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A Comparison Between Different Cognitive Radio Antenna Systems

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Abstract— **This paper presents different reconfigurable antenna systems for a cognitive radio environment. Mainly, two different schemes are discussed. The first one is based on detecting the unused frequency bands via an ultra-wideband (UWB) antenna and tuning the reconfigurable antenna operation correspondingly. The second scheme is based on performing transmission via a UWB antenna while producing notch frequencies to minimize interference between the cognitive radio users. The use of reconfigurable filters within the antenna structure for both schemes is also highlighted. A comparison between both schemes is finally presented and discussed.**

Keywords-band-pass, band-stop, channel sensing; cognitive radio; filter, reconfigurable antenna; UWB;

I. INTRODUCTION

A cognitive radio system decides to change its transmitter parameters based on the interaction with the environment in which it operates. The monitoring of the wireless spectrum is the key in cognitive radio since the spectrum can be idle for most of the time. The aim of such a system is to improve the spectral utilization by dynamically interacting with the RF environment. A cognitive radio is an intelligent communication system that is able to *learn* from the environment and *adapt* to the variations in its surrounding by adjusting the transmit power, carrier frequency, modulation strategy or transmission data rate. Therefore, the main objective of a cognitive radio system is to ensure highly reliable communication whenever and wherever needed [1].

In such a system we should differentiate between two types of users. Primary users, who own the channel, have the right to communicate at any time. Secondary users access the channel whenever it is idle. They should minimize interference with other active primary users and must leave the channel whenever the idle primary user wants to re-communicate [2-3].

In this paper, two different RF front-end systems for cognitive radio are presented. The first one is intended for the spectrum "interweave" cognitive radio. For this case, both, a UWB antenna for channel sensing and a reconfigurable antenna for communication are required. In the second case, we discuss how to implement an antenna system for the spectrum "underlay" cognitive radio. For this case, primary and secondary users can transmit simultaneously. Secondary users should transmit below a specific interference margin. This is achieved via a UWB antenna that has the capability to tune its notch frequency to minimize interference between primary and secondary users.

Some research is done on the design of reconfigurable antennas for the "interweave" and "underlay" cognitive radio environments [4-8]. In section II, we present an antenna system for the "interweave" cognitive radio. It is based on optically reconfigurable antennas. Section III discusses an antenna system for the "underlay" cognitive radio. The implementation of reconfigurable antennas by tuning their operating or notch frequencies using band-pass or band-stop filters for the "interweave" or "underlay" cognitive radio are shown in Section IV. The comparison between the different antennas structures is shown in Section V. Concluding remarks are included in section VI.

II. ANTENNA DESIGNS FOR THE "INTERWEAVE" COGNITIVE RADIO ENVIRONMENT

For this case, the RF front-end system must be able to sense the spectrum and search for the unused frequency bands. A sensing antenna is needed to capture the spectrum holes. The data acquired by the sensing antenna is analyzed and immediately the reconfigurable antenna is tuned to transmit at some specified frequencies. Thus, the secondary users are now able to utilize the spectrum holes.

Since two antenna structures are required to achieve an "interweave" cognitive radio environment, an antenna engineer should consider three key parameters during the design process. The first parameter is the isolation between the two ports of the sensing and the reconfigurable antennas. The operation of one antenna should not affect the other. The second parameter is the dimension of the cognitive radio antenna system which consists of the sensing and the reconfigurable antennas. The space required to accommodate both antennas should be minimal. The last parameter is that the sensing and the reconfigurable antennas should have an omni-directional radiation pattern. Both antennas must be able to receive a signal at any given direction. A general layout for an "interweave" antenna system is shown in Fig. 1.

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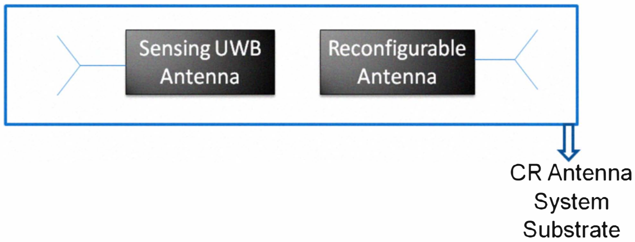

Fig. 1 A layout for an antenna system for the "interweave" cognitive radio environment

Here the reconfigurable antenna is operated by utilizing photoconductive switches that are used to connect different radiating parts. The activation of the photoconductive switches is done by integrating laser diodes within the antenna substrate. The detailed antenna structure is shown in Fig. 2. The total dimension of the whole antenna system is 75 mm X 30 mm. The sensing antenna occupies 40% of the total cognitive radio antenna area. The reconfigurable antenna includes two silicon switches to allow tuning its resonant frequency [9].

