FULLY RECONFIGURABLE FPGA-BASED COGNITIVE RADIO PLATFORM FOR RELIABLE COMMUNICATIONS

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ABSTRACT

Cognitive radio and dynamic spectrum access are two of the technologies that enable nowadays the securing of reliable communications. In order to solve some of the problems that appear in wireless communications (e.g. wideband interferences or multipath fading) it is necessary to carry out a complete change of the transmission band and not only small in-band channel changes. It is necessary to ensure that the new chosen band is uncorrelated with respect the previous one, in terms of coherence bandwidth and RF interference. A complete change of band does not only imply the reconfiguration of some parameters in the digital domain of the cognitive-radio, but requires the reconfiguration of the analog part too. On this basis, this paper presents a fully reconfigurable FPGA-based cognitive-radio platform for reliable communications. The platform provides runtime reconfiguration at all levels: FPGA baseband processing, RF front-end and antenna. This enables both in-band channel change and dual-band (ISM 868 MHz and 2.45 GHz) reconfiguration.

1. INTRODUCTION

Software Defined Radio (SDR) [1] and Cognitive Radio (CR) [2] are the technological answer that nowadays fulfils with the requirements that robust wireless communications demand (such as reliability, interoperability, opportunistic spectrum sharing, advanced networking, etc). Dealing with reliable communications, industrial environments are one of the use cases where SDRs or CRs can show their potential due to the harsh conditions present in this type of environment (electromagnetic interferences, metallic objects...). Dynamic Spectrum Access (DSA) is one of the techniques that cognitive radios can use in order to achieve the previous objective. The change of transmission frequency looking for an unused channel has proved to be an effective way of avoiding interferences [3,4]. Unfortunately, the presence of wide band interferences, multipath fading or attenuation-related issues require a change not in the channel but in the transmission band. This change of the transmission band cannot be carried out by just updating some parameters in the digital domain (actually the domain of SDRs or CR) but also requires some changes in the analog domain (RF front-end and antenna). Consequently, this paper continues with the work presented in [3,4] and introduces a fully reconfigurable, FPGA-based cognitive-radio platform for reliable communications, where the use of a reconfigurable antenna allows to carry out the change of the transmission band.

Therefore, the proposed architecture provides runtime reconfiguration capabilities at all the levels of the system, namely: FPGA baseband processing, RF front-end and antenna. The main contributions with respect to the previous works are the design and implementation of a frequency reconfigurable antenna that can switch between the two ISM bands, and the implementation of a cognitive signal detection algorithm based on the spectral characteristics of the signal. Similarly to the previous developments, FPGA dynamic partial reconfiguration and rapid prototyping tools are used in the design and implementation of the digital part of the platform.

2. PLATFORM DESCRIPTION

The designed cognitive radio platform consists of a transmitter and a receiver node that implement a cognitive wireless communication at 1.6 Mbps. The system uses QPSK modulation and is able to change its transmission frequency depending on the availability of the channel. The platform aims to achieve the maximum possible flexibility and reconfigurability at the service of reliable communications. On this purpose, it is reconfigurable at the three main parts that make up each of the nodes: the Virtex 6 FPGA in charge of baseband processing, the RF front-end and the antenna. A block diagram and the implementation of the platform can be seen on Figure 1 and Figure 2 respectively.

2.1. Baseband Processing

Reconfiguration in the FPGA baseband processing is carried out via FPGA dynamic partial reconfiguration [5]. This

