A New Compact Small Circular Patch Antenna for UWB Communication

Soufian Lakrit, Hassan Ammor, Jauoud Terhzaz, Mohamed Chaibi, and À. Mediavilla Sánchez

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 $18 \times 12 \times 1.58$ mm$^3$, was fed by an SMA female connector with characteristic impedance of 50$\Omega$ 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 GHz to 14.23 GHz 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 and wideband antennas for their terminal stations. In fact, both 3G and 4G technologies need high bit rates to transmit their terminal stations.

The enhancement of the antenna bandwidth lead 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 radiation 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 $S_{11} < -6$ dB [1] and from 3.52 to 13.67 GHz for $S_{11} < -10$ dB. 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 $a = 5$ mm, 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 $12 \times 3.5$ mm$^2$ in this study. The patch is fed by a 50$\Omega$ coaxial probe from the side of the antenna through a 50$\Omega$ 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 $S_{11}$ with frequency for different values of the radius ‘$a$’. The optimal result is obtained for a value of 5mm.
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.

### Table 1

| 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.
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 \cite{1,20}. The fabricated antenna satisfies the -6 dB return loss requirement from 3.26 to -14.23 GHz 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.

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.

The UWB characteristic for the antenna is also valid for the radiation.

**TABLE 2**

| 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         | 4.45GHz            | -22.43             |
|                         |                          |                    | 7.29 GHz           | -27.01             |
|                         |                          |                    | 9.57 GHz           | -17.02             |
|                         |                          |                    | 12.53 GHz          | -14.63             |

Figure 10 shows the 3D radiation pattern of the proposed antenna at frequencies 4.45GHz, 7.29GHz, 9.57GHz and 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.

### 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.

### TABLE 3

| Antenna | Bandwidth (GHz) at -10dB | Antenna size (mm²) | 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 |
REFERENCES

[1] Dalia M. Elshekah and Esmat A. Abdallah, “Ultrawideband Vivaldi Antenna for DVB-T, WLAN,andWiMAX Applications”, International Journal of Antennas and Propagation, Volume 2014, Article ID 761634, pp.1-7, http://dx.doi.org/10.1155/2014/761634, 2014.

[2] Cheolbok Kim, Ultra-Wideband Antenna, chapter 2 in Microwave and Millimeter Wave Technologies: Modern UWB antennas 20 and equipment, pp. 19-49, 2010, ISBN 978-953-7619-67-1 www.intechopen.com.

[3] “Federal Communications Commission Revision of Part 15 of the Commission’s Rules Regarding Ultra Wideband Transmission System from 3.1 to 10.6 GHz,” in FEDERAL Communications Commission, Washington, DC: ET-Docket, pp. 98–153, FCC, 2002.

[4] Chia Ping Lee, Chandan Kumar Chakrabarty, “Ultra Wideband Microstrip Diamond Slotted Patch Antenna with Enhanced Bandwidth”, Int. J. Communications, Network and System Sciences, vol 4, No 7, pp: 468-474, 2011. doi:10.4236/ijcns.2011.47057.

[5] KoraySürmeli, BahattinTüretken, “U-Slot Stacked Patch Antenna Using High and Low Dielectric Constant Material Combinations in S-band”, 30th URSI General Assembly and Scientific Symposium, URSIGASS, 13-20 Aug. 2011 Istanbul turkey. 10.1109/URSIGASS.2011.6050299.

[6] Raj Kumar, DhananjayMagar, K. Kaillas Sawant, “On the design of inscribed triangle circular fractal antenna for UWB applications”, AEU - International Journal of Electronics and Communications, vol 66, No 1, pp: 69-75, 2012. doi:10.1016/j.aeue.2011.05.003.

[7] Soufian Lakrit, Hassan Ammor, Jaouad Terhzaz, “Design of H-slot Patch Antenna for Ultra Wideband “, European Journal of Scientific Research, Vol 106, No. 2,pp.224-228, 2013.

