*Progress In Electromagnetics Research Letters, Vol. 55, 121–128, 2015*

# Integrated Flexible UWB/NB Antenna Conformed on a Cylindrical Surface

**Nadjet Sahnoun[1, 2, *], Idris Messaoudene[1, 2], Tayeb A. Denidni[2], and Abdelmadjid Benghalia[1]**

**Abstract**—In this paper, an ultra-wideband (UWB) conformal monopole antenna integrated with a narrow-band (NB) rectangular slot antenna is designed and fabricated. The proposed structure consists of a circular disc monopole antenna printed on a cylindrical surface and fed by a coplanar waveguide line (CPW). A rectangular slot antenna, excited by a microstrip line, is integrated in the front of the UWB antenna. The simulations are performed using the CST Microwave Studio software. To validate the proposed antenna concept, an experimental prototype is fabricated and measured. The measured results show that the monopole antenna covers an ultra wideband from 2 GHz to 12 GHz with $S_{11} < -10$ dB and provides a very good isolation with a transmission coefficient below $-20$ dB across the operating band. Compared to planar integrated antennas, the proposed conformed structure possesses an important wideband, which can be used in many wearable electronic applications and communication systems.

## 1. INTRODUCTION

Since the first report that permitted the commercial operation of ultra wideband (UWB) adopted by FCC (The Federal Communications Commission of the United States) in 2002 [1], many researchers have developed several antenna designs to enhance the impedance bandwidth of small antennas, to make it suitable for UWB applications [2–6]. Recently, the UWB technology has been regarded as one of the most promising wireless technologies that allows the revolutionizing highdata transmission rate and enables the personal area networking industry leading to new innovations and greater quality of services for mobile users [7].

In recent years, one of the most important innovations in modern antenna technology is the incorporation of two antennas in the same package: the first antenna has an ultra-wideband for spectrum sensing, and the second is a narrow band antenna used to transmit the collected information. This design has received much attention, and many investigations have been reported in the literature [8–13]. The majority of these designs are mounted on planar substrates and mainly proposed for radar, medical microwave imaging systems, cognitive radio applications and weapon detection systems [14, 15]. On the other hand, some applications require non-planar shapes, so the antennas used in this case need to have some additional characteristics, such as low weight, thin substrate thickness, and flexibility to conform to non-planar surfaces [16]. This leads to concluding that the substrates chosen for these kinds of antennas exhibit a good balance of physical and electrical properties and offer a low thickness, making them more flexible.

The cylindrical antenna is a very popular type of conformal antenna and was analyzed in the past using different configurations; for example, cylindrical conformal antennas have been proposed in [17, 19]. Currently, some research groups have been focused their work on the study of cylindrical antennas for

*Received 18 June 2015, Accepted 21 August 2015, Scheduled 27 August 2015*
* Corresponding author: Nadjet Sahnoun (nadjet.sahnoune@emt.inrs.ca).
[1] Laboratoire des Hyperfréquences et Semiconducteurs, Université de Constantine 1, Route d'Ain El Bey 25000, Constantine, Algérie.
[2] INRS Place Bonaventure, 900 De la Gauchetière Ouest, Niveau C, Montréal H5A, 1C6, Canada.

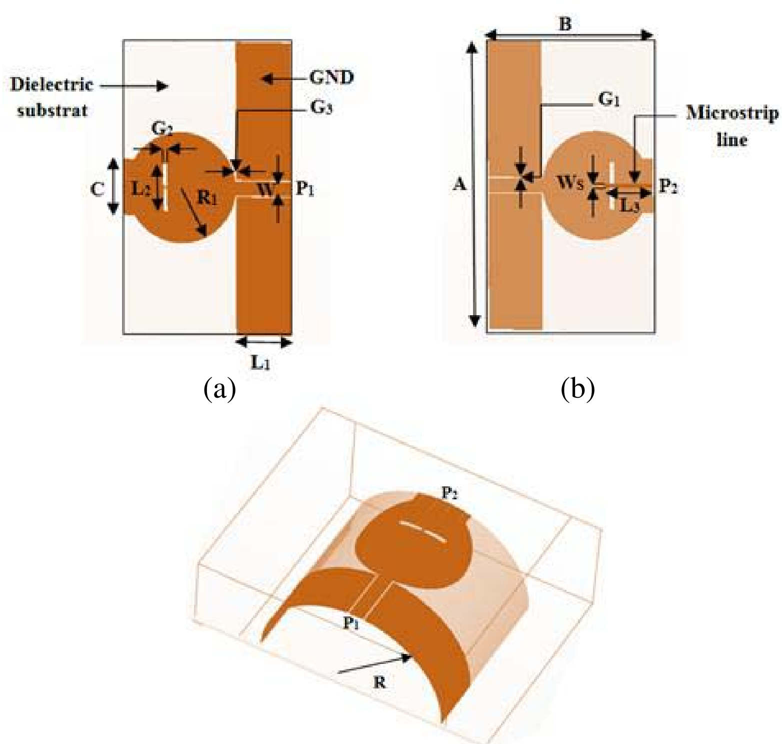
UWB applications [16, 20, 21] and extended these concepts to other studies such as integrated UWB/NB antennas. These antennas can offer some desirable characteristics that are not provided by planar elements and can be used in wearable electronic applications. However, the effect of the conformal integrated UWB/NB shape has not been investigated yet.

