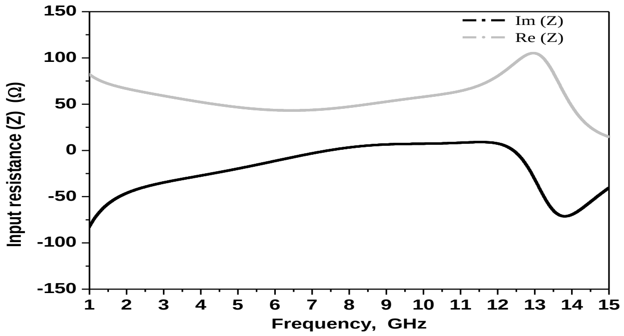
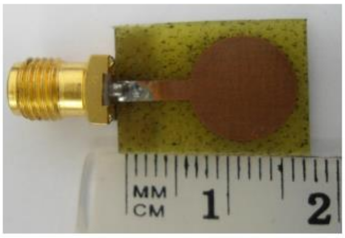


Fig. 6. Real and imaginary part of the antenna input impedance

The fabricated prototype is shown in Fig. 7 according to the aforementioned parameters. Commercial FR4 was used because it resists to heat and has excellent chemical and mechanical properties. The S_{11} of the fabricated antenna was measured using vector network analyser PNA E8634A.The measured and simulated values for the reflection coefficient are shown in Figure 8.

To determine the bandwidth of the antenna, two relationships should be mentioned: a return loss of -10 dB corresponds to a VSWR of 2:1 and -6 dB corresponds to 3:1 [1,20].

The fabricated antenna satisfies the -6dB return loss requirement from 3.26 to -14.23GHz and -10 dB from 3.52 to 13.67 GHz. The simulated and measured characteristics such as return loss, bandwidth and resonant frequency of the antenna are compared in fig. 8 and illustrated in table 2.



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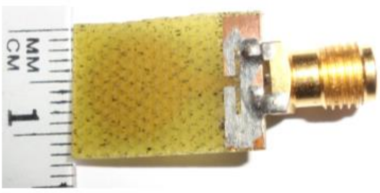


(b)

Fig. 7. The fabricated antenna (a) Top view and (b) Bottom view

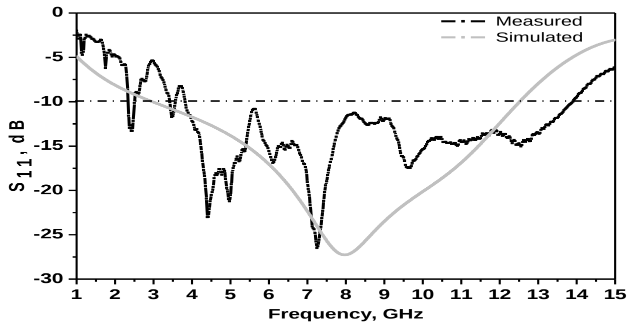


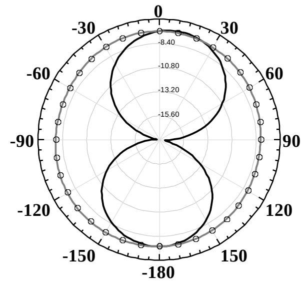
Fig. 8. Comparison between the simulated and measured $S_{11}$of the proposed antenna

TABLE 2
COMPARISON BETWEEN MEASURED AND SIMULATED VALUES OF S_{11}

	Bandwidth at -6dB (GHz)	Bandwidth at -10dB (GHz)	Resonant frequency	Level S_{11}(dB)
Simulated	1.28 -13.54	2.72-12.61	8GHz	-27.30
Measured	3.26-14.23	3.52-13.67	4.45 GHz 7.29 GHz 9.57 GHz 12.53 GHz	-22.43 -27.01 -17.02 -14.63

Figure 9 shows the 2D simulated radiation patterns of our antenna at frequencies 4.45GHz, 7.29GHz, 9.57GHz and 12.53GHz. The results show that the frequencies that give a good return loss, give also a good radiation pattern. This last is omnidirectional in the H plane and bidirectional in the E plane. Thus, the UWB characteristic for the antenna is also valid for the radiation.

Omni-directionality is needed to transmit and receive information to and from all directions. The 3D radiation pattern of the proposed antenna is shown in Fig. 10 at four frequencies 4.45GHz, 7.29GHz, 9.57GHz and 12.53GHz.



