Implementation of a Cognitive Radio Front-End Using Optically Reconfigurable Antennas

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***Abstract* – This paper presents a reconfigurable radio front-end antenna scheme suitable for cognitive radio communications. Our scheme comprises of an UWB antenna structure (antenna-1) and a reconfigurable antenna structure (antenna-2) incorporated together on the same substrate. The UWB antenna-1 is used for channel sensing while the reconfigurable antenna-2 is designed to frequency-hop between pre-determined communication channels. The reconfiguration of antenna-2 is achieved by using photoconductive switches which are selectively illuminated by laser light from a series of integrated laser diodes. A prototype was fabricated and tested to prove the applicability of our proposed radio front-end scheme.**

1 INTRODUCTION

Cognitive radio communication schemes have begun to receive a lot of attention with the advent of 3G and 4G mobile communication standards. A cognitive radio system is capable of continuously monitoring gaps in the finite-extent frequency spectrum occupied by other wireless systems, and then dynamically altering it's transmit/receive characteristics to operate within those unused carrier frequencies channels; thereby minimizing interference with other wireless systems and maximizing throughput [1]. A generic implementation of such a scheme would require a "sensing antenna" that continuously monitors the wireless channel searching for unused carrier frequencies, and a "reconfigurable transmit/receive antenna" to perform the data transfer over unused frequency channels [2].

A top-level logic flowchart for one possible implementation of a cognitive radio communication scheme is shown in Fig.1. The sensing antenna is an UWB antenna and would communicate with the "Spectrum Sensing" module of the cognitive radio engine. The reconfigurable antenna should be able to tune its transmitting frequency depending on the logic control acquired from the "Spectrum Decision" module.

Some research has been done on the design of reconfigurable antennas for cognitive radio system. In [3], a quad-antenna with a directional radiation pattern is presented. The operating frequency can be adjusted by the use of MEMS switch making it suitable for cognitive radio applications. The authors in [4] incorporate both the sensing and the reconfigurable antennas into the same substrate. The reconfigurable antenna is able tune between 3GHz-5GHz and 5GHz-8GHz. An antenna cross-talk of less than -10 dB was achieved between the sensing and the reconfigurable antennas. A reconfigurable C-slot microstrip patch antenna is proposed in [5]. Reconfigurability is achieved by switching on and off two patches using PIN diodes. The antenna can operate in a dual-band or in a very wide band mode.

The antenna system discussed in this paper consists of two radiating structures incorporated together on the same substrate. The first radiating structure is an ultra wideband antenna covering the spectrum from 3 GHz to 11 GHz for channel sensing. The second radiating structure is a frequency reconfigurable antenna to achieve data-communication with other wireless devices over unused frequency channels. The reconfiguration of the second antenna structure is obtained via photoconductive switches illuminated by laser light of suitable wavelength.

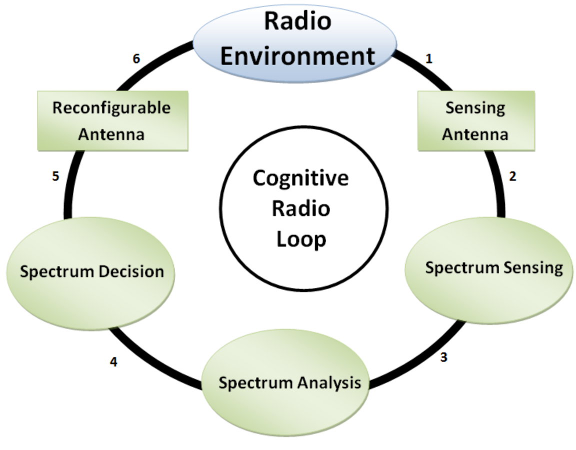

Figure 1: The Cognitive Radio Chain.

