Chipless RFID Tags for Passive Wireless Sensor Grids

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Abstract

This paper discusses the potential of some chipless RFID tags in term of sensing. Two configurations of chipless sensor tags are studied and experimented. The first configuration is based on a chipless RFID tag coded in frequency domain and transformed into a sensor thanks to a deposit of a nanomaterial that exhibits high sensitivity to humidity. One of the advantages of such a transformation is to combine both identification and sensing in the same and unique device. Very interesting sensitivity is observed in practice. The second configuration is based on the use of frequency coded tag where sensing capability consists in measuring a flight time. Then several sensors located on an object in preselected positions are used in order to monitor the deformation of the object. Interesting accuracy better than 500 µm is observed in practice. It is demonstrated that anti-collision schemes can be implemented leading to read concurrently several chipless sensor tags.

1. Introduction

Needs in identification and physical information capture are crucial issues for modern societies. Many areas of society rely on the identification and measurement of physical parameters such as humidity, temperature for localization purpose. The Radio Frequency Identification (RFID), whose principle was introduced 60 years ago, is one of the key technologies that have grown considerably. It has recently been shown that, it is possible to use the traditional UHF RFID without adding specific components for sensor applications [1, 2]. However, we observed that tag's performances are not enough reproducible for such an application. From there, a solution where we can get grid of the chip will provide better performance in terms of sensitivity. Thus, just like for conventional RFID, the question of adding the sensor application in chipless arises [3-7].

In this paper, we introduce for the first time the principle of reading multiple chipless RFID sensor-tags at the same time. The difficulty here is that, unlike chipped RFID, the lack of hand-shake communication protocols does not allow to address the problem of collision in the same way. So, it is essential to implement completely different approaches. Here we present two examples based on the frequency discrimination that allows, to differentiate each tag and also to retrieve the measured physical information. The first example is a humidity sensor: two sensor-tags are used to measure simultaneously the humidity inside and outside of a container. The second example shows the possibility of measuring the deformation of an object by placing it on chipless tags.

2. Anti-collision schemes in chipless RFID

Chipless tags are fundamentally different from conventional RFID tags; they operating principle doesn't require any communication protocol. They can be seen as targets with a specific radar signature that can be processed either in frequency or time domain [8]. Chipless tags are most often made of resonant elements (frequency domain approach) [9] or delay lines to produce a set of delays (time domain approach) [10, 11]. Now, if we consider that a sensitive material has been added close to the conductive portion of the tag, its EM properties will vary depending on the physical quantity φ to be measured [4-7]. This material will induce a shift in the response of the tag (in frequency or in time) . Ultimately, this shift will allow to measure or monitor the the physical quantity under consideration. To read several tags at the same time, we must be able to isolate each tag that is to say the part of the signal that embed its own ID and the sensor data related to it. In practice, the chipless reader will emit a short pulse and acquire the total backscattered signal reflected by the set of the *n* tag-sensors. To separate the response of only one tag we can adopt either the principle of discrimination in time or frequency. If we do it in time, the tag will induce a specific delay. Then, we can assign a time slot to each of the *n* tags. The same principle can be used in frequency: each of the *n* tags operating at a different frequency, the information on the presence of the tag can be obtained by identifying the peaks in the signal spectrum. Windows are assigned in frequency, and the peak belonging to one or the other of these bands determines its identifier (see Fig. 1b)).

The following step is to consider how it is possible to take into account the sensor data effect on the backscattered

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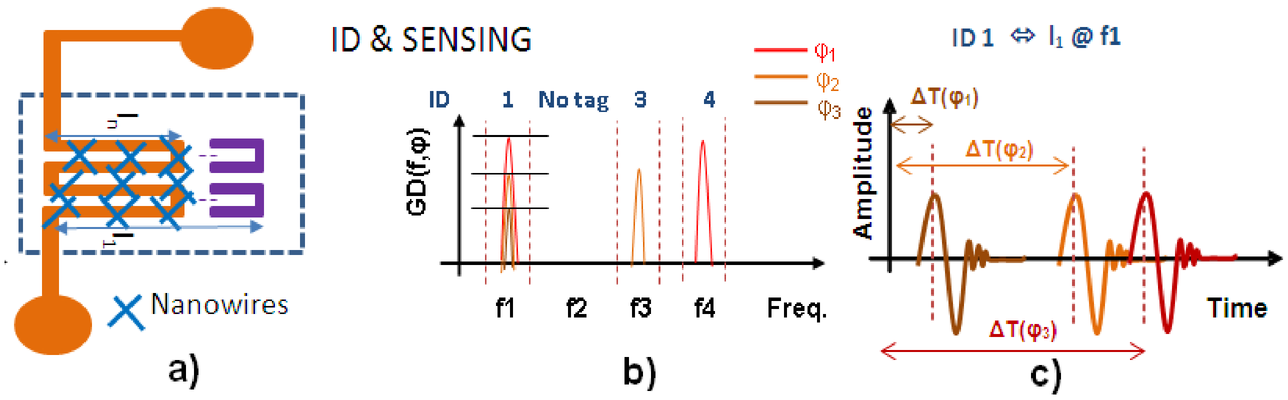

