Reconfigurable Antennas in Cognitive Radio that can Think for Themselves?

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Abstract. **This paper discusses the use of reconfigurable antennas in cognitive radio. Most of the emphasis on cognitive radio so far has been in the area of spectral estimation and signal classification. In this paper we show that once a cognitive device manages to learn the RF environment (cognition part), from past observations and decisions using machine learning techniques, we can use the collected data to train reconfigurable antennas to adapt to any change in the RF environment.**

Keywords-component; reconfigurable antennas; cognitive learning, machine learning.

I. INTRODUCTION

Antennas have become a necessary and critical component of all personal electronic devices, microwave and satellite communication systems, radar systems and military surveillance and reconnaissance platforms. In many of these systems, there is a requirement to perform a multitude of functions across several frequency bands and operating bandwidths, especially in the area of Cognitive radio. Reconfigurable antennas and reconfigurable systems in general show significant promise in addressing these system-requirements, given their ability to modify their geometry and behavior to adapt to changes in environmental conditions or system requirements (such as enhanced bandwidth, change in operating frequency, polarization, radiation pattern etc.). Reconfigurable antennas can thus provide great versatility in applications such as cognitive radio, MIMO systems, RFIDs, smart antennas, etc.

In this talk, several issues related to reconfigurable RF circuits and reconfigurable antennas are presented. Examples of reconfigurable antennas using MEMS, semiconductor and photoconductive switches are presented and discussed. These antennas are also shown how they can be used in Cognitive radio applications.

II. CHALLENGES

A cognitive radio (CR) system that can work (in real-time) with other devices across multi-bands, multi-standards or multi-channels by learning and adapting to the RF environment is envisioned. The devices can learn and adapt to, *both* in real-time, their RF environment for the purpose of establishing seamless communication with other RF devices across multi-standards, multi-bands and/or multi-channels. At the PHYsical layer, the defining characteristics of the envisioned system include: a) *cognition:* the ability of spectrum sensing across multi-bands, multi-standards and multi-channels to detect and classify RF activities of interest, and the ability to decide in which band under what standard the radio needs to establish communication with a chosen RF device via learning and reasoning. b) reconfigurability [1]: ability to adapt RF communications parameters, such as standard, carrier frequency, transmit power, modulation format, coding scheme and its rate, in software without having to change hardware.: i.e. **these are cognitive RF plug-and-play devices.**

To be able to autonomously detect and establish communication with another RF device in its range across different standards, frequency bands and multiple channels, the RF device should be able to monitor and sense its RF environment to detect RF activity, classify a detected RF activity as one of several possibilities, and establish communications in appropriate modes. Due to impairments inherent in the wireless channel as well as ambient noise, it is possible that a cognitive RF plug-and-play device can both be mistakenly detect or miss an RF device in its range as well as misclassify a detected device. Thus, for a successful implementation, it is critical that the plug-and-play device has built-in intelligence and cognition to effectively learn from its observations and past actions, and correct its behavior as necessary in real-time. Hence, the proposed RF Plug-and-Play devices are to be designed based on the following four-step cognition cycle (ODAL loop), shown in Figure 1 [2-4].

- **Observe (Self-awareness)**: Scan and sense the RF environment for detection of RF activity across multiple bands, standard and channels, followed by classification of detected signals. This requires developing efficient techniques for spectrum sensing,

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detection and classification, as well as solutions to hidden-terminal problems.

- **Decide (Intelligence and cognition):** Based on observations and past experience the RF plug-and-play device reasons to determine which possible actions from its current state is optimal and decides on its course of action. This entails developing a cognitive engine that has reasoning, planning and decision-making capability.

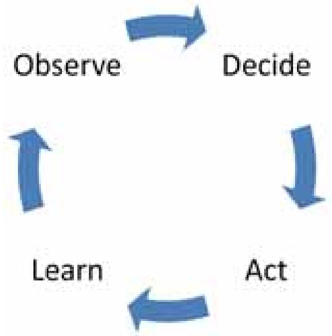

Figure 1. The ODAL cognition cycle of the proposed smart RF plug and play device.

