Encoding/Decoding Strategies for Frequency Domain Chipless RFIDs Employing Periodic Surfaces

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***Abstract*— This paper reviews the main features of chipless RFID tags realized with High-Impedance Surfaces. These tags, which comprise a periodic surface printed on top of a grounded dielectric slab, can be exploited in a number of encoding and decoding schemes. Several encoding methods have been investigated and the results are here analyzed and organized into a broad overview. In particular, the attention is devoted to the physical phenomenon at the basis of each design that is obtained by resorting to absorption, polarization conversion or polarization diversity.**

I. Introduction

Chipless RFID is a new technology that is still in the infancy and many products have not left the prototyping cycle. There have been some reported chipless RFID tag developments in recent years but most of them are still reported as prototypes and they are not considered commercially viable. Two general types of RFID tags can be identified: time domain (TD)-based and spectral (frequency) signature-based chipless RFID tags. The most popular tag classifiable as chipless RFID tag is the surface acoustic wave (SAW) tag [1]. SAW tags have been commercialized in nineties but still have a niche market due to high realization costs. Thin Film Transistor Circuits (TFTCs), which are being developed using organic or printed inorganic semiconductors, can be used to design TD tags [2]. Research efforts in this field are concentrated towards low-cost manufacturing processes of TFTC tags but now issues exist about low electron mobility of TFTC.

TD tags with printed circuit board technology are large and are unable to encode a high number of bits [3]. The second class of chipless tags encodes data into the spectrum using resonant structures [4]–[7]. Initial designs were based on multiple antennas accorded on multiple frequencies but with this design criterion the size of the tag increases dramatically with the number of bits. Two main design methods have emerged. The former is based on two orthogonally polarized antennas with a series of resonators in between [6] whereas the latter employ several resonators of different size [4]. At the current stage, none of the available designs has showed sufficient robustness when employed in practical scenarios. Often, a high number of bits is claimed but the robustness of the encoding methods turn out to be insufficient when measured in terms of detection probability. The proposed tags are generally structures without a ground plane and therefore are unable to work when placed on metallic platforms. Here, the encoding/decoding properties of chipless tags made with High-Impedance Surfaces (HIS) are discussed.

I. Chipless Tags Layout

Chipless tags synthesized with metasurfaces are a promising solution which allows different bit-encoding methods. Metasurfaces are a class of two-dimensional metamaterials comprising a periodic arrangement of resonators. To synthesize the chipless RFID tag, the periodic surface is printed on top of an ultra-thin grounded dielectric slab to form a so-called High-Impedance Surface (HIS) [8]. The layout of the structure is represented in Fig. 1. Properties of Frequency Selective Surfaces (FSSs) and HIS can be advantageously modelled through simple yet accurate circuital approach which is also useful for acquiring physical insights [9].

There are three main reasons for using HIS-based tags. The first is that the structure can be quickly analysed by using a Periodic Method of Moments (PMM). The second and more important one is that the average value of RCS can be controlled by increasing or decreasing the number of unit cells and thus the footprint of the tag. Increasing the RCS, while keeping fixed the encoded information, can be very important to guarantee an acceptable detection probability. The third is because of the presence of the ground plane, which allows isolating the response of the tag from the one of the surrounding objects.

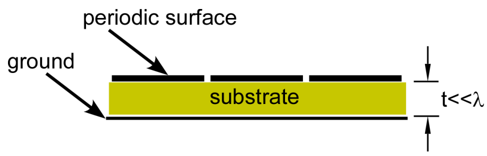

Fig. 1. Layout of the chipless RFID tag.

II. Encoding Methods

By exploiting the peculiar properties of high impedance surfaces various encoding mechanisms are possible. The first method is to synthesize a multi-frequency narrowband absorber [10]. The second approach consists in exploiting the polarization conversion capability of metasurfaces [11], [12]. The third approach relies on the phase encoding [13] whereas another one is based on a differential encoding exploiting a dual- polarized reader [14]. The last approach is more robust with respect to the environment and it has been proved a viable

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solution for performing a reading procedure without any type of background subtraction [15].