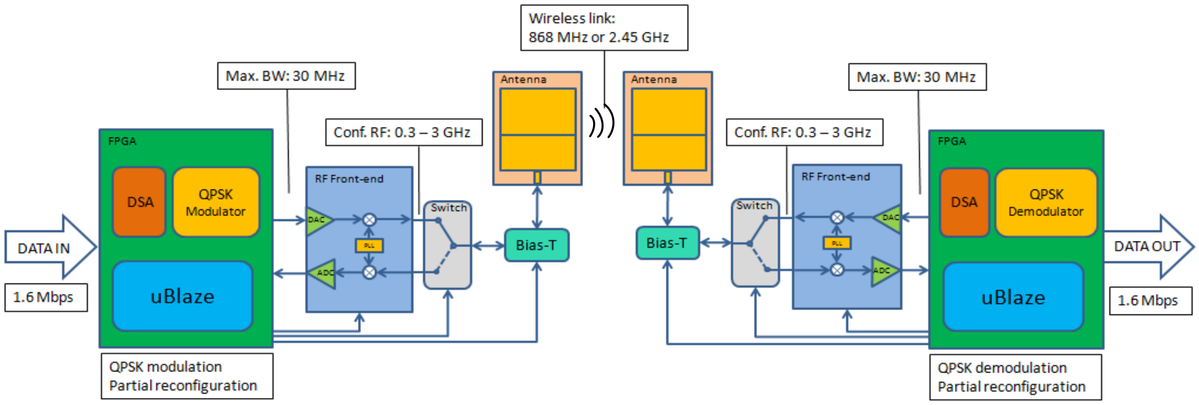


Figure 1: Block diagram of the fully reconfigurable cognitive radio platform

feature enables the change of functionality of part of the FPGA while the rest continues unaltered, which leads to a reduction in the required amount of FPGA resources and consequently in its size. The implemented baseband processing is mainly divided into two tasks, present both in the transmitter and in the receiver node: data modulation/demodulation and DSA (Dynamic Spectrum Access). The first task, in which FPGA dynamic partial reconfiguration is applied, performs the QPSK modulation of the input data in the transmitter and recovers it in the receiver. The DSA task, in turn, looks for channel availability in the transmitter prior to any transmission and performs the search of signal in the receiver. Taking into account that no information about the transmission frequency is provided to the receiver, it carries out an analysis of the spectral characteristics of the received signal in order to separate the valid one from the possible interferences. These signal processing tasks have been hardware-implemented in the FPGA using System Generator [6], Xilinx's rapid prototyping tool. Besides, both FPGAs in the transmitter and the receiver implement a MicroBlaze processor mainly in charge of the control of the different parts of the architecture: dynamic partial reconfiguration, programming of the front-end and control of the antenna. FPGA dynamic partial reconfiguration is used in this implementation in order to perform small in-band frequency changes (< 10 MHz) in the transmission frequency by reconfiguring the digital oscillator that generates the IF frequency; however, it could also be used in order to change any other parameter in the aforementioned baseband signal processing tasks (e.g. modulation, data rate, etc.).

2.2. RF Front-End

A Nutaq Radio420S module has been chosen as reconfigurable RF front-end for the transmitter and the receiver [7]. This module provides a carrier frequency

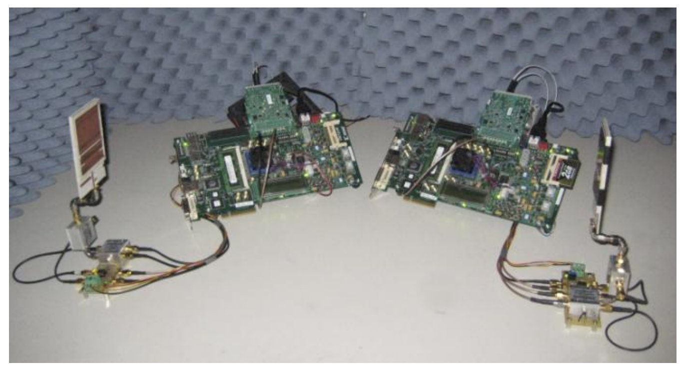


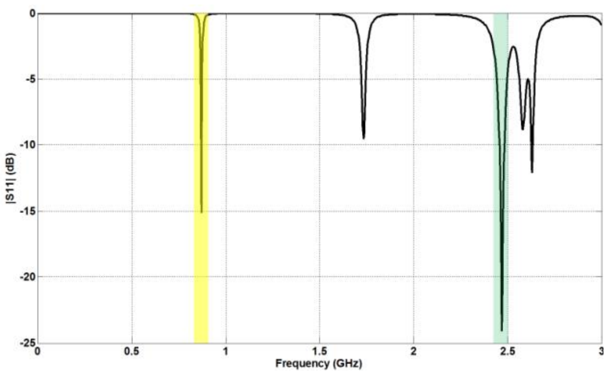
Figure 2: Implementation of the fully reconfigurable cognitive radio platform

between 300 MHz and 3 GHz with a bandwidth between 1.5 MHz and 28 MHz. Its transmitted power can be adjusted between -21.5 dBm and 10 dBm, and its sensitivity ranges between -90 dBm (0.3-1.5 GHz) and -103 dBm (1.5-3 GHz). It should be raised that this module has separate RF transmission and reception ports. Hence, in order to use a single antenna, a RF-switch (Mini-Circuits ZYSW-2-50DR) has been used. This switch has a wideband operation (DC-5 GHz) and is controlled with a TTL signal coming from the main FPGA.