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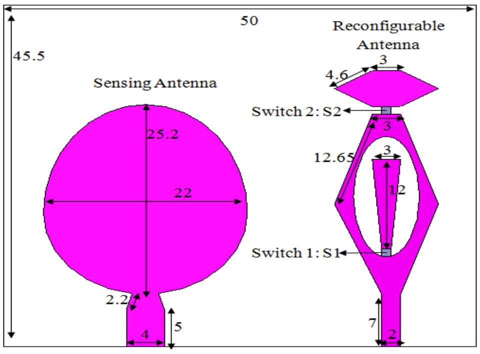
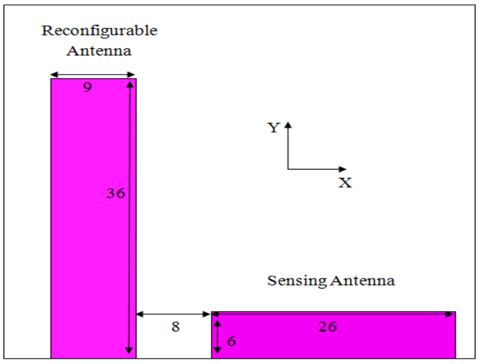
2 ANTENNA STRUCTURE

The antenna top layer is shown in Fig.2 (a); its bottom layer is shown in Fig.2 (b). It is printed on a Taconic TLY substrate with a dielectric constant of 2.2 and a height of 1.6 mm. The sensing and the reconfigurable structures are fed via a stripline. They both have a partial ground in order to allow radiation above and below the substrate. The reconfigurable antenna ground is 36mm × 9mm. It has a longer length than the ground of the sensing antenna in order to accommodate the copper piece which acts as a fixture for the laser diodes and also serves as a thermal sink to dissipate heat generated by the laser diode. The distance between the two ground planes is chosen to be 8 mm to minimize the coupling between the two structures. All the dimensions shown in Fig.2 are in mm.



(a)



(b)

Figure 2: The antenna structure (a) Top Layer (b) Bottom Layer

The sensing antenna is a modified elliptical shaped monopole. It covers the band from 3GHz up till 11 GHz. It has a major axis of 25.2 mm (≈0.38*λ_{eff}) and a minor axis of 22 mm (≈0.35*λ_{eff}) where λ_{eff} corresponds to the lowest frequency (3 GHz). A small tapered microstrip section matches the input impedance of the antenna to the input impedance of the patch. The design of the patch, the partial ground plane, and the feed matching section guarantee an ultra-wideband response of the sensing antenna.

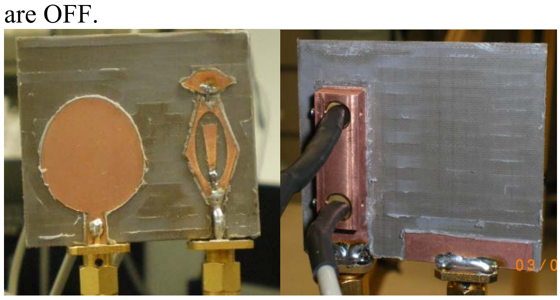
The reconfigurable antenna is a modified printed monopole. It has an elliptical slot that contains a triangular arm. Both structures are connected together via a Silicon switch. At the end of the modified monopole, a hexagonal patch is attached via another Silicon switch. The detailed dimensions of the different parts of the reconfigurable antenna are shown in Fig.2 (a).

The Si switch used in this work is n-type of an initial carrier concentration of 10^{15} cm^{-3}. It is 1mm × 1mm with a thickness of 280 µm. Photoconductive switches offer superior performance as compared to MEMs, PIN diodes and lumped elements. The photoconductive approach does not require the use of bias lines, which typically lie in the plane of the antenna and can interfere with the electromagnetic performance of the antenna. Also, photoconductive switches exhibit extremely fast switching speeds, and consume low current and voltage levels. By illuminating the Si switches by light of suitable wavelength from the laser diode (785 nm), the mobility of charges in the Si decreases but their density increase. This increase in the charge carrier density results in a general increase in the conductivity of a semiconducting material [6].

