Toward System Modeling Dedicated to Frequency Reconfigurable Antennas

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Abstract

With the recent evolution of wireless systems such as cognitive radio, new antennas have to be developed to provide large bandwidth, compact size and especially adaptive parameters for changing environments. The antennas are become more again an essential part of wireless systems. They play a fundamental role both in the propagation and also at a system level. New antennas models must be developed being radically different from those currently available. The potential of linear invariant time models associated to parametric approaches to describe antennas is presented. Based on these approaches, a new method for modeling reconfigurable antennas is proposed.

1. Introduction

Cognitive radio has been attracting significant interest and has the potential of shaping the future of wireless communication systems. Since the concept of cognitive radio is still at the stage of being developed, there is no consensus on what kind of wireless technologies to employ for realizing it. There are a number of requirements a wireless system has to satisfy in order to be considered as a suitable candidate for cognitive radio. There requirements include no spurious interference to licensed systems, adjustable pulse shape, bandwidth, and transmitted power, supporting various throughputs, providing adaptive multiple access, and ensuring the security of information. The next development of cognitive radio will imply the need of new antennas integrated with new functionalities. For many RF designers, the antenna appears as the most important piece and its performance will enable the overall characteristic of the wireless communication system. Furthermore, the functions of antenna will evolve and accommodate new technology aspects, such as diversity and reconfigurability. The future UWB antennas will be able to scan the environment, to harvest ambient energy, and to reconfigure spatially and spectrally themselves while maintaining the basic communication functions in transmission and reception. Obviously, the antenna is not only one or several radiating elements but it will also be integrated with sensors and electronic circuits. Under this evolution, embedded signal processing will be an obligatory stage.

More particularly, reconfigurable antennas can offer multiple functions by dynamically changing their properties (operating frequency, polarization, radiation pattern, and a combination of all these factors) [1]. Antenna reconfiguration is achieved by changing the current distribution over the volume of the antenna and each distribution corresponds to a specific mode. In recent years, there has been particularly growing effort in the development of frequency reconfigurable antennas [2]. Compared to broadband antennas, similar radiation pattern and gain for all designed frequency bands and frequency selectivity can be obtained. In the literature, a lot of frequency reconfigurable antenna designs have been proposed. These antennas can be classified according to their reconfiguration techniques. Lumped-elements [3, 4], variable capacitors [5, 6], silicon photo switches [7, 8], MEMs (micro-electro-mechanical) switches [9, 11] or PIN diodes [12, 13] are usually incorporated in the design of the antenna. The characteristics of frequency reconfigurable antennas are estimated from parameters such as effective bandwidth, operating frequencies and associated applications, tunable frequency range or number of resonant frequencies, and their performance especially depend on the consistency of matching, gain and radiation pattern. If many reconfigurable antennas have been proposed in the literature, few works concerns design guidelines or modeling dedicated to these special antennas. Furthermore, the few studies propose models based on only electromagnetic and/or electric models, and somewhere this is a fundamental limit in the presented context. Original and more complete modeling has been done by the research team of Pr. Christodoulou which recently proposed the use of graphs for modeling, optimizing and analyzing reconfigurable antennas [14]. The representation in automat form is compatible with the modeling of all possible

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configurations of one antenna or an antenna system. A state represents a configuration which depends on one or several parameters, and the transitions correspond to the commands allowing the modification of configuration. The graph models optimize both the topology and the employ.

Finally, with the evolution of wireless systems, new antennas models must also be developed being radically different from those currently available, and this implies the development of original and innovative approaches. New models should allow the intrinsic characterization of antennas and also the evaluation of their performance in given situations. These models will be able to take into account different functions, such as microwave, signal processing and radiated elements. They must be scalable, generic and adaptive. Taking into account the long term vision of silicon integration of smart antennas, these models must be compliant with classical silicon integrated circuit design tools. Several levels of abstraction must be envisaged, notably with a co-design orientation. Further, the suggested models must give new ways to improve the current structures of antennas and to associate them with new control laws.

In the second part of this paper, we show the importance and the impact of modeling approaches based on Linear Time Invariant (LTI) systems. The third part presents an evolution of these techniques in the case of reconfigurable antennas from a simple example demonstrating the proposed model.

2. Potential of System Approaches for Modeling Antennas

To describe and to specify transient radiation and reception characteristics of antennas, the effective lengths (or effective heights) have been firstly considered in the literature [15]. With the emerging of UWB systems and in particular pulsed modulations, the modeling of antennas as LTI systems have been very considered in the last years [16]. In effect, this approach offers the advantage to model the antennas in time domain and in frequency domain, easily and simultaneously, and in the same time, to describe notably their performance in terms of dispersion. The techniques are generally the same however with some variants: the radio link including antennas is modeled as a two-port network and characterized thanks to the network theory using S-parameters, Z-parameters, Y-parameters, h-parameters or ABCD-parameters.