In this paper, a new cylindrical integrated UWB/NB antenna is proposed. It consists of two antenna parts: an UWB antenna fed by a coplanar waveguide (CPW) from Port 1 and a NB antenna excited via a microstrip line from Port 2. The two antennas are conformed on a cylindrical substrate. The measured results of the proposed structure exhibit a good matching and isolation between the two antenna ports with transmission coefficient less than −20 dB over the operational frequency band from 2 GHz to 12 GHz.

This paper is organized as follows. In Section 2, the geometry and design of the proposed antenna are described. In Section 3, the results of simulation and measurements are presented and discussed. Finally, this work is concluded in Section 4.

## 2. ANTENNA DESIGN

Figure 1 shows the proposed antenna. This structure is composed of two antennas integrated in the same limited area: the first is an UWB antenna that consists of a circular disc monopole antenna combined with a rectangular patch, excited from Port 1 via a 50 Ω CPW transmission line as illustrated in Figure 1(a). The second one is a rectangular slot antenna excited from Port 2 trough a microstrip line printed on the reverse side of the substrate, as shown in Figure 1(b). The two antennas are printed on a flexible Rogers RO3003 substrate with a relative permittivity $\varepsilon_r = 3$, thickness $h = 0.254$ mm and loss tangent of 0.0013. The two antennas are conformed on a cylindrical Styrofoam ($\varepsilon_r = 1.03$) with radius $R = 20$ mm, as illustrated in Figure 1(c). The main objective of this work is to develop an integrated flexible antenna with UWB and NB characteristics on the same structure. Some requirements such as bandwidth, good impedance matching and high isolation between the ports of the antenna must be




(a) (b)

(c)

**Figure 1.** Geometry of the proposed structure; (a) Top view of planar form, (b) bottom view of planar form, (c) cylindrical form.

reached. For this reason, the effects of different parameters on the antenna performances have been studied. The optimal values of the antenna parameters that give the best performances are summarized in Table 1.

**Table 1.** Final optimised dimensions of the structure.

| *Parameter* | $A$ | $B$ | $L_1$ | $L_2$ | $L_3$ | $G_1$ |
|---|---|---|---|---|---|---|
| *Value (mm)* | 63.6 | 37 | 12 | 10.4 | 10 | 0.2 |
| *Parameter* | $G_2$ | $G_3$ | $R$ | $R_1$ | $W_s$ | $W$ |
| *Value (mm)* | 1 | 0.2 | 20 | 12 | 0.64 | 3 |

When integrating multiple antennas within a limited space, the most important challenge is to reduce the mutual coupling between the two ports of these antennas. For this purpose, the surface current distribution analysis is used to study the principle of the isolation. In Figures 2(a), (b), and (c), the simulated surface current distributions on the UWB antenna, without integrating the rectangular slot, is plotted at 3.5 GHz, 6.5 GHz, and 9.5 GHz, respectively. Form these figures, it can be observed that the surface current density on the front extremity of the UWB patch antenna is very low, which allows to use this area for integrating a second antenna.

Figure 3 shows that the surface current distributions at 5.8 GHz on both sides of the proposed antenna (integrated UWB/NB antenna), when Port 1 is excited and Port 2 terminated with 50 Ω and vice versa, are very low, which leads to an efficient integration with good isolation.