- **Absorption encoding**: A first chipless RFID transponder is obtained by employing a multi-resonant FSS unit cell, such as a series of concentric loops. In this way, it is possible to obtain several resonant frequencies in the reflection coefficient magnitude [10], thus a binary amplitude modulation. The compact tag comprises 2x2 or 3x3 unit cells formed by nested square loops. Every absorption peak of the reflection coefficient is associated to one of the concentric loop elements. This allows to encode a desired bit sequence in the scattered electromagnetic footprint encoding the states 'total reflection' as the bit '1' and 'total absorption' as the '0' bit, respectively. It is worthwhile to highlight that the overall footprint of the transponder does not limit in principle the amount of bits (levels of information) that can be included in the tag. The proposed chipless RFID tag is therefore a finite HIS comprising only few unit cells. The structure is basically a subwavelength resonant cavity characterized by an input impedance approaching to infinite and a reflection phase crossing zero at the resonance. If the suitable amount of loss is introduced in the resonant structure, a perfect absorption can be achieved at the resonance frequency.

- **Cross-polar encoding**: By using the cross-polar reflection of the tag, it is possible isolating the contribution of the tag from the one of the backing metallic platform, which tends to conceal the resonant peaks of the resonator. The proposed chipless RFID tag must comprise a structure able to reflect polarization-rotated electromagnetic waves over multiple frequency bands [16]. The field of multi-frequency polarization converters is almost unexplored in the literature. A structure able to provide polarization conversion for arbitrary polarizations and without high-order resonances is the closed-loop resonators although the achieved level of polarization conversion is not satisfying (around -40 dB of cross-polar reflection). Another promising configuration we plan to investigate comprises several Z-dipoles in the unit cell of the periodic surface [12]. The periodic arrangement typical of metasurfaces guarantees, differently from configurations proposed in the literature [16], that the entire surface interacts with the impinging electromagnetic signal creating well defined frequency peaks even when the number of bit becomes high. This will lead to an improved reading reliability and to the possibility to increase without any limitation the number of bit.

- **Phase encoding**: Another possible method to encode information within the metasurface is to use the reflection phase. Indeed the HIS surface is characterized by a phase transition of the reflection coefficient at the resonance. The phase typically goes from 180° to -180° passing through 0 degrees. Keeping the frequency fixed, it is possible to change the reflection phase value at a fixed frequency by simple varying a dimension in the unit cell of the resonant element [13]. In this case several bits can be encoded in a single frequency therefore the potential number of states is higher than the amplitude scheme case.

- **Differential encoding**: The differential chipless RFID coding can be obtained by using a passive resonator characterized by a quasi-identical but slightly shifted scattering frequency response for two orthogonal polarizations. By subtracting the reflected signals obtained with two simultaneous interrogations of the tag, it is possible to obtain well visible spikes in correspondence of every resonance frequency. It is important highlighting that the shifting of the first resonant peak does not lead to any variation of the other two resonant peaks thus guarantying the robustness of the encoding mechanism.

III. Efficient Decoding Methods

Beyond the specific configuration adopted to encode the information, the main limitation of chipless technology is that the tag detection requires a calibration procedure based on two or three independent measurements performed on the same scenario (tag and background and eventually ground plane). Even if in a laboratory environment this procedure is feasible, this is not an option in a real scenario. A normalization is feasible only in a few situations where it is possible to store the background response in advance (those cases where a tag moves with respect to the interrogating antenna). However, in general, the absence of a reference makes the tag reading nearly unfeasible. In order to overcome this fundamental problem a new encoding/decoding scheme based on two simultaneous acquisitions along two orthogonal planes of incidence can be adopted [15]. The methodology relies on the previously proposed differential encoding method. In order to perform a calibration-free reading, three strategies are jointly adopted: dual polarization interrogation, time domain gating and antenna (*i.e.* antenna operating in free space, not in the operative scenario) response subtraction.

Encoding the information in the difference between two responses is a key point since it allows encoding the information in a differential response instead of an absolute one. Time domain gating allows removing some harmful effects due to the antenna coupling and to the multipath phenomena.

The reading range of this approach is limited by the presence of big objects behind the tag. Indeed the used time window has to fulfill to two opposite requirements: it should be long enough to have a frequency response of the time window at least smaller than the resonant peak bandwidth but, at the same time, should be short enough to filter out the RCS contributions of the objects close to the tag.

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