In this context, we presented several techniques leading to a system description of antennas. Compact time-frequency models of TX and RX antennas have been established from the use of scattering parameters, the determination of directional impulse responses (and associated transfer functions) and using singularity expansion methods (i.e., Prony and matrix pencil methods) [17]. Based on this approach and using same parametric models, a procedure to determine an equivalent electric circuit of antenna input impedance has also been introduced [18]. We also developed a method that permits to model an UWB radio ling including antennas in VHDL-AMS showing that a mixed-signal modeling approach of communication systems was possible [19]. For MIMO antennas, we proposed the use of a model based on LTI systems allowing the compensation or the positive exploitation of the mutual coupling between radiating elements [20]. We have demonstrated that the influence between radiated elements can be considered as an interaction system described thanks to transfer function and impulse response. This particular case is interesting because it proved that the design of the antenna system could be improved after the step of modeling adding for example pre-processing as filters. Finally, in [21] a method to obtain a generic model based on a state-representation of an antenna has been determined; such as modeling is well defined to study the observability and the controllability properties of the systems. The main advantage of this modeling could be to present new solutions to envisage adaptive techniques of transmission. If the majority of given examples concerns UWB systems, all these approaches are general and can be applied in the case of narrow band systems. Moreover, it is possible to extend the defined models for reconfigurable systems and especially reconfigurable antennas.

3. System Model of Reconfigurable Planar Dipole Antenna

In order to illustrate the proposed approach for modeling reconfigurable antennas, a simple, well-known and extensive used antenna is chosen: the planar dipole antenna shown in Figure 1. The arms of the dipole are connected with PIN diodes to additional patches. The role of switches is to conductively couple the additional metallic patches thus extending each arm's length. They can be modeled as metal pad with dimension 0.3 × 0.9 mm^2 [22]. To avoid unnecessary discontinuities in the structure, the width of the arms is equal to 0.3 mm. Figure 2 depicts the reflection coefficient S_{11} performance of this antenna. Figure 3 illustrates the pattern diagram for the configuration presenting an adaptation at 900 MHz. This diagram is the same for all configurations and characterizes the dipole antenna pattern. This representation gives the spatial dimension to the antenna response. Figure 4 presents the shape form of the transmitted signal for the different configurations. The main frequency of the time response is obviously linked to the resonant frequency. This representation leads to the frequency dimension of the antenna response.

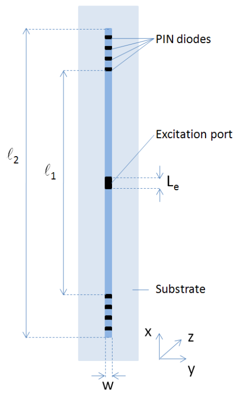

Figure 1. Topside view of the design of the reconfigurable planar dipole antenna.

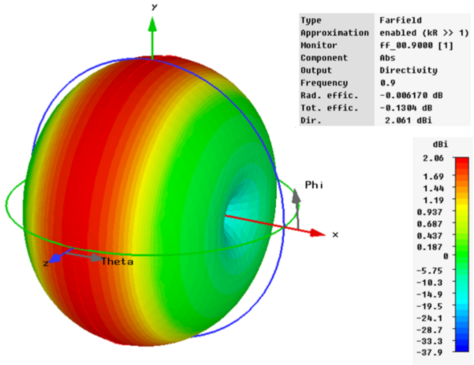

Figure 2. Pattern diagram (resonant frequency at 900 MHz)

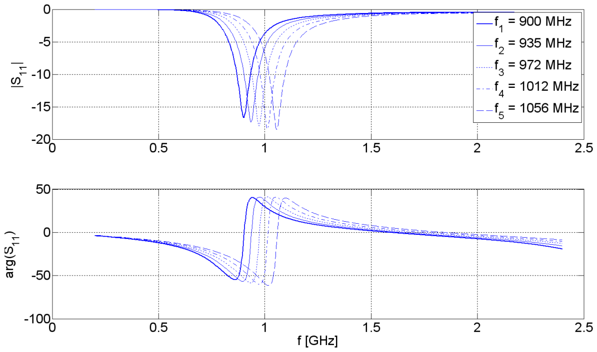

Figure 3. Reflection coefficient for the different configurations illustrating the covered bandwidth.

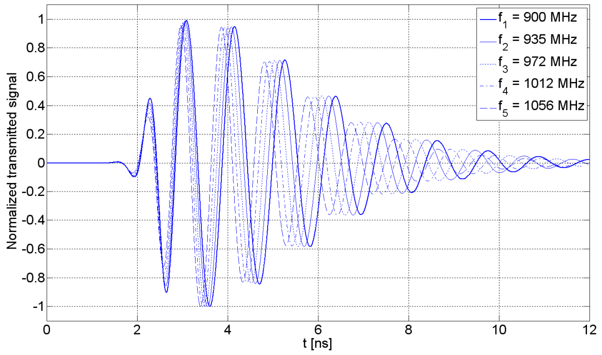

Figure 4. Normalized transmitted signal for the different configurations (S_{21} time domain).

Inspired to the presented method in [17], the impulse response antenna can be considered as a LTI model described by complex and conjugate couples of poles and residues. From the time response of the transmission coefficient S_{21}, the Matrix Pencil technique associated to singular value decomposition is applied for determining the parametric models of all configurations with same comparable accuracy. Each configuration leads to a different model, i.e. characterized by different couples of poles and residues. However the order of the models is the same. After the first step, it is possible to generalize and to obtain a more compact model taking into account all configurations by combining results. This general model consist to choose the most significant poles of all responses and to calculate the associated residues according the configuration. In a co-design context, the proposed modeling can describe the behavior of the frequency reconfigurable antenna both in space and frequency dimension, from the pattern function and the poles and associated residues for each configuration respectively. The approach could be generalized for other types of reconfiguration.

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