- **Act (Reconfigurability):** Adapt and respond to the observed RF environment, via a parameter-controlled Software Define Radio (SDR) architecture. This is a critical requirement to make the RF Plug-and-Play resilient to any EM interference. This entails developing a unifying parameterized representation for multi-standard, multi-channel and multi-band signals, SDR implementations of parameter-controlled communications and reconfigurable FPGA solutions.

- **Learn (cognition):** Learn the RF environment, from past observations and decisions, to be able to anticipate, predict and correct communication standard, mode of operation, and RF parameters. Machine learning techniques, such as neural networks and support vector machines, can be used to train these devices to not only learn how to adapt but also how to predict changes in the RF environment.

Our work focuses mainly in designing reconfigurable antennas [5-8] that can be used in cognitive radio and RF Plug-and-Play devices. These antennas are controlled via neural networks [9] or support vector machines [10] and can be programmed on FPGAs (Field programmable gate arrays). Several examples will be presented and discussed that incorporate the challenges and tradeoffs in designing such antennas.

III. EXAMPLE

Figure 2A illustrates a reconfigurable PIFA [7] fabricated on a standard printed circuit board substrate (i.e. FR-4 epoxy) which allows miniaturization of the end-loading parallel plate capacitor, while keeping the majority of the antenna dielectric material air, to avoid unnecessary dielectric loss and maximize the antenna's efficiency. Using the outer metal of the PIFA structure as the device package, the space underneath the antenna-feed pedestal and above the loading capacitor can be used to house all of the requisite transceiver circuitry, power supply batteries for many portable wireless devices, and any FPGAs that can be used to control the antenna via machine learning algorithms. Since the antenna and the battery are typically the two biggest roadblocks to portable wireless device miniaturization, integrating them together into the device package is often the optimal solution. The battery will have an effect on the antenna performance, and batteries for specific applications should be included in full wave 3D EM simulations during the design process for specific applications. Figure 2B illustrates an extremely simple-to-manufacture version of this design that can be fabricated using two copper clad printed circuit board substrates connected with shorting posts.

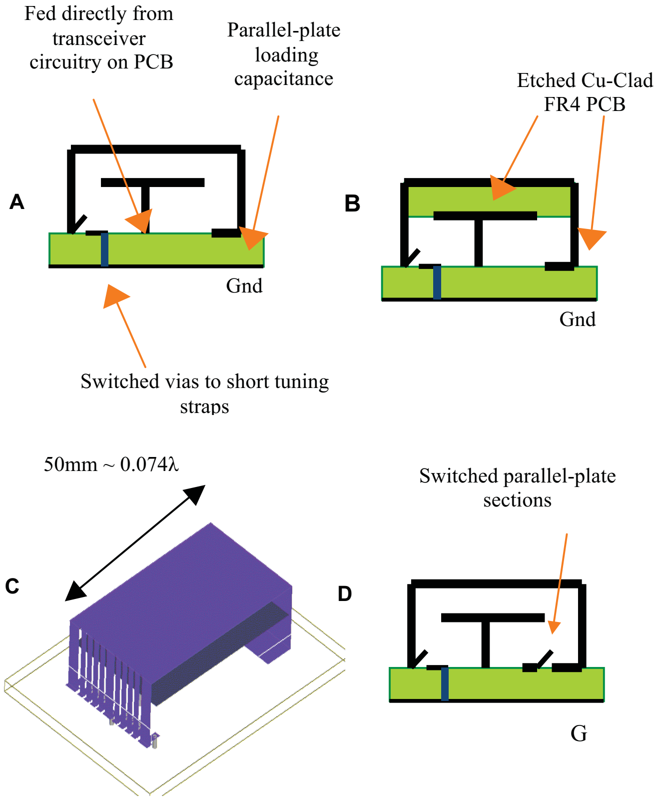

Figure 2. Reconfigurable PIFA

Figure 2C shows a 3D rendering of the UHF-band reconfigurable PIFA-as-a-package. The antenna measures less than 0.08 λ on its longest side (50mm), 25mm in width and stands less than 7.5mm high. Ten surface mount low-loss switches are used to tune the ~5.5MHz instantaneous 10dB impedance bandwidth across approximately 53 MHz. If a broader tuning range is required, the parallel plate loading capacitance can be tuned in conjunction with the strap tuning technique as illustrated in Figure 2C. Figure 2D indicates that one can have switches on both sides of the antenna. Simulated full-wave Return Loss results using four parallel plate loading capacitance states are shown in Figure 3.