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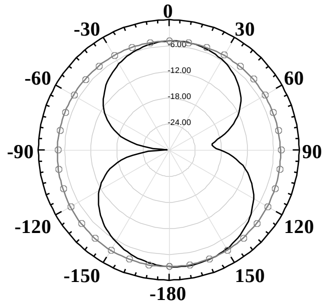

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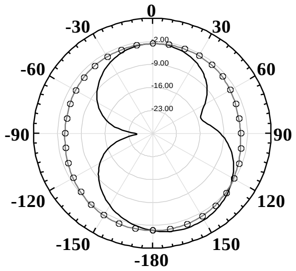

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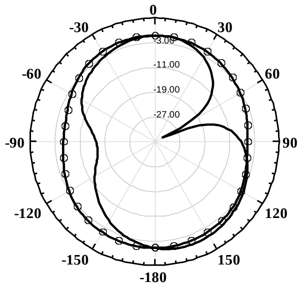
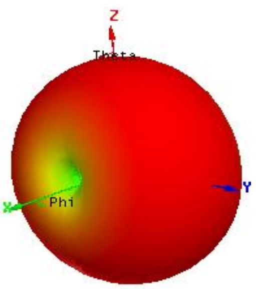
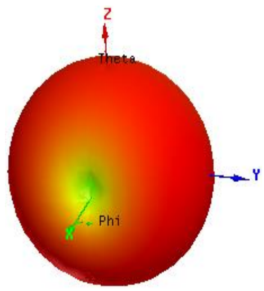


(d)

Fig. 9. E- and H-field patterns at different frequencies (a) 4.45GHz, (b)7.29GHz, (c) 9.57GHz and(d) 12.53GHz



(a)



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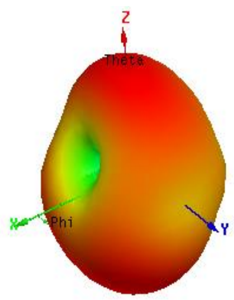

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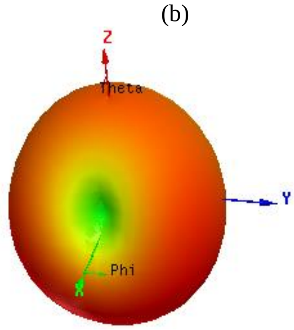

(d)

Fig. 10. 3D Radiation pattern at different frequencies (a) 4.45GHz, (b) 7.29GHz, (c) 9.57GHz and (d) 12.53GHz

The 3D pattern of this antenna is similar to that of a monopole antenna [21].

Figure 11 shows the variation of the antenna gain vs frequency from 3GHz to 13 GHz. The maximum gain is 3.55 dB at 11.5GHz. This result was obtained by simulation only because an anechoic chamber is not available. Also, Fig. 12 shows that the directivity values are near to the gain values on the majority of the frequency band. That means that our dielectric substrate does not degrade the efficiency.

Table 3 presents a comparison between the performance of some recently developed UWB antennas and the proposed antenna. Our antenna shows wide impedance bandwidth, compact size, and good gain features.

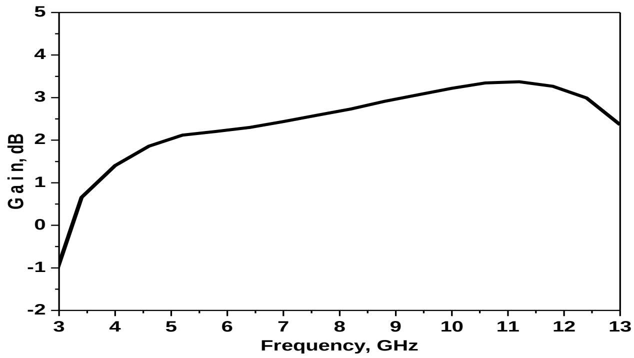

Fig. 11. Gain in dB of our antenna against frequency

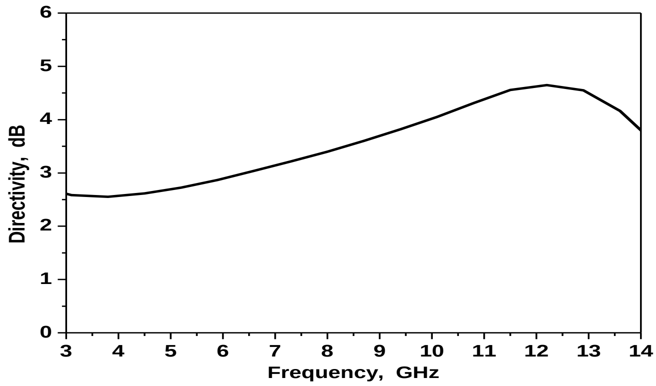

Fig. 12. Directivity in dB of our antenna against frequency

TABLE 3
COMPARISON OF PREVIOUS DESIGNS WITH THE PROPOSED ANTENNA

Antenna	Bandwidth (GHz) at -10dB	Antenna size(mm^2)	Gain (dB)
This work	3.52-13.67	12x18	1 - 3.55
[13]	3.92-11.32	16x25	2.25 - 4.56
[14]	3.1-10	30x40	Not reported
[22]	4-9	30x30	2 - 6
[23]	3-10.26	34x36	Not reported
[24]	1.15-4.4	75x75	2 - 8

IV. CONCLUSION

A new small compact circular patch antenna for UWB applications has been proposed. We showed that by embedding a pair of slots with appropriate dimensions and positions that form a T shape in the partial ground plane, a wide impedance bandwidth is achieved. It ranges from 3.52GHz to 13.67 (118.1%) for VSWR<2. Thus, the antenna can cover the whole 5.8GHz-band of RFID system as well as WLAN, HiperLAN, X-band satellite communication systems, radar systems and European standard UWB systems.

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