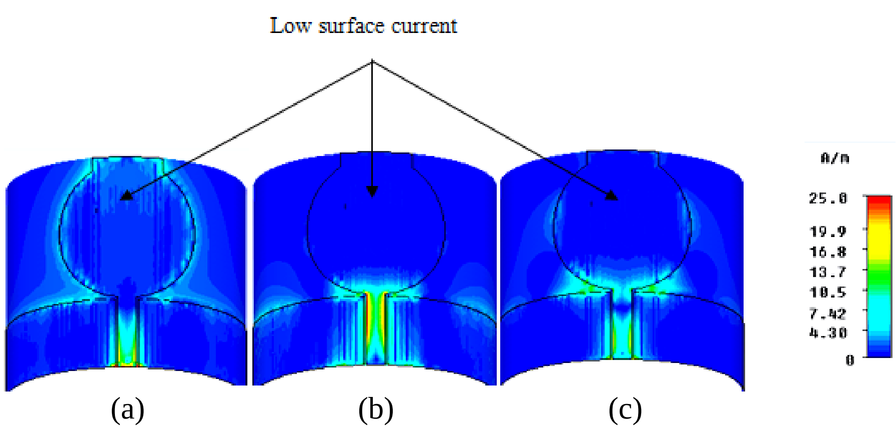



**Figure 2.** Surface current distributions on the UWBA without integrating NBA at (a) 3.5 GHz, (b) 6.5 GHz, (c) 9.5 GHz.

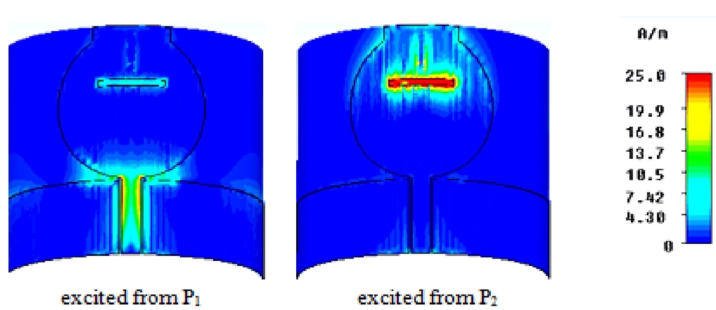



**Figure 3.** Surface current distributions on the integrated UWB/Slot antenna at 5.8 GHz.

## 3. SIMULATED AND MEASURED RESULTS

The simulations were carried out using the commercial electromagnetic simulator CST Microwave Studio, which is based on Finite Integration Technique (FIT) in time domain. In order to validate the simulated results, an experimental prototype of the proposed antenna was fabricated, as shown in Figure 4. The $S$-parameters were measured using the Agilent 8722ES vector network analyzer and the radiation patterns were also measured inside an anechoic chamber.

Figure 5 presents the plot of the simulated and measured reflexion coefficients of the proposed antenna. From these graphs, it is clear that the monopole printed antenna provides a bandwidth from 2 GHz to more than l2 GHz for the measurement results for return loss below $-10$ dB, and 2.12 GHz to more than l2 GHz for the simulated results, which is enough to cover the UWB applications operating in the band 3.1–10.6 GHz. In addition, the slot antenna operates around 5.8 GHz with an impedance bandwidth between of 5.7 GHz and 5.9 GHz (covering the 5.8 GHz WLAN band, with normalized frequency band between 5.725 GHz and 5.875 GHz), which is suitable for wireless local area network communications.

From Figure 6, it can be observed that the transmission coefficients ($S_{12}/S_{21}$), which represent the mutual coupling quantity between the two ports, are less than $-20$ dB throughout the full operation band for both simulated and measured results. These results ensure a good isolation between the two antenna ports. The measured and simulated $S$ parameter results are in a reasonable agreement. However, the small discrepancy is mainly caused by the fabrication imperfection and the RF cable of the network analyzer.

The radiation patterns were measured and simulated at selected frequencies to evaluate the antenna behavior across the operating band. The simulated and measured radiations patterns in the two principal