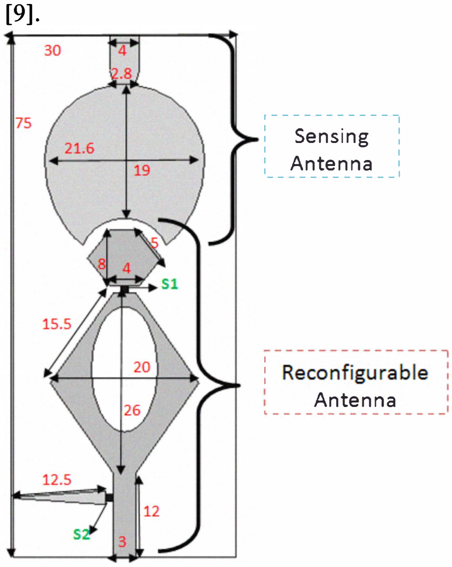

Fig. 2 An "interweave" cognitive radio antenna system using optically reconfigurable antenna

The sensing and the reconfigurable antennas are fed via a stripline and they both have partial ground in order to allow radiation above and below the substrate. The antenna bottom layer is shown in Fig. 3. The sensing antenna covers the band from 3 GHz till 11 GHz. Fig.4 shows the tuning in the operating frequency of the reconfigurable antenna for the different switch combinations. The measured coupling for the case when both switches are OFF and when S1 is ON are shown in Fig. 5. A minimum coupling of -20 dB is obtained.

III. Antenna Designs For The "Underlay" Cognitive Radio Environment

For this type of cognitive radio communication, we need the capability to achieve UWB communication with tunability in the antenna notch frequency. A UWB antenna is required to allow secondary users to continuously transmit with low power in short distance communication. To minimize the interference between the primary and the secondary users, the UWB antenna should produce notches in its operating band.

