Study on the detection reliability of chipless RFID systems

Arnaud Vena, Etienne Perret, Brice Sorli, Smail Tedjini

Study on the detection reliability of chipless RFID systems

Arnaud Vena[1], Etienne Perret[2], Brice Sorli[1], Smail Tedjini[2]

[1]Institut d'Electronique du Sud, Université Montpellier 2, France, arnaud.vena@um2.fr, brice.sorli@um2.fr

[2] University of Grenoble Alpes, LCIS, F-26900, Valence, France, etienne.perret@lcis.grenoble-inp.fr, smail.tedjini@lcis.grenoble-inp.fr

Abstract

We report in this paper several techniques to make a chipless RFID system more reliable in order to overcome some drawbacks such as the detuning, the unwanted echoes from the surrounding environment as well as the spurious interferences due to concurrent wireless systems in the ISM bands. As a figure of merit, we show through the implementation of signal processing techniques and by using optimized design that reading a chipless tag on water bottles or on a pack of metallic cans is possible. Such readings are usually not possible by using conventional designs and systems. The various techniques proposed are tested with the help of simulations, and measurements in a practical indoor environment.

1. Introduction

For several years, chipless technology [1-7] appears as a new promising field of research of the radio frequency identification (RFID) [8]. Industrials see chipless RFID as a promising technology but still too young to propose a true global system able to compete with the optical barcode, which is today the biggest market of identification worldwide with ten trillion units sold per annum. Indeed, a conventional RFID tag contains an antenna connected to an IC. The estimated unit cost is close 0.1$. Even if it is low, this price is still too high for most of the goods sold in the consumer market. As opposite to a chipped tag, a chipless tag is made of an antenna only (see Fig. 1 (a), (b) (c)), so that it can be realized with a single process, using roll to roll industrial printing techniques. In this case, the achieved unit cost has been recently estimated at 0.004$ with flexography printing technique [4]. Now that we know how to make a chipless tag with a very competitive price, the question is how to detect this tag with a reading system, at least as reliable as for optical barcodes?

In this paper, we propose several techniques to overcome the common hurdles that we encounter when dealing with chipless technology, illustrated in Fig. 1 (a). In section 2, we study a solution to handle the detuning of ungrounded chipless tag. Then in section 3, we present a design optimized for a reliable detection among highly reflective objects such as metallic objects. Finally, in section 4 before concluding we discuss about a technique to remove the effect of concurrent wireless channels that may interfere with the resonant frequencies of chipless tags.

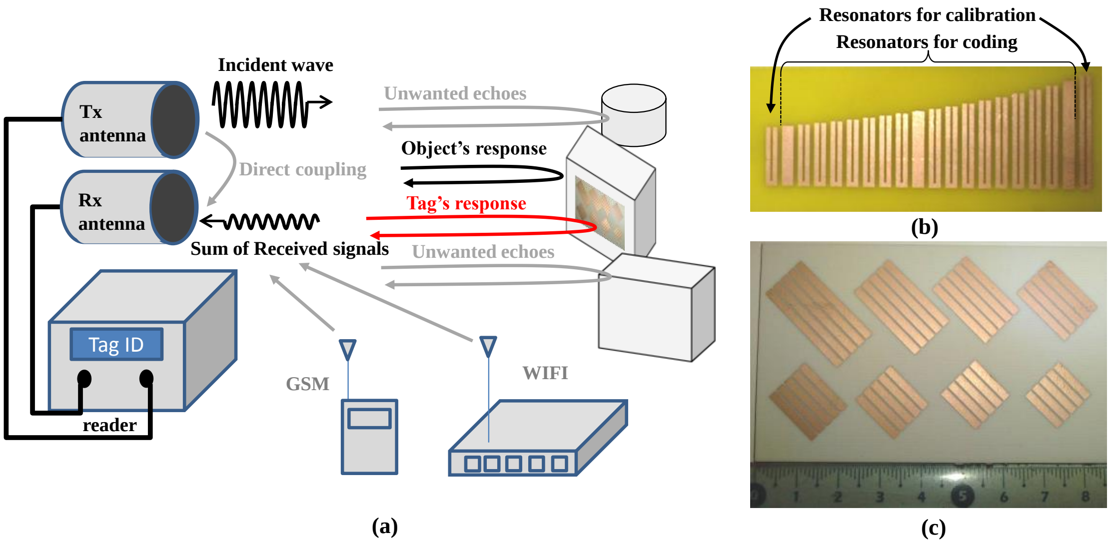


Figure 1. (a) Chipless system in indoor environment. (b) Single layer 20 bits chipless tag using two calibration resonators [5]. (c) Grounded depolarizing chipless tag [7].

2. Improving the detuning by using additional sensing scatterers

A tag designed to operate in free space will not likely work when this specific tag is placed on an object having a permittivity higher than one. This is especially true when this tag has no ground plane because the fringing field is spread all around so that most of the electrical field lines generated by the tag's response cross the object. When the ID relies upon the detection of magnitude or phase shifts for a given frequency span, this can be problematic. In this case, a frequency shift of the tag's response means that the ID will be corrupted.

Using a ground plane is obvious to overcome this issue. Indeed if a chipless tag is designed so that it behaves like a patch antenna, the fringing field only stays close to the boundaries of the patch like a dual slot antenna. If the ground plane is large enough, this means that the fringing field will never get into contact with the material back to the ground plane. This technique is well used in most of the design of chipless tags and sensors [1].In some other cases, to reach the unit cost of optical barcodes, chipless tags are designed with a single conductive layer, without any ground plane so that we cannot avoid the detuning of the resonant modes. Physically, the resonant mode frequencies are linked to the effective permittivity around the scatterer. Thus depending on the object to identify, this effective permittivity can vary a lot. One way to handle this issue is to add one or more resonators, which do not participate to the coding but play the role of effective permittivity sensors [5;6]. Previous works in [5] proved that a frequency shift up to 120 MHz can be compensated with an error on the initial resonant frequency of 25 MHz. To explain this technique let's start with a generic relationship between a physical length L of a half-wavelength scatterer and its first resonant frequency f_{res} as in equation (1). The effective permittivity is given in ε_{eff}.

$$f_{res} = \frac{c}{L \cdot w\sqrt{\varepsilon_{eff}}} \qquad (1)$$

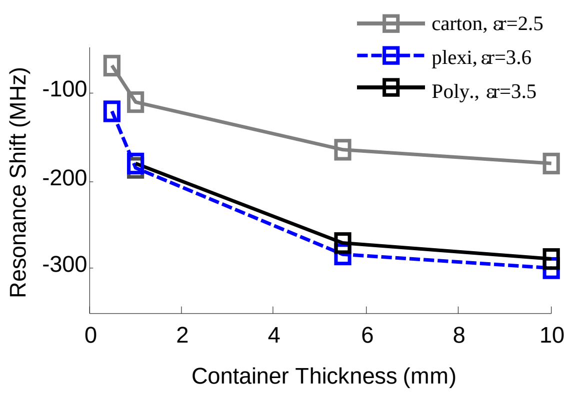
$$\left[\frac