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EXPERIMENTAL INVESTIGATIONS OF ULTRA-WIDE-BAND ANTENNA INTEGRATED WITH DIELECTRIC RESONATOR ANTENNA FOR COGNITIVE RADIO APPLICATIONS

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Abstract—In this paper, an ultra-wideband (UWB) patch antenna integrated with a dielectric resonator is proposed for cognitive radio applications. The patch antenna is fed by a coplanar waveguide (CPW) line, and it consists of a rectangular monopole having an elliptical base, and operates from 2.44 to 12 GHz. This UWB antenna is intended to collect the information. Moreover, the proposed structure integrates a narrow-band rectangular dielectric resonator antenna (RDRA) for operation, with very good isolation between the two ports (transmission coefficient S_{21} less than -20 dB). The RDRA provides a bandwidth from 5.23 GHz to 6.11 GHz. The electromagnetic analysis is carried out using tow commercial software tools. Furthermore, to validate the proposed concept, experimental measurements are also performed.

1. INTRODUCTION

Since the allocation of a bandwidth for UWB (from 3.1 to 10.6 GHz) by the Federal Communications Commission (FCC), UWB technology has attracted much interest for high data-rate wireless communication systems [1, 2]. Therefore, several techniques have been proposed to broaden the impedance bandwidth of small antennas and to optimize their characteristics. These techniques include several approaches, such as coplanar waveguide (CPW) fed slot antennas using a tuning stub

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with rectangular shape [3], circular shape [4], fork-like shape [5] and CPW-fed planar broad-band monopole antennas, having rectangular, circular, elliptical, and trapezoidal forms [6–9].

In recent years, some investigations for integrating both UWB and narrow-band antennas in the same package have been reported for cognitive-radio (CR), and medical imaging systems [10–14]. In such a structure, the challenge is to integrate two antennas into a limited space and to have good isolation between the two ports.

For category A of the cognitive radio systems, two antenna types are required: an UWB antenna used for sensing the spectrum and a narrow-band antenna that can be reconfigured for communication in a suitable frequency band [15]. In the previous work, the narrow-0band antennas are mainly based on the microstrip and slot antennas, which suffer from low radiation efficiency and high dissipation losses.

In this work, a new integrated UWB/narrow-band antenna is designed and fabricated. The structure is composed of two antennas: a rectangular-elliptical monopole UWB antenna used to sense the spectrum from 2.44 to 12 GHz and a rectangular dielectric resonator antenna (RDRA) for operation around 5.8 GHz. The UWB antenna is excited via a coplanar waveguide (CPW) transmission line while the rectangular DRA is fed by a microstrip transmission line through a narrow slot etched in the UWB antenna. The use of the DRA, as NB antenna, provides a broadside radiation pattern, improved gain and high radiation efficiency. Moreover, the hybrid configuration exhibits more isolation between ports, with transmission coefficient less than -20 dB, comparing to the existing designs.

This paper is organized as follows. The geometry and design of the antenna are described in the next section. In Section 3, the results of simulation and measurements are presented and discussed. Finally, a conclusion is given in Section 4.

2. ANTENNA DESIGN

Several UWB planar antennas have been designed with various shapes, slot [3–5] and monopole [6–9]) and different types of excitation, including microstrip and coplanar wave-guide CPW. They have been proposed to operate within the UWB spectrum band between 3.1 GHz and 10.6 GHz. Compared with microstrip antennas, the CPW-fed antenna has many attractive features, such as low radiation loss, easy integration with RF Monolithic Microwave Integrated Circuits (MMIC) and etching on only one side of the substrate providing a simplified configuration [16]. Our design consists of two parts: an UWB CPW-fed monopole antenna for sensing spectrum, and a rectangular dielectric resonator antenna used as a narrow-band antenna for communication.

Figure 1 shows the configuration of the proposed antenna. The UWB antenna is composed of a rectangular monopole having an elliptical base and printed on Rogers TMM6 substrate with permittivity $\varepsilon_r = 6$, loss tangent of 0.0023, thickness $h = 0.762\,\text{mm}$, and area of $42 \times 40\,\text{mm}^2$. The patch antenna is excited from Port 1 by a CPW transmission line having width Ws, as illustrated in Fig. 1.