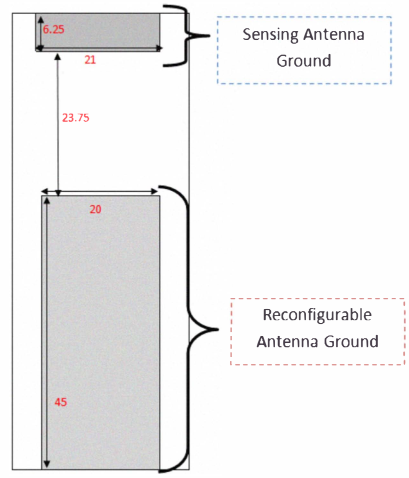

Fig. 3 The ground plane for both the sensing and the reconfigurable antennas

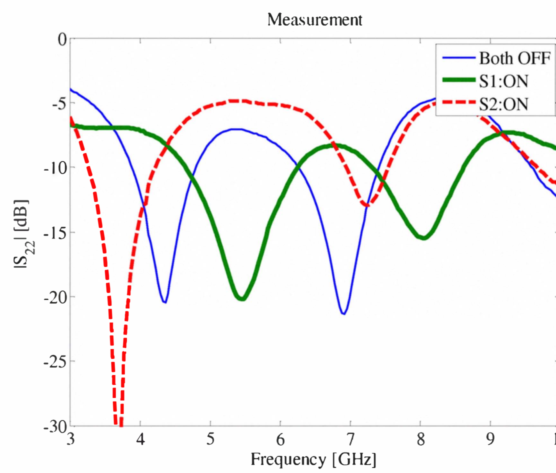

Fig. 4 The tuning in the reconfigurable antenna operating frequency

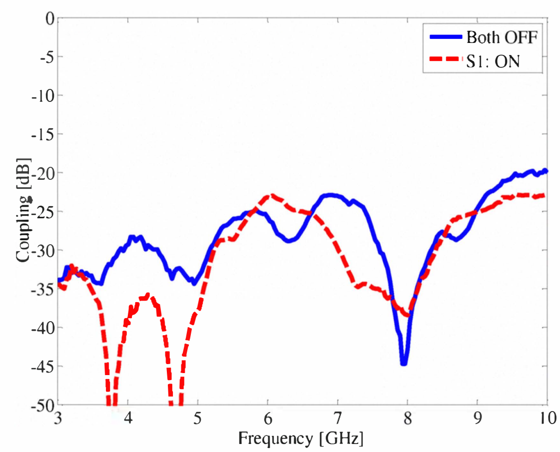

Fig. 5 The measured coupling when both switches are OFF and when S1 is ON

These notches should be reconfigurable based on the primary users' activity. The antenna should be able also to cancel its notch frequency in case a scan for the whole UWB band is needed.

An antenna engineer should consider the following three parameters during the design process of such types of cognitive radio antenna systems. The first parameter is to achieve a reflection coefficient at the notch frequency of the UWB antenna as high as possible (close to 0 dB), in order to minimize the interference between the primary users who operate at the notch frequency and the secondary users. The second parameter is to achieve a minimal fluctuation in the UWB antenna gain. The last one is to preserve an omni-directional pattern over the whole UWB band. A general layout for an "underlay" antenna system is shown in Fig. 6.

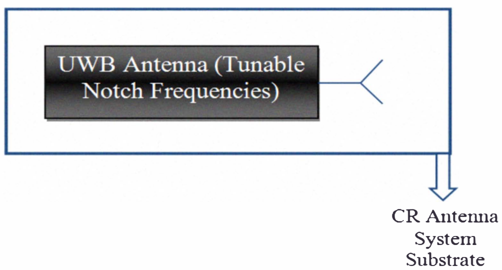

Fig. 6 A layout for an antenna system for the "underlay" cognitive radio environment

The "underlay" antenna system discussed here has three band notches that are independently controllable. One, two, three, or none of these notches can appear in the frequency profile of the UWB antenna. Two circular split ring slots are etched on the patch, and two identical rectangular split rings are placed close to the microstrip line feed. Four electronic switches, S1, S2, S3 and S3', are mounted across the split ring slots and split rings, as shown in Fig. 7 [10].

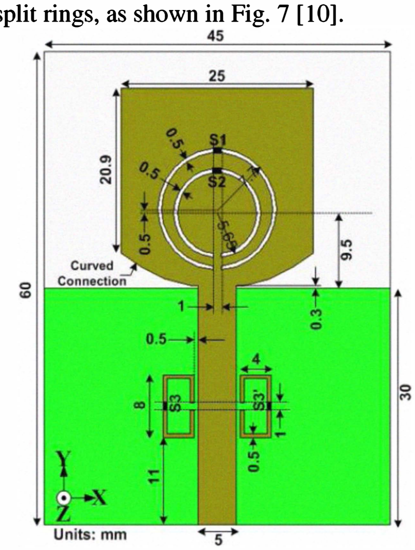

Fig. 7 An "underlay" cognitive radio antenna system

The measured reflection coefficients for the four different cases [Case 1: S2 ON, Case 2: S1 ON, Case 3: All ON and Case 4: S1/S2 ON] are shown in Fig. 8. The antenna tunes its notch frequency correspondingly and is able to operate throughout the whole UWB band when both S1 and S2 are ON.

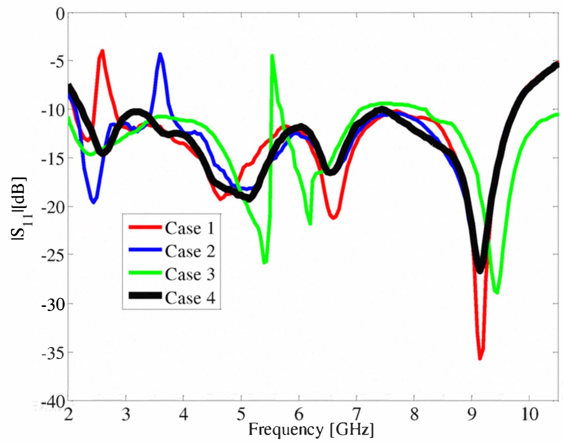

Fig. 8 The tuning in the band notch of the "underlay" cognitive radio antenna system

IV. ANTENNA DESIGNS FOR THE "INTERWEAVE/UNDERLAY" COGNITIVE RADIO ENVIRONMENT USING RECONFIGURABLE FILTERS

The reconfigurability in both cognitive radio antenna systems can be obtained by integrating a tunable filter with the antenna structure. The filter is incorporated within or parallel to the antenna feeding line. The antenna should cover the UWB range. For the "interweave" cognitive radio, a band-pass filter should be designed to allow the antenna to tune its operating frequency according to the spectrum holes. As for the "underlay" cognitive radio antenna system, a band-stop filter should be implemented so that the antenna tunes its notch frequency according to the primary user activities. For both scenarios, we should be able to turn OFF the filter to scan the whole UWB band.