3 FABRICATION AND RESULTS

The proposed antenna structure was fabricated as shown in Fig.3 (a) (top layer) and Fig. 3(b) (bottom layer). In order to couple the light from the laser diodes efficiently, two holes of diameter 1mm are drilled through the substrate. The copper piece used to integrate the laser diodes with the antenna structure is shown in Fig.4. It is attached to the ground of the reconfigurable antenna as shown in Fig.3 (b). It acts as the ground of the reconfigurable antenna where inside each drill a laser diode is fixed.

The comparison between the measured and the simulated return loss for the sensing antenna is shown in Fig.5. The antenna is able to cover the spectrum from 3 GHz up to 11 GHz. Good qualitative agreement is observed between simulation and experiments. This data-set corresponds to the case when both switches are OFF.



(a) (b)

Figure 3: The fabricated antenna structure (a) Top Layer (b) Bottom Layer

Figure 4: The drilled copper piece for laser diode integration

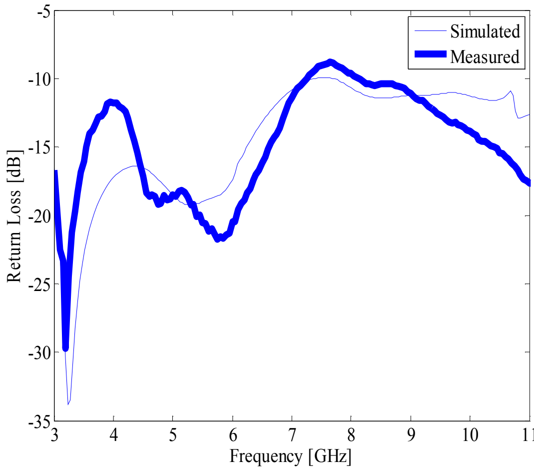
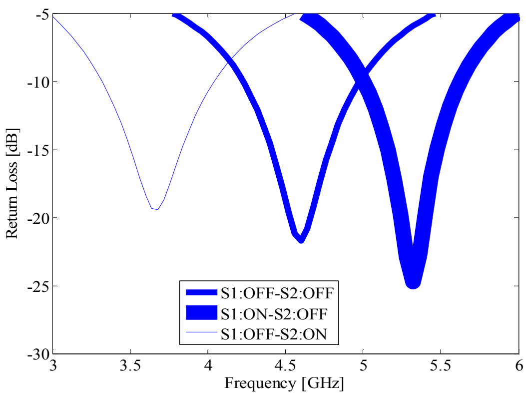
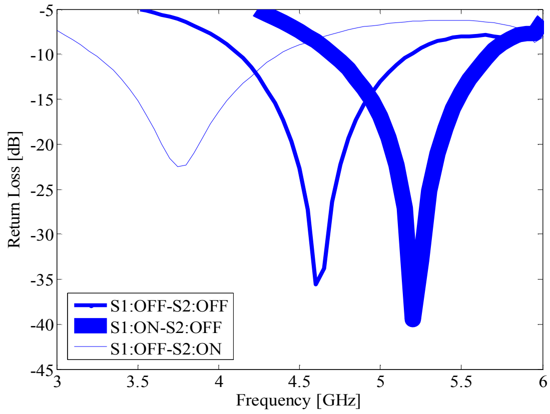


Figure 5: The measured and simulated return loss for the sensing antenna

For the sensing antenna, when the two silicon switches (S1 and S2) are not illuminated by a laser light (OFF state), only the modified monopole is fed. This results in an antenna resonance between 4.15 GHz and 5.1 GHz. Upon activation of the first switch (S1) by driving the laser diode via a current of 87 mA and a voltage of 1.9 V (this correspond to 50 mW pump power), the antenna shifts its resonance to the 4.8-5.7 GHz band. By illuminating the second switch (S2) by the same amount of pumped power, the band 3.2-4.3 GHz is covered. The case when both switches are ON produces a resonance outside the band of the sensing antenna, and is not considered for our application. The simulated and measured return loss is summarized in Fig.6 (a) and Fig. 6(b).