Fig. 1. Principle of operation of the chipless sensor-tag: identification and capture of the physical quantity φ. a) Schematic of the chipless tag used for the sensor application [7], b) backscattered signal expressed in group delay, 3 tags are read at the same time. As presented for the tag n°1, the signal can have different values depending on the physical quantity φ. c) Backscattered signal of the tag shown fig 3a) filtered at f1 and expressed in time. For each of the 3 values of φ, a different backscattered signals that can be obtained by the reader.

signal. If we assume that the physical variation produces a time lag, it is now interesting to study the relationship between group delay and frequency (Fig. 1). In such case, we still can identify the tag ID by the presence / absence of a non-zero group delay for a specific frequency [7]. After that, the physical data φ is directly linked to the magnitude of the group delay as we can see Fig. 1 for the humidity tag sensor. Subsequently, we will present two examples that illustrate how it is possible to read several chipless sensor tags simultaneously.

3. Chipless tag for Humidity sensing

The tag-sensor introduced here to measure humidity is based on the use of silicon nanowires [6, 12]. Currently, nanotechnology has a growing interest in the field of environment sensing since they allow obtaining highly sensitive materials. The proposed chipless tag consists of cross-polarized antennas and a structure known as C-sections as shown in Fig. 2a). Classical disc monopole antennas are used as the tag antennas due to its broadband frequency characteristics. The tag antennas are cross-polarized in order to reduce the interference between the interrogation signal and the backscattered signal that contains the tag information. Nanowires change their electrical properties upon humidity absorption, which in turn changes the magnitude, phase and also group delay (GD) of the reflected signal from the tag. The authors already proved the concept of using nanowires in chipless tags [6, 12]. However, here wireless sensor measurement using multiple tags is presented. Two tags with lengths of C-section as l1=14.9 mm and l2=11 mm is chosen as devices under test (DUT). The nanowires have been put in a solution of alcohol and a drop has been manually deposited on the strip of the C-section where the electric field is maximum, using a pipette. The measurement set-up is shown in Fig. 2a). As shown in the figure, one wireless sensor tag is kept on the inner wall of the plastic box that contains water, and another tag is kept on the outer wall of the plastic box. The box was closed and the probe of a humidity-temperature meter was used to monitor the ambient temperature and relative humidity (RH) inside the box. The S_{21} magnitude and phase of the reflected signal from the tag has been measured. Fig. 2b) shows the group delay corresponding to the two sensor tags during the experimentation. It is clear from the figure that the tag placed in the