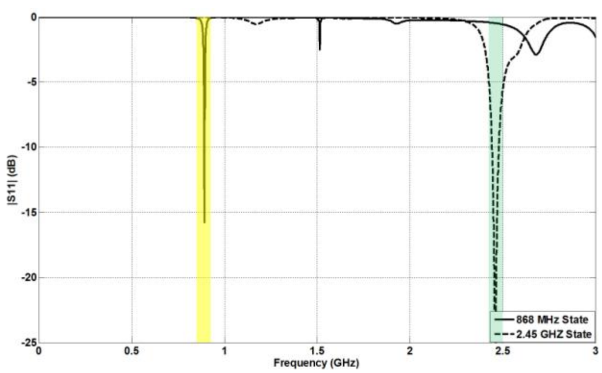
2.3. Antenna

In industrial environments, the antenna is likely to have metallic objects in its vicinity. As it has been studied in [8] a monopole-like antenna exhibits significant variations in its input impedance and in its radiation efficiency when it is placed near a metallic object, so its clearance distance (minimum distance between the antenna and the metallic object where the antenna still works properly) must be determined. Hence, to make the antenna suitable for harsh environments, a microstrip topology has been chosen which shows a great robustness against any object placed under the antenna.

The use of reconfigurable antennas provides extra filtering against undesired signals, compared to the multi-band antennas used in current communications systems (e.g. smart-phones). When using a multiband antenna both bands are covered at the same time, which means that if any interference is detected, even though the whole system changes its operating frequency the interference is received and the front-end has to be able to filter the undesired signal. In Figure 3 a comparison is shown between the return loss of a microstrip patch multiband antenna and a microstrip patch reconfigurable antenna. It can be observed that while the multiband antenna (Figure 3(a)) is receiving the power at both bands, the reconfigurable antenna (Figure 3(b)) receives only the power of the working band.



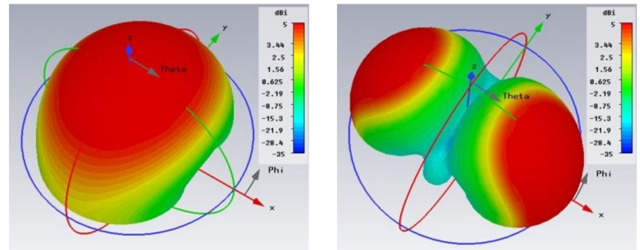
(a)



(b)

Figure 3: Simulated return loss: (a) Multiband antenna (b) Reconfigurable antenna

Moreover, by using microstrip patch reconfigurable antennas, it is possible to keep the radiation features of the different bands alike. It should be taken into account that if the radiation pattern is not kept constant it could happen that the antenna performs a broadside radiation pattern in one band and an endfire radiation pattern in the other. Hence, in the direction where one of the bands has its maximum the other will perform a null of radiation, resulting in a problem



f = 868 MHz f = 2.45 GHz

Figure 4: Simulated radiation pattern of a microstrip patch multiband antenna

to align properly the antennas in order to ensure the correct work of the two bands. In Figure 4 the radiation pattern of a microstrip patch multiband antenna is shown. As it can be observed, at the 868 MHz band it shows a broadside radiation pattern while it exhibits an endfire radiation pattern at 2.45 GHz. In that case, if the antennas are meant to be placed facing one to each other, at 2.45 GHz the antenna will exhibit a null of radiation in the direction where a maximum would be desirable, leading to a decrease in the range of the communication link. However, when using a microstrip patch reconfigurable antenna the radiation patterns between the two bands are kept alike as shown in Figure 5 (b) and Figure 6 (b).

Therefore, a frequency-reconfigurable antenna has been designed to work in two ISM bands (868 MHz and 2.45 GHz). In order to ensure the required bandwidth in both bands, a reconfigurable matching network (RMN) has been designed and added to the antenna. The RMN is a microstrip stub based network and the reconfiguration is handled through PIN Diodes such as in [9]. At the lower band, the antenna has a matching bandwidth of 6 MHz, while at the upper band the bandwidth is 100 MHz. The switching between the two bands is handled by a pair of PIN Diodes. These PIN Diodes are placed in the antenna and they are fed by DC lines. It should be noted that both the RF signal and the DC power are provided by the FPGA and combined with a Bias-T (Mini-Circuits ZFBT-4R2G-FT). Depending on the frequency of operation, the FPGA will provide a DC voltage to the PIN diodes that control the antenna and the RMN states. In Table 1 it is shown the PIN diode's state depending on the operation band.

Table 1: States of the PIN Diodes

		ISM 868 MHz	*ISM 2.45 GHz*
Antenna's PIN Diode	*#1*	*ON*	*OFF*
	#2	*ON*	*OFF*
RMN's PIN Diode	*#1*	*OFF*	*ON*
	#2	*OFF*	*ON*

3. MEASUREMENTS

In this section the measurements of the basic characteristics of the designed system are presented. Table 2 shows the FPGA resources consumed by the baseband digital part of both the transmitter and the receiver of the cognitive-radio platform.