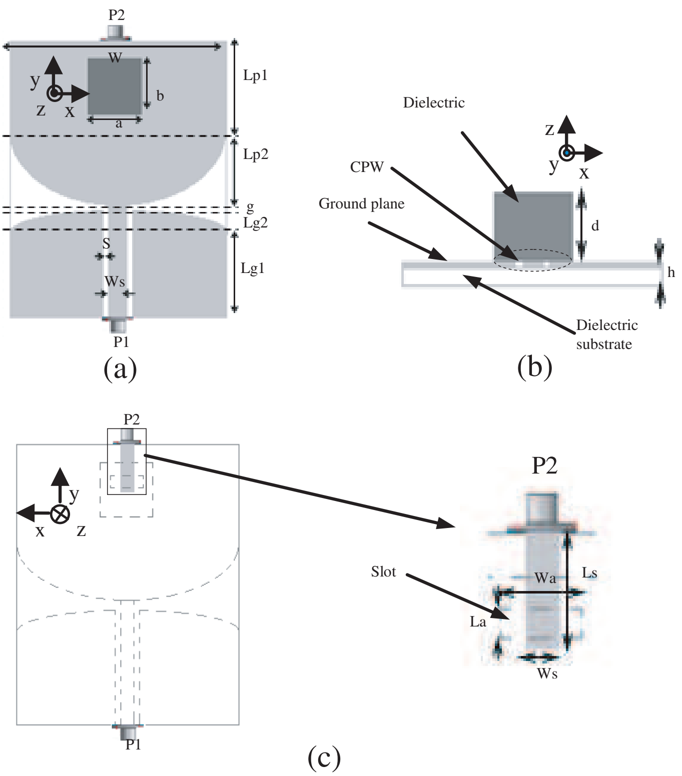


Figure 1. Geometry of the proposed antenna, (a) top view, (b) side view, (c) bottom view.

The narrow-band antenna consists of a rectangular dielectric resonator antenna, with dimensions $12.5 \times 12.5 \times 6.35\,\text{mm}^3$ and a relative permittivity $\varepsilon_{rd} = 9.8$ (TMM10i), placed above the patch antenna and excited from Port 2 by a microstrip transmission line (with width $Ws = 3\,\text{mm}$ and length $Ls = 12\,\text{mm}$) through a narrow aperture having dimensions $1 \times 6\,\text{mm}^2$.

The optimal design parameters for the proposed antenna are given as follows: $Ws = 3\,\text{mm}$, $S = 0.3\,\text{mm}$, $a = 12.5\,\text{mm}$, $b = 12.5\,\text{mm}$, $W = 40\,\text{mm}$, $Lg1 = 9\,\text{mm}$, $Lg2 = 4\,\text{mm}$, $g = 0.2\,\text{mm}$, $Lp1 = 15\,\text{mm}$, $Lp2 = 13.8\,\text{mm}$, $h = 0.762\,\text{mm}$, $d = 6.35\,\text{mm}$, $La = 1\,\text{mm}$, $Wa = 6\,\text{mm}$, $Ls = 12\,\text{mm}$.

Figure 2 shows the simulated current distributions on the UWB antenna without integrating the dielectric resonator at 3.5 GHz, 6 GHz, and 10.5 GHz, respectively. It can be seen that the surface current density on the other extremity of the patch antenna are very low. Fig. 3 shows that the surface current density at 5.8 GHz on both the UWB antenna and the integrated narrow-band antenna, when Port 1 is excited and Port 2 is terminated with $50\,\Omega$ and vice versa, is very low, what allows the integration with good isolation.

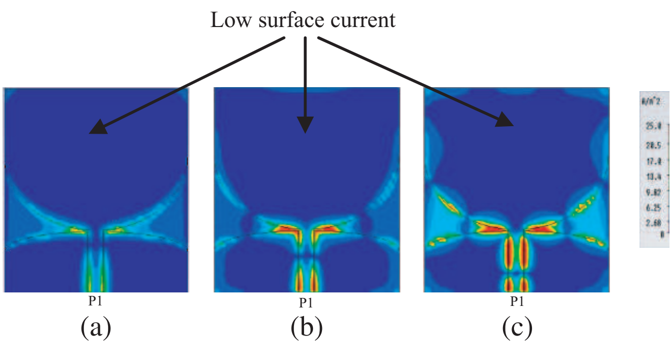


Figure 2. Surface current distributions on the UWBA without integrating narrow-band antenna at (a) 3.5 GHz, (b) 6 GHz, (c) 10.5 GHz.

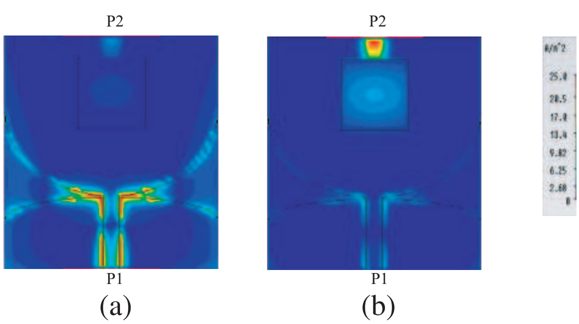


Figure 3. Surface current distributions on the proposed antenna at 5.8 GHz when excited from (a) Port 1, (b) Port 2.