An antenna structure for the "interweave" scenario is shown in Fig. 9. It consists of a dual-sided tapered slot antenna (DTSA) with a reconfigurable defected microstrip (DMS) band-pass filter. The DMS filter is integrated within the microstrip feed line of the antenna structure. Such configuration allows the antenna to be frequency reconfigurable based on the mode of operation of the filter [11]. The reconfigurability is achieved by integrating 9 switches within the T-slot of the filter. The switches are activated in pairs of two from the two edges of the T-slot. The purpose of the switches is to change the length of the slot in order to produce a reconfigurable band-pass filter. The corresponding antenna reflection coefficient is shown in Fig. 10 for the case when:

1- All switches are OFF (data 1)
2- 8 switches are ON (data 2)
3- All switches are ON (data 3)
4- The filter is OFF (data 4)

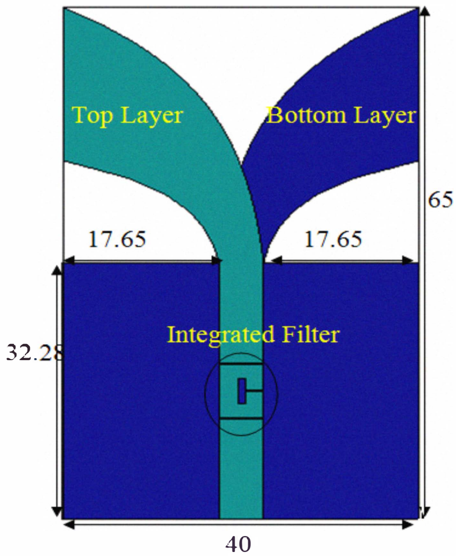

Fig. 9 An "interweave" cognitive radio antenna system with reconfigurable band-pass filter

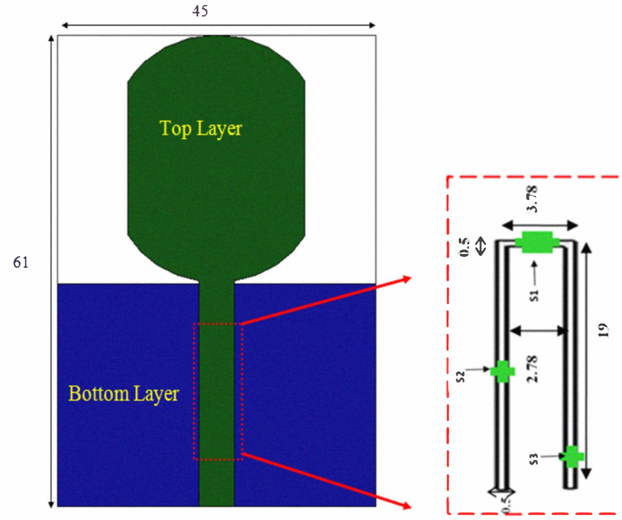

Fig. 11 An "underlay" cognitive radio antenna system with reconfigurable band-stop filter

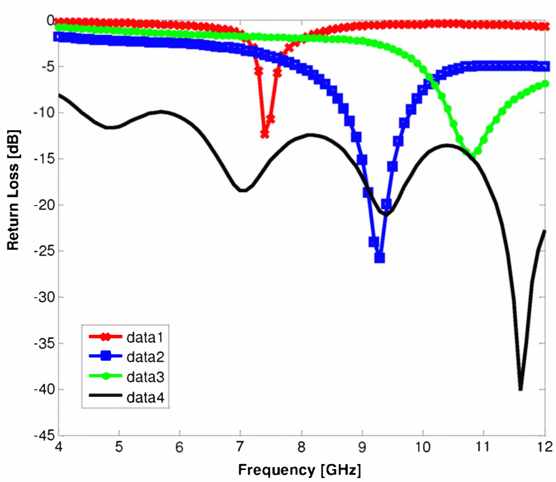

Fig. 10 The reflection coefficient for the "interweave" antenna system for different switch combinations