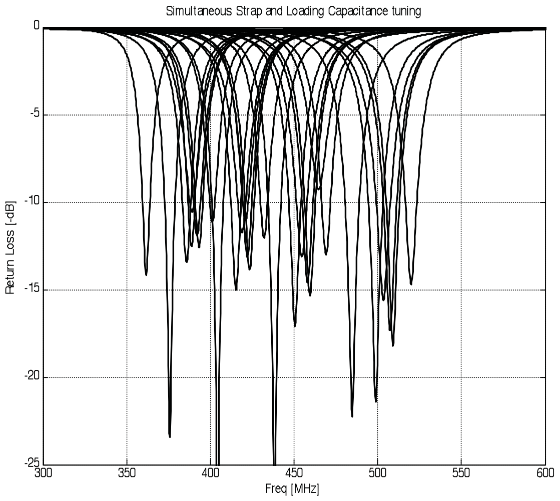

Figure 3. S11 results

This example illustrates how one can build an electrically small antenna with an FPGA embedded in it that can act as the “brain” and the “Cognitive host” for cognitive radio and RF plug-and-play applications. The appropriate machine learning algorithms can then make the antenna think for itself in various RF environments.

III. CONCLUSIONS

The development of the next generation responsive circuits and cognitive radio can significantly benefit from the use of real-time reconfigurable systems. Reconfigurable antennas come in a large variety of different shapes and forms. These antennas exhibit different forms of reconfiguralibity. They can have a reconfigurable return loss, reconfigurable radiation pattern, reconfigurable polarization or different combinations of the previous properties. Such antenna and RF systems will form the next generation of plug-and-play electronic components, allowing us to produce scalable components that can be used to optimize performance in terms of both speed and power.

REFERENCES

1. Lyke J., “Reconfigurable Systems: A Generalization of Reconfigurable Computational Strategies for Space Systems”, IEEE Aerospace Conference, March 9-16, 2002.
2. Mitola, J. III, *Cognitive Radio Architecture*, John Wiley, New York, 2006.
3. Hentschel, T. and G. Fettweis, Sample rate conversion for software radio, *IEEE Communications Magazine*, pp. 142-150, Aug. 2000.
4. F. Jondral, Software-defined radio – Basics and evolution to cognitive radio, EURASIP Journal on Wireless Communications and Networking, pp. 275-283, vol. 3, 2005.
5. Brown E. R., ‘RF-MEMS switches for *reconfigurable integrated circuits*’, Microwave Theory and Techniques, IEEE Transactions on, Volume: 46, Issue: 11, Nov. 1998, pp. 1868 –1880.
6. Anagnostou D. E., Zheng G., Feldner L., Chryssomallis M. T., Lyke J. C., Papapolymerou J. and Christodoulou C. G., ‘*Silicon-etched Reconfigurable Self-Similar Antenna with RF-MEMS Switches*’, IEEE APS/URSI International Symposium, Monterey, CA, 20-26 June 2004, vol. 2, pp. 1804-1807.
7. Feldner L. M., C. D. Nordquist, and C. G. Christodoulou, “RF MEMS Reconfigurable Triangular Patch Antenna”, IEEE AP/URSI Symposium, Washington, DC. 2005.
8. Anagnostou, D.E., G. Zheng, M. T. Chryssomallis, J. C. Lyke, John Papapolymerou, and C. G.Christodoulou, “Design, Fabrication and Measurements of a Self-Similar Re-configurable Antenna with RF-MEMS Switches”, *IEEE Transactions on Antennas and Propagation, Special Issue on Multifunction Antennas and Antenna Systems, pp. 422-43,* Feb. 2006.
9. Christodoulou C. G and Georgiopoulos, Neural network applications in electromagnetics, Artech House, Jan. 2001
10. Martinez-Ramon and C. G. Christodoulou, Support Vector Machines for Adaptive Antenna Array Processing and Electromagnetics, Morgan & Claypool, October 2006.