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On the Reading of Moving Chipless RFID Tags

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Abstract

Reading chipless RFID tags represents one of the major obstacles towards the practical use of this technology in a realistic environment. It is demonstrated that the quite common scenario of a moving tag can be advantageously exploited to greatly improve the reliability of the tag detection. The proposed reading procedure is based on the Inverse Synthetic Aperture Radar processing. The detection scheme relies on the integration of multiple received signals coming from the tag travelling along a known path. Remarkably, the moving scenario benefits also from the possibility to preemptively store the background echo of the environment where the tag is embedded in. This technique greatly enhances the detection probability in realistic scenarios subjected to a high clutter. Successful experimental tests of tag readings with low Signal to Noise Ratio (SNR) are illustrated.

1. Introduction

Chipless RFID is an emerging technology aimed at the identification of objects and sensing. The key idea is to further simplify the tags thus removing any active circuit. Even if the cost of RFID tags is already low (about 10 eurocents when distributed in large quantities), the removal of the integrated circuit could make radio frequency labels available at a sub-cent cost. Indeed, it has also to be taken into account that the chipless tag fabrication is fully compatible with printed electronics low-cost fabrication methods such as screen printing, flexography, gravure, offset lithography, and inkjet printing [1,2]. A widespread paradigm is based on frequency domain (FD) codification [3–9]. The other important advantage connected with the removal of the integrated circuit on the tags is the application of radio frequency labels in extreme environments when the chip might be damaged. Beside these advantages, the use of an entirely passive label, without any dynamic modulation capabilities and communication protocols, poses important limitations which are currently impeding their applications outside research laboratories. The most important limitations of chipless technology are the limited number of bits allocable in a few square centimeters' area typically used for an RF label and, in particular, the reliability of the reading procedure. While the former aspect is frequently addressed in the literature and could not be an issue in some particular applicative scenarios, the latter aspect is less investigated and more difficult to solve in a definite way. Indeed, a resonator with a small footprint is characterized by a very low backscattered field level, i.e. a very low radar cross section (RCS) so that retrieving of the frequency response of the tag using a single interrogation with a non-directive antenna involves several problems. First of all, the signal backscattered by the tag resonator is characterized by a much smaller amplitude with respect to the signals coming from the scenario where the tag is placed in (multipath). The reading procedure, similar to a radar scenario, is strongly affected by the response of the environment and by the size of the scatters. It is therefore crucial to isolate the weak response of the tags from the stronger signals received from unwanted scatterers. A few works dedicated to this aspect have been recently presented in the literature [10,11]. These approaches exploit time and/or polarization diversity to separate the tag echo from the multipath contributions. The aforementioned methods are useful to improve the reliability of reading procedure, but they cannot guarantee a 100% accuracy especially in presence of other scatterers.

In this paper, a scenario that is potentially suitable for employing chipless RFIDs, where the reading antenna is fixed, and the tag moves along a known trajectory, is investigated. The latter scenario, even if it has not received an adequate attention in the literature, is potentially very promising for chipless RFID and metamaterial tag sensors interrogation. In this case, the background can be stored before that the tag is in front of the antenna and the calibration can be easily performed. In addition, Inverse Synthetic Aperture Radar (ISAR) processing can be used to improve the signal to noise ratio (SNR).

2. Detection procedure

The moving tag scenario provides the intrinsic advantage that the calibration of the system can be easily performed by preliminarily storing the background response in the absence of the tag. Once the tag response is acquired and the background subtraction is available, the useful signal can be obtained as:

$$S = S_{11}^{tag} - S_{11}^{background} \qquad (1)$$

This procedure is very useful to remove most of the effects due to the multipath as well as the reflections caused by cable-antenna connection. However, this technique requires a preliminary measurement, which is not feasible

if the tag is fixed in a specific position and the reader is moved away.
In addition to this intrinsic advantage, the moving scenario with tags or sensors moving along a conveyor belt allows to integrate several acquisitions of the same tag. This lets drastically improving the reliability of the chipless tags reading process by using a basic one-dimensional ISAR processing technique. After compensating these phase differences, the signals can be integrated for obtaining one single processed signal:

$$S^{INT} = \sum_{i} \left| s_i \right| e^{j\angle S_i} e^{jk_0 d_i} \tag{2}$$

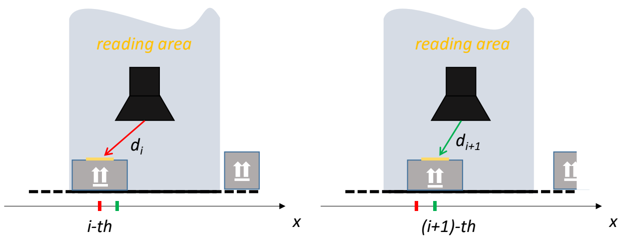


Figure 1. Reading procedure of a moving chipless tag.