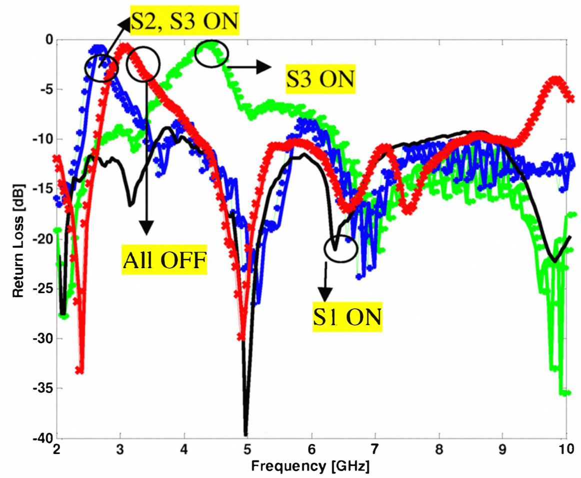

Fig. 12 The reflection coefficient for the "underlay" antenna system for different switch combinations using reconfigurable band-stop filter

An antenna structure for the "underlay" scenario is shown in Fig. 11. The dashed rectangle corresponds to the position where the filter should reside in the partial ground of the antenna. The filter is integrated parallel to the microstrip feeding line of the antenna structure. By changing the length of the U-slot, a notch is created at a frequency proportional to the slot length [12]. Three switches S1, S2, and S3 are integrated within the U-slot of the filter as shown in Fig. 11. The measured antenna reflection coefficient for the case when S1 ON (black curve), {S2, S3} ON (blue curve), All OFF (red curve), S3 ON (green curve) are shown in Fig. 12.

V. Comparison Between Both Scenarios

In the previous sections, different antenna structures are presented for both the "interweave" and "underlay" spectrum sharing cognitive radio environment. For the "interweave" spectrum sharing case, secondary users are only present whenever primary users are idle as opposite to the "underlay" case where secondary users always transmit using the impulse radio based UWB technology (IR-UWB) or the orthogonal frequency division multiplexing based UWB (UWB-OFDM).

From the antenna side, the "interweave" spectrum sharing case requires two antennas. One antenna continuously senses the channel and searches for unused frequency bands. The second antenna performs the required communication. On the other hand, for the "underlay" spectrum sharing only one antenna is needed. This antenna should be able to perform UWB transmission. Tunability in the antenna notch frequencies is required to minimize the interference between primary and secondary users. The disadvantage from using this kind of cognitive radio is that short range communication is a must with restriction on the transmission power levels.

Antenna systems for both cognitive radio scenarios can also be implemented by integrating reconfigurable filters with the antenna structures. The importance of such topology is that no switching elements are incorporated within the radiating plane of the antenna. The filter and its switching circuitry lie within the feeding line of the antenna. This has the advantage of minimizing the negative effects produced by the switching elements on the antenna operation. It is essential to note that the disadvantage from using reconfigurable band-pass filter for the "interweave" case lies in the fact that the channel sensing cannot be done continuously. The antenna is able to scan the whole UWB only by turning the filter OFF and then it tunes its operating frequency correspondingly by turning the filter ON.

The important point is that for both cognitive radio scenarios, the RF front-end must have the capability to change its operating or notch frequency. This must be achieved by designing reconfigurable antenna structures or antenna structures with reconfigurable band-pass/band-stop filters. The decision on what type of cognitive radio scenarios to be used depends on the communication system and also on the design requirements.

VI. Conclusion

In this paper, the RF front-end for the "interweave" and "underlay" cognitive radio environment are presented. For the "interweave" case, a cognitive radio antenna system consists of a sensing and a reconfigurable antenna. Another solution is to design a reconfigurable band-pass filter with the capability to have the filter turned OFF for a given amount of time in order to perform channel sensing. As for the "underlay" case, the RF front-end consists of either a UWB antenna that is able to reconfigure its notch frequency by using some kind of switching elements or a reconfigurable band-stop filter integrated with a UWB antenna.

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