[8] B.-K. Ang and B.-K. Chung, “A wideband E-shaped microstrip patch antenna for 5–6 GHz wireless communications”, Progress In Electromagnetics Research, PIER, vol 75:pp: 397–407, 2007.

[9] Rezaul AZIZMER, Mohammad Tariqul ISLAM, Ahmed Toaha MOBASHSHER, “Ultra-wideband Antenna with Band-notches for Lower and Upper WLAN”, PRZEGLĄD ELEKTROTECHNICZNY. Issue 01a/2013.

[10] Kiran, K. U. Vani, R. M.: Ravi, R. M.: Hunagund, P. V., "Slot-loaded Rectangular Microstrip Antenna with Meandering Slots in the Ground Plane for Compact Broadband Dual-frequency Operation", Antennas, Propagation & EM Theory, 2006. ISAPE'06. 2006. 10.1109/ISAPE.2006.353480.

[11] Prabhakar, H.V.; Kumuri, U.K.; Yadahalli, R.M.; Munnappa, V. “Effect of various meandering slots in rectangular microstrip antenna ground plane for compact broadband operation”, Electronics Letters, vol 43, No 16, pp: 848-850, 2007.

[12] D. C. Chang, J. C. Liu, and M. Y. Liu, “A novel tulip-shaped monopole antenna for UWB applications,” Microw. Opt. Technol. Lett., vol. 48, pp. 307–312, 2006.

[13] Radouane KARLI, Hassan AMMOR, Jaouad TERHZAZ, Mohamed CHAÏBI and A.MEDIVAILLA SANCHEZ, “Design and construction of miniaturized UWB microstrip antenna with slots for UWB applications”, MICROWAVE and OPTICAL TECHNOLOGY LETTERS, Vol. 57, Issue 2, pp. 460–463, Feb 2015.

[14] Sunita Rani, Er. Devender Singh, Krishan Sherdia, "UWB Circular Microstrip Patch Antenna design simulation & its Analysis", International Journal of Advanced Research in Computer and Communication Engineering, Vol. 3, No.7,pp. 7519-7521, July 2014.

[15] Amritkumar F Sonar, Nitesh S Mishra, Rahul P Mishra, Jayesh Mhaskar & Shilpa Kharche, “UWB Circular Monopole Antenna”, ITSI Transactions on Electrical and Electronics Engineering, Vol. 1, No. 1, 2013.

[16] Xian-Ling Liang, Shun-Shi Zhong and Wei Wang, “UWB printed circular monopole antenna”, Microwave and Optical Technology Letters, Vol. 48, No. 8, 2006.

[17] Amin M. Abbosh and Marek E. Bialkowski, “Design of Ultrawideband Planar Monopole Antennas of Circular and Elliptical Shape”, IEEE transactions on antennas and propagation, Vol. 56, No. 1, 2008.

[18] Soufian Lakrit, Hassan Ammor, “Design Of Ultra Wideband Small Circular Patch Antenna For Wireless Communication”, ARPN Journal of Engineering and Applied Sciences, Vol 10, No. 4, pp: 1762-1765, MARCH 2015.

Soufian lakrit was born in Morocco, in 1985. He received the B.S. degree from Faculty of Sciences, Fez, Morocco in 2009 and M.S from National School of Applied Sciences, Fez, Morocco in 2011. His research interests include RF/microwave techniques, antenna design, microstrip antennas for UWB applications, medical applications, miniaturization techniques and analysis of antennas with equivalent circuits.

Hassan Ammor: Professor in the Department of Electrical Engineering at Mohammadia School of engineering in 1996 in electronics and telecommunications. Head of Team STRC (Radiocommunications Systems and Communication Technology) and member of RUSTE (university Networks Science and Space Technology).

Jaouad Terhzaz was born in Morocco, in September 1977. He received the Ph.D degree in electronics and telecommunications from the E.M.I. Mohammed V University-Agdal, Rabat, Morocco, in 2008. He is currently a professor of physics in CRMEF, Casablanca, Morocco. He is involved in dielectric characterization of materials using microwave techniques and antennas systems design for mobile communications.