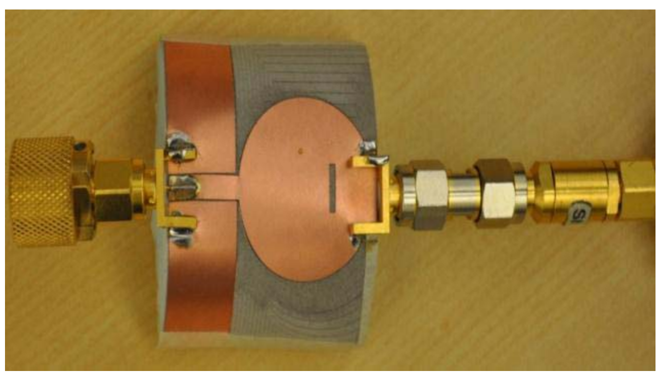


**Figure 4.** Photograph of fabricated prototype antenna.

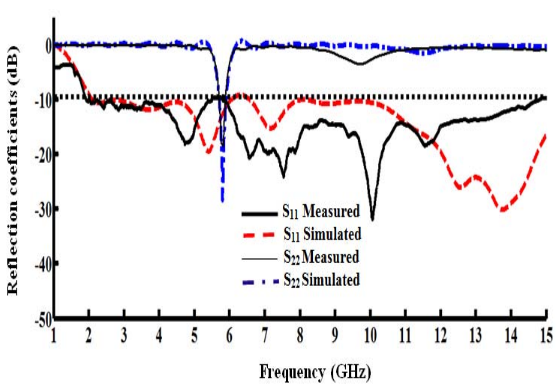



**Figure 5.** Reflexion coefficients of the proposed antenna.

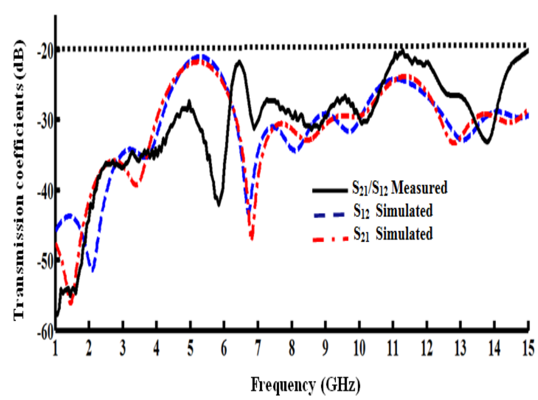



**Figure 6.** Transmission coefficients of the proposed structure ($S_{12}/S_{21}$).

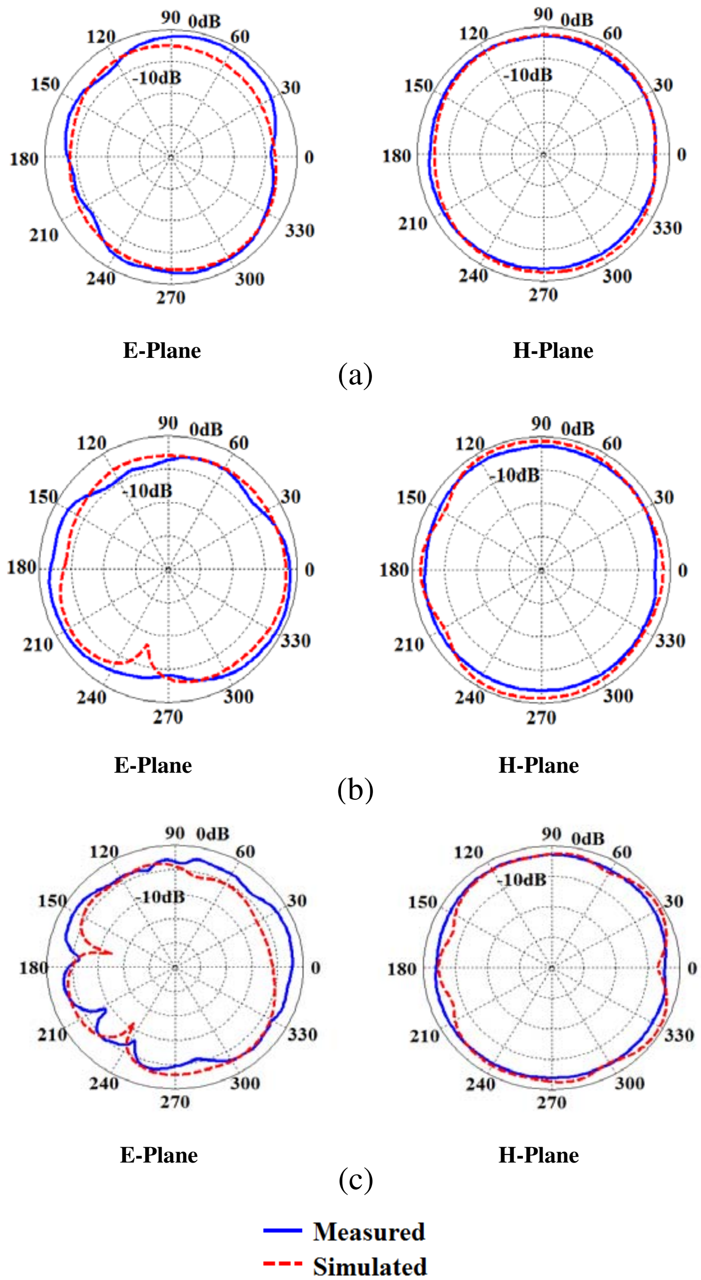



**Figure 7.** Measured and simulated radiation patterns of the UWB antenna at; (a) 3.5 GHz, (b) 6.5 GHz, (c) 9.5 GHz.

planes ($E$-plane and $H$-plane) are plotted in Figure 7, at 3.5 GHz, 6.5 GHz and 9.5 GHz for the UWB antenna. Figure 8 shows the radiation patterns at 5.8 GHz for the rectangular slot antenna. It can be seen that the $H$-plane measured patterns of the proposed antenna exhibit a stable radiation patterns in the full operating band with an omni-directional patterns in the lower frequency region, whereas at higher frequencies the patterns are slightly distorted because of the effect of the high order modes. In the $E$-plane, nearly omni-directional patterns are observed through the entire operated frequency band.

The simulated and measured gains of the wideband antenna are presented in Figure 9. It is found that the UWB antenna gain ranges from 1.298 dB to 4.997 dB for measurement, and from 2.108 dB to 5.707 dB for the simulated results. The measured results in terms of far-field radiation pattern and gain are in a good agreement with simulated ones.

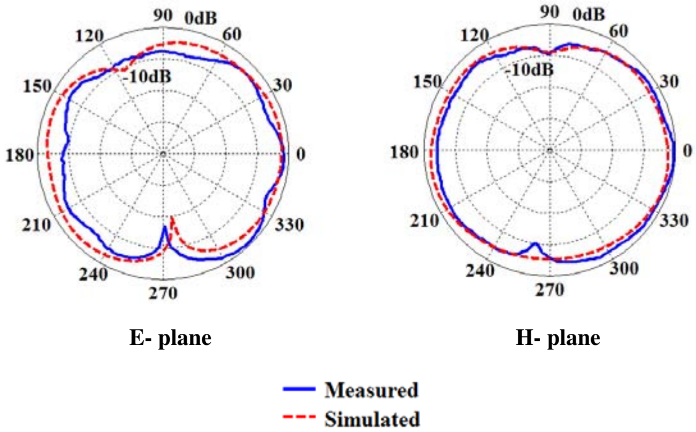



**Figure 8.** Measured and simulated radiation patterns of the NB antenna at 5.8 GHz.

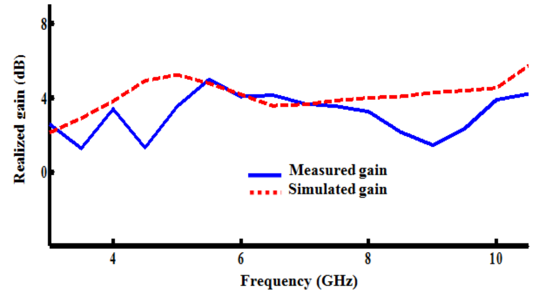