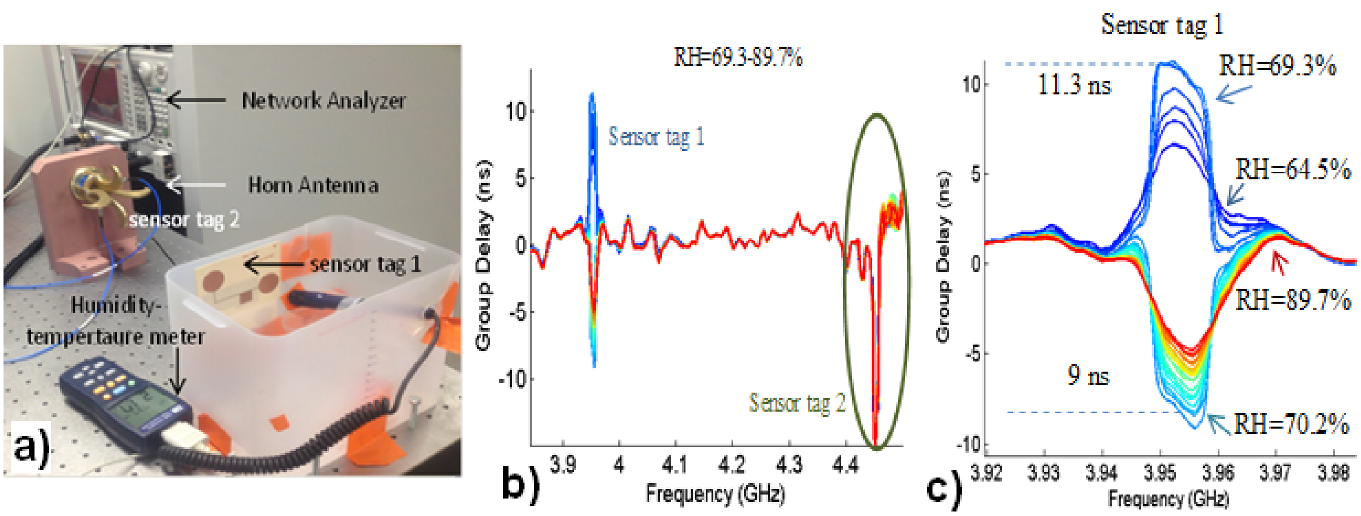

Fig. 2. a) Chipless humidity sensor tag measurement set-up. b) Group delay corresponds to the two sensor tags for a humidity variation of 64.5%-89.7%, c) zoomed view of group delay variation corresponds to sensor tag 1.

interior of the box (sensor tag 1) shows more variations of group delay (see Fig. 2c)), while the GD for the outer tag remains almost constant (sensor tag 2). A group delay variation of 20 ns was observed for sensor tag 1 for a relative humidity of 64.5%-89.7%. A negative group delay of 9 ns was observed like in [7]. The delay peak increases with respect to humidity and reaches the maximum value. This is due to the known fact that, a high permittivity causes the signal traveling through a medium to be delayed.

4. Chipless tag for deformation sensing

As shown Fig. 3a), the system is composed of a fixed chipless RFID reader and several chipless tags positioned on the reflector in the locations where the measurement of the deformation is planned. The deformation would be obtained from the measurement of the signal phase variation. Like in the previous example, an anti-collision approach based on frequency discrimination is used to monitor the read range variation detected at each node. In the configuration presented Fig. 3b), we can see that the tag response is modified by any deformation/displacement relative to an initial position. These tags are the ones used in [13], they can be considered as high quality-factor resonators, with a specific resonance frequency. This is why the frequency band is used to distinguish the tag's ID. Form the signal spectrum, a

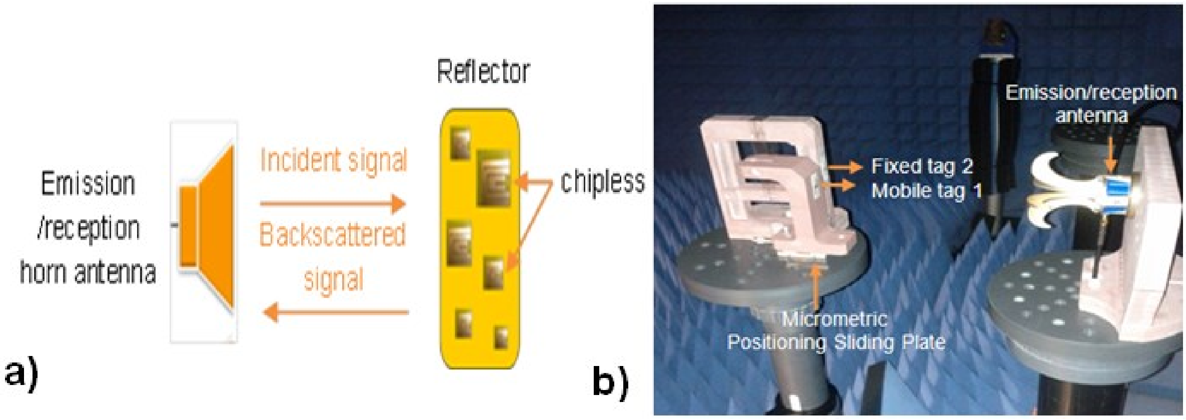

Fig. 3. a) Principle of the chipless RFID system used to monitor deformations. b) Displacement chipless sensor tag measurement set-up.

frequency windowing is performed in order to isolate the response of each tag. Then, an inverse Fourier transform is applied to get back to the time domain. By this way, the time shift of the maximum of the obtained signal is directly linked to the physical tag displacement.