(a)



(b)

Figure 6: The simulated (a) and the measured (b) return loss for the reconfigurable antenna

Since both structures are incorporated into the same antenna substrate, it is essential to look at the mutual-coupling (or cross-talk) between the sensing and the reconfigurable antenna. This is quantified by the transmission (S21) between the two antenna ports. The comparison between the simulated and the measured coupling for the case when both switches are OFF is shown in Fig. 7. A cross-talk of less than -20 dB is achieved throughout all the covered band of the sensing antenna.

The comparison between the simulated and the measured radiation pattern in the XZ plane is shown in Fig.8. The radiation pattern is taken at f=3.6 GHz (S1: OFF-S2: ON), f=4.6 GHz (S1: OFF-S2: Off) and at f=5.2 GHz (S1: ON-S2: OFF).

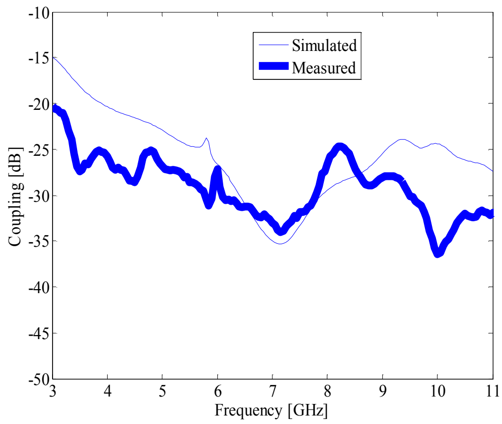


Figure 7: The simulated and the measured antenna cross-talk

4 CONCLUSION

In this paper, a new antenna front-end scheme for cognitive radio communication systems is presented. The reconfigurable antenna is based on photoconductive switches. The switches are activated using a novel technique of integrating the laser diodes directly into the antenna substrate. A prototype antenna was fabricated to test the suggested method. Good qualitative agreement is observed between the simulated and the measured data.

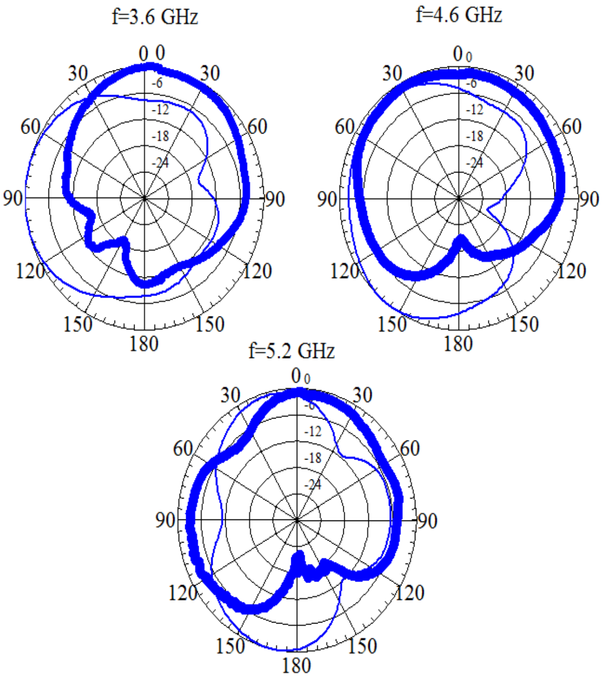


Figure 8: The simulated (thin line) and the measured (thick line) radiation pattern for the three cases [f=3.6 GHz (S1: OFF-S2: ON), f=4.6 GHz (S1: OFF-S2: Off), f=5.2 GHz (S1: ON-S2: OFF)].

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