**Figure 9.** Simulated and measured gain of the proposed UWB antenna.

Table 2 reports the radiation efficiency of both ultra-wide band and narrow band antennas at selected frequencies. It can be seen that the UWB antenna has an average efficiency of 79.28%, and the rectangular slot provides high radiation efficiency, more than 76%, at its resonant frequency.

**Table 2.** Radiation efficiency at selected frequencies.

| *Frequency (GHz)* | *Radiation Efficiency, $\eta$(%)* | |
|---|---|---|
| | UWB Antenna | Narrow Band Antenna |
| 3.5 | 69.23 | / |
| 5.8 | / | 76.92 |
| 6.5 | 83.33 | / |
| 9.5 | 85.29 | / |

## 4. CONCLUSION

In this paper, a novel integrated UWB/narrow-band antenna conformed on a cylindrical substrate has been proposed. To validate the proposed antenna concept, an experimental prototype has been fabricated and measured. The obtained results have shown that the UWB antenna covers the 2–12 GHz band, suitable for sensing the UWB spectrum, the NB antenna operates around 5.8 GHz, and a stable radiation patterns over the operational band are given. Moreover, the proposed design provides low mutual coupling between the two antenna ports with transmission coefficient less than −20 dB, ensuring efficient integration between the two antennas. These features of the proposed integrated conformal design demonstrate that this antenna is suitable for communication applications, especially for wearable electronic applications.

## ACKNOWLEDGMENT

The authors would like to thank Dr. Gijo Augustin from the EMT-INRS centre, Canada, for his valuable helps during the fabrication and measurement.

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