3. RESULTS AND DISCUSSION

The simulations were carried out using two commercial electromagnetic simulators: Ansoft HFSS which utilizes Finite Element Method (FEM) in frequency domain, and CST Microwave Studio that 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 illustrated in Fig. 4. The measurements were carried out using Agilent 8722ES Network Analyzer and an anechoic chamber for S-parameter and radiation pattern measurements, respectively.

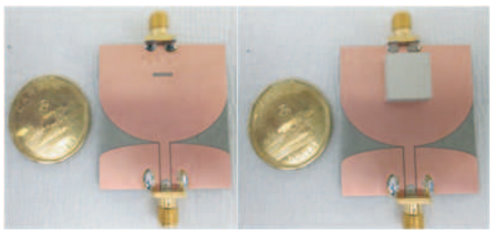
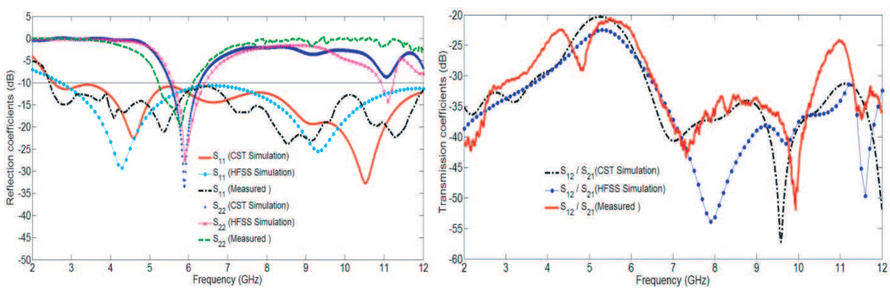


Figure 4. The photo of fabricated antenna prototype.



(a) (b)

Figure 5. S parameters of the proposed antenna, (a) reflection coefficients, (b) transmission coefficients.

The simulated and measured S parameters of the proposed structure are plotted versus frequency as illustrated in Fig. 5. From Fig. 5(a), it can be seen that the measured impedance bandwidth of the UWB patch antenna is from 2.44 GHz to more than 12 GHz for return loss below −10 dB (largely covering the 3.1–10 GHz UWB spectrum band). In addition, the proposed wideband antenna presents almost the same bandwidth in the simulation (from 2.54 GHz to 12 GHz for CST MS and from 2.7 GHz to 12 GHz for Ansoft HFSS).

The dielectric resonator antenna operates at 5.8 GHz where the fundamental TE_{111} mode of the DRA is excited (the operation details of this exciting rectangular DRA scheme are given in [17]), and provides an impedance bandwidth ($S_{22} < -10$ dB) of 900 MHz (5.2–6.2 GHz) in the measurement results and 800 MHz in the simulations (between 5.5–6.3 GHz for CST and 5.6–6.4 GHz from HFSS), which is suitable for High Performance Local Area Network (HiPerLAN or WLAN) band. In order to adjust the operating frequency of The DRA, to be suitable for Cognitive Radio systems, an external matching circuit can be used. The procedure for matching rectangular dielectric resonator antennas has been reported in recent papers [18, 19].

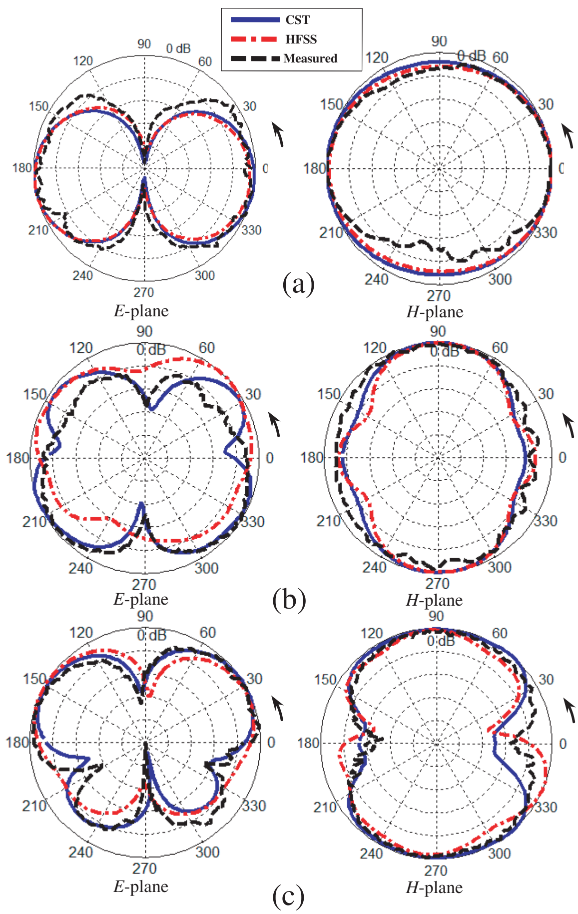


Figure 6. Radiation patterns for wideband antenna at (a) 3.5 GHz, (b) 6.5 GHz, (c) 10.5 GHz.

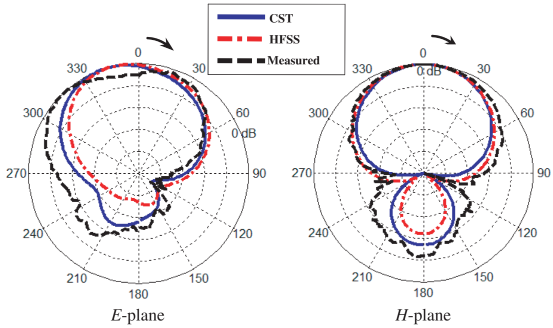


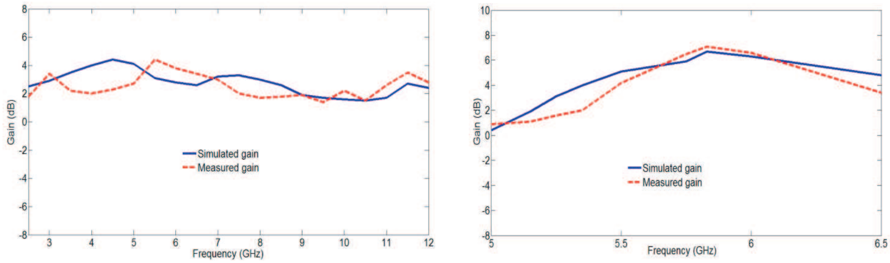
Figure 7. Radiation patterns for narrow-band antenna at 5.8 GHz.

From Fig. 5(b), it can be observed that the transmission coefficient is less than −20 dB in the full operational band ($S_{21} < -20$) for both simulated and measured results, which ensures very good isolation between the two antenna ports. The measured and simulated results are in a good agreement. However, the small discrepancy is mainly caused by the fabrication error, and the RF cable of the network analyzer, which slightly affects the measurements of small antennas.

The radiation patterns in the two main planes (E and H-planes) of both UWB and narrow-band antennas, at sampling frequencies (3.5 GHz, 6.5 GHz, and 10.5 GHz for the UWB antenna and 5.8 GHz for the band antenna), are simulated and measured, as illustrated in Figs. 6 and 7. From Fig. 6, it can be observed that the patch antenna has monopole-like patterns in the E-plane with little variation at 6.5 GHz and 10.5 GHz, while the H-plane radiation patterns are nearly omnidirectional through the entire resonant frequency band. It is noted that that the H-plane pattern exhibits a beam splitting at 10.5 GHz because the effects of higher order modes.

The simulated and measured gain of the wideband and narrow-band antennas are presented respectively in Figs. 8(a) and (b). It is found that the UWB antenna gain ranges from 1.4 dB to 4.4 dB for measurement and 1.6 dB to 4.4 dB for the simulated results. The narrow-band antenna gain reaching the 7.1 dB (6.7 dB for the simulation) at the resonant frequency (5.8 GHz). The measured results in terms of far-field radiation pattern and gain are in a good agreement with simulated ones.

Table 1 reports the radiation efficiency of both UWB and narrow-band antenna at selected frequencies. It can be seen that the patch antenna has an average efficiency of 84.3%, and the rectangular DRA provides high radiation efficiency, more than 98%, at its operated frequency.



(a) (b)

Figure 8. Simulated and measured gain of (a) UWB antenna, (b) narrow-band antenna.

Table 1. Radiation efficiency at selected frequencies.

Frequency (GHz)	*Radiation Efficiency*, η (%)	
	UWB Antenna	Narrow-band Antenna
3.5	96.8	/
5.8	/	98.46
6.5	80	/
10.5	76.2	/

4. CONCLUSION

A novel integrated UWB and narrow-band antenna has been studied, fabricated, and proposed for cognitive radio applications. The measured results show that the UWB antenna covers the 2.6–12 GHz band, suitable for sensing spectrum and the rectangular DRA operates around 5.8 GHz, which can be used for communication. Furthermore, the proposed design provides a good isolation between the two antenna ports (mutual coupling less than −20 dB) ensuring efficient integration. With these features, this antenna can be a suitable candidate for radar, medical imaging, and cognitive-radio systems.

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