In order to validate our approach in a successful way, the same configuration shown in the first example is used. We have positioned two tags in front of the antenna at a distance of 30 cm. Subsequently, one tag is moved relative to the other (which remains fixed) in steps of 0.5 mm using a micrometric positioning sliding plate (see Fig. 3b)). For the configuration n°1, the tag 1 with 4.72 GHz frequency of resonance is placed on the positioning sliding plate. The tag 2 operating at 5.26 GHz is kept as fixed. Configuration n°2 consists in inverting the two tags, i.e. to place the tag 2 on the mobile support. The RCS measurement deduced from the S_{21} parameter [9] is performed for each displacement of the tag. After filtering around the resonant frequency of the tag and applying an inverse Fourier transform as explained above, results presented Fig. 4 are obtained. It should be noted that, with a displacement step of 0.5 mm, the curves are

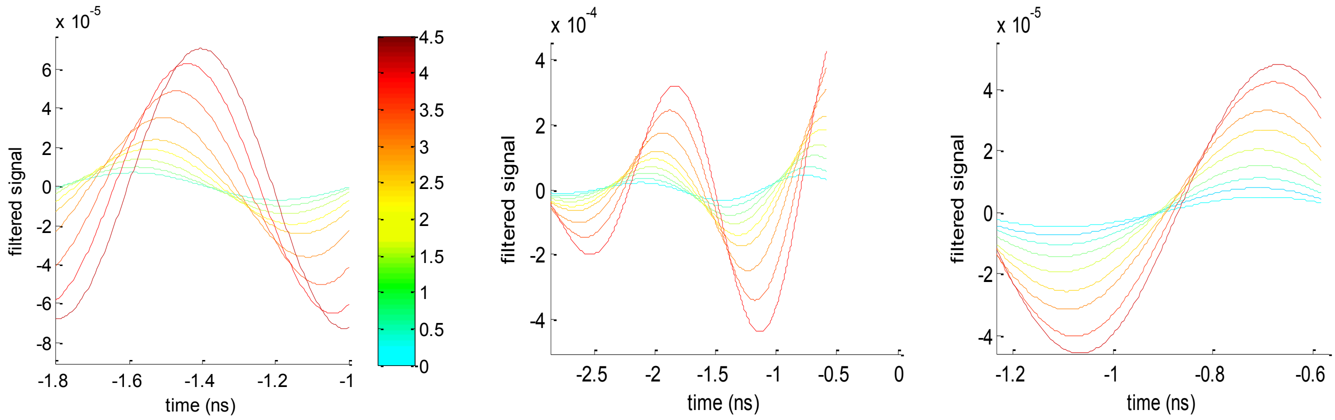

Fig. 4. Measurement results of the reflected signals form, a) tag 1 (signal filtered at 4.72 GHz), configuration n°1, b) tag 2 (signal filtered at 5.26 GHz, configuration 2, c) tag 1 (signal filtered at 4.72 GHz), configuration n°2. Colorbar indicated the value in mm of 10 displacements for the 3 figures (step of 0.5 mm). Displacements are towards the reader.

clearly separated both in amplitude and time. This proves that the resolution of this approach is less than 500µm. Therefore, we can relate these measured variations to the physical displacements. For example, the detection variation of the maximum of each curve gives the temporal shift between various positions of the tags. Based on this, we can deduce a value that is directly linked to the displacement. Fig. 4c) shows the signals reflected by the tag which is fixed (tag 1 (signal filtered at 4.72 GHz, configuration 2). As expected, the maximum of each curve are obtained at the same time. This proves that the extraction of a signal directly related to the distance between tags and a reader is possible to obtain with the chipless technology. A good accuracy (less than 0.5 mm) and reliability is obtained.

5. Conclusion

Chipless RFID is a recent option that allows very low cost and could be competitive compare to barcode. One of the main objectives of this paper is to demonstrate some examples of the ability of chipless tags to evolve as chipless sensors, roughly for free. We considered two possible options. In the first case, sensing capability is obtained thanks to a deposit of some nanomaterials (silicon nanowires) that are known to be sensitive to the humidity in their environment. We demonstrated the effectiveness of this transformation, as we were able to measure the relative humidity, which has been embedded in the ID of the chipless tag, without any additional circuitry or specific measurement setup for sensing. This technique has been experimentally validated for two chipless sensor tags coded in frequency domain, simultaneously read. From another point of view, the ability of chipless tags to form a grid for deformation sensing is demonstrated. To do this, several chipless tags are used to monitor the deformation of a reflector that could be designed for a large spatial communication antenna. We succeeded in measuring reflector deformation as low as 500µm. Again the sensing information is embedded in the ID of tags, and the tags are read at the same moment provided that their IDs are located in different frequency bands. It is remarkable that just an Ultra Wide Band reader is needed to collect the information for all the tags with one shoot interrogation only. To conclude, the potential of chipless tags to be transformed into chipless senor is experimentally demonstrated. Their ability to build sensors grids is also successfully carried out. In all cases, chipless reader is needed, just like conventional RFID.

7. References

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