In presence of clutter, both the desired signal and the clutter contribution can be represented as complex variables in polar form depending on frequency *f*. The tag signal can be modelled with a shunt connection of an inductance and a capacitance [7]. The resonator introduces a frequency peak in the amplitude of the reflection coefficient at the resonant frequency and a phase transition at the same frequency. The resonator can synthesized for instance by using a FSS on top of a grounded dielectric slab [7] but also other tags configurations can be employed [4]. The clutter can be modelled as a normal random process with standard deviation equal to the signal amplitude. The phase ϑ_n is also a uniform random process with a variance of π. When multiple signals are integrated (ISAR processing), a summation of tag contributions and clutter contributions is obtained [12]:

$$S^M(f) = \sum_{i=1}^{M} s_i(f) = M \cdot s(f) + \sum_{i=1}^{M} n_i(f) \tag{3}$$

As it is apparent by examining (3), the useful part of the received signal is strengthened by the integration of the *M* measurements whereas the clutter contribution does not increase, being a summation of random numbers.
To theoretically demonstrate the viability of the presented method, the Bit Error Rate (BER) as a function of the number of integrations is analyzed. A resonator with a single resonance at 5 GHz is considered over a band ranging from 1 GHz to 10 GHz. A decision strategy based on the correlation between the ideal signal without the clutter and the signal in presence of random noise is implemented (a correlation coefficient *R* higher than 0.8 is considered as the presence of the bit "1" while a level lower than 0.8 codifies the bit "0". Based on this decision method, the Bit Error Rate (BER) has been computed for different SNR levels (-5, 0 and 5 dB).
The statistics are performed with a Montecarlo simulation with 10^6 realizations. The BER of the system as a function of the number of integrations is shown in Figure 2 for different level of SNR. As it is evident, the increase of the number of integrations, allows to drastically improve the reliability of the system since the tag signal, even if very low in amplitude, always brings the same encoded information while the disturbing signals are uncorrelated.

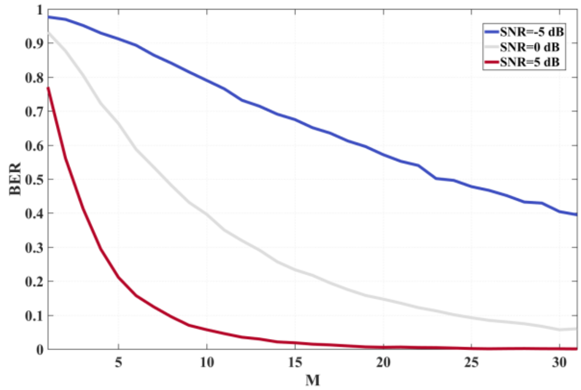
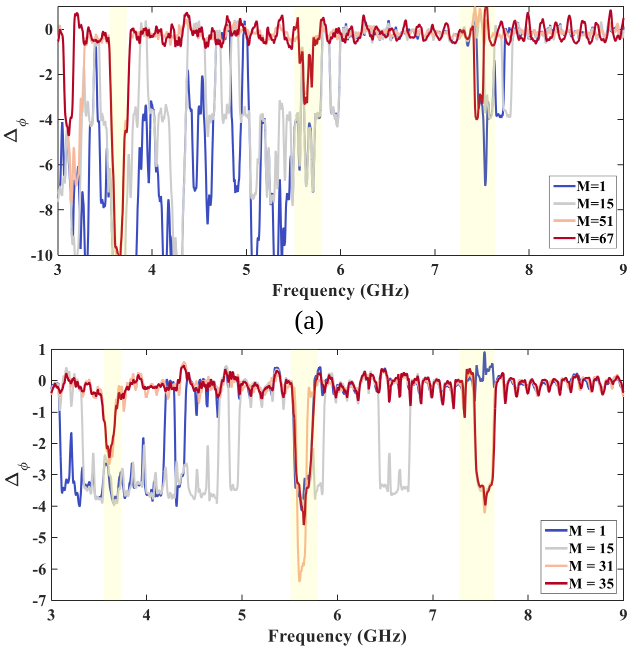


Figure 2. BER as a function of the number integrations (M) for three different level of SNR (-5, 0, 5) dB.

3. Experimental Demonstration

To verify the reliability of the reading procedure, a chipless RFID tag comprising 3 bits has been used as benchmark. The tag is formed by 3 nested loops repeated in a periodic configuration placed at 1.6 mm from a ground place. The substrate is a standard FR4. The tag has been initially interrogated from 130 cm with a single polarized horn antenna operating between 2 GHz and 18 GHz. The tag is moved manually by using a Styrofoam support. The tag has been interrogated in 67 positions around the antenna. The S_{11} of the antenna for each position has been collected, calibrated by using the background measurement stored in absence of the tag and the signals are finally processed according to relation (2). To detect the bit sequence, the derivative of the phase of the integrated signal has been calculated. The presence of a peak indicates the presence of the bit. The derivative of the phase for the tag interrogated at 130 cm for different number of integrations is reported in Figure 3a. Subsequently, to further stress the detection procedure and to analyze a situation closer to a practical scenario, the tag was installed on a plastic box filled with 8 tape rolls. The RCS of the box itself is larger than the RCS of the tag. For this reason, it is almost impossible to read the tag even by using a calibration procedure involving the background subtraction. The box has been moved along a straight trajectory with steps of 1 cm. The distance between the tag and the transmitting antenna is 50 cm. The number of acquisitions of the S_{11} of the antenna was equal to 37 while the box was moving within the -3dB beamwidth of the horn antenna. By applying the ISAR integration procedure, we obtained the integrated signal and the derivative of the phase has been used to evaluate the presence or the absence of a peak at a predetermined frequency. The derivative phase of the total signal for a different number of integrations is shown in Figure 3. As it is evident, when 31 or 35 signals are integrated, it is possible to detect three sharp peaks in the phase gradient. If a lower number of integrations (M=15 or M=1) is considered, some peaks are missed, and the signal is much less intelligible. The case with a single measurement (M=1) is reported for comparison but it represents a case-limit since, in this case, the background subtraction would not be feasible since the scenario is fixed and no background signal can be stored before the presence of the tag in front of the reading antenna.



(b)

Figure 3. Phase derivative of the integrated signal as a function of the number of integration number M. (a) free space measurement of the tag located at 130 cm from the antenna, (b) measurements performed on a tag place of a plastic box filled with tapes located at 50 cm from the reading antenna.

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