Table 2: FPGA Resource Consumption

	SLICE	Flip-Flop	LUT	BRAM	DSP48
Transmitter	7180 (20%)	13943 (4%)	14410 (4%)	97 (23%)	630 (82%)
Receiver	8834 (23%)	23902 (6%)	22765 (15%)	98 (23%)	368 (47%)

Table 3: Frequency Reconfiguration Time

FPGA	Front-end	Antenna
94 µs	79 µs	53 µs

It can be observed the small form factor of the designed baseband processing algorithms occupying only a 20–23 % of the FPGA (assuming the number of SLICES as the most representative value of the design's size).

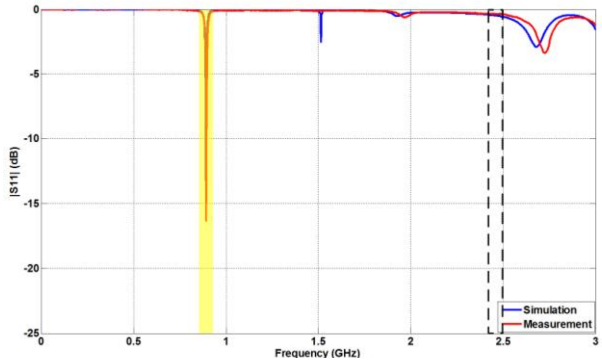
On the other hand, Table 3 shows the time that the different components in the system require for carrying out a frequency change.

Two different cases have to be distinguished though: the in-band channel change and the complete band change. The first case only requires the partial reconfiguration of the FPGA; hence the front-end and the antenna remain unaltered. On the other hand, in case a complete band change is needed, the front-end and the antenna have to be reconfigured and the FPGA remains unchanged in this specific application.

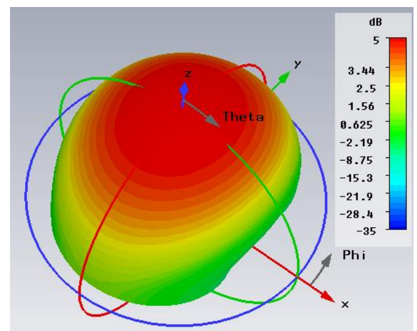
Eventually, Figure 5 and 6 show the return loss and the radiation pattern for the two frequency states (i.e. 868 MHz and 2.45 GHz). In the return-loss pictures, the operational band is colored and the non-operational band is marked with a dashed line. It can be seen that in the working band (e.g. at 868 MHz, Figure 2 (a)) the antenna shows a high degree of impedance matching (low return loss), which means that the vast majority of the received power is delivered to the antenna, while in the other band (e.g. 2.45 GHz at Figure 2 (a)) the impedance matching is very low, so almost all the power is reflected. Regarding to radiation features, it can be observed that the radiation patterns are quite alike in both bands, as it was expected.

4. CONCLUSION

This paper has presented a fully reconfigurable FPGA-based cognitive-radio platform for reliable communications. The proposed architecture provides runtime reconfiguration at all levels (FPGA baseband processing, RF front-end and antenna) enabling both in-band channel change via FPGA

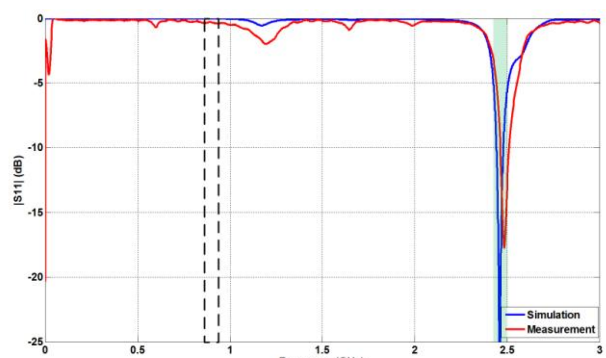


(a)

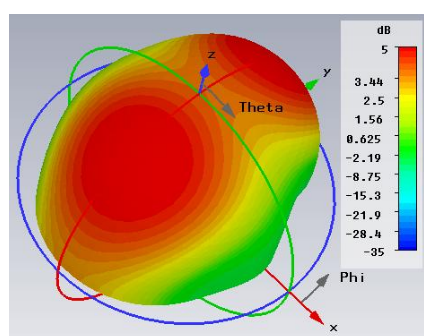


(b)

Figure 5: Reconfigurable antenna at ISM 868 MHz state: (a) Simulated and measured return loss; (b) Simulated radiation pattern at 868 MHz



(a)



(b)

Figura 6: Reconfigurable antenna at ISM 2.45 GHz state: (a) Simulated and measured return loss; (b) Simulated radiation pattern at 2.45 GHz dynamic partial reconfiguration and dual-band (ISM 868 MHz and 2.45 GHz) reconfiguration. The system demonstrates the feasibility, necessity and benefits of joining reconfigurable components at different system levels in a single architecture in order to secure reliable communications.

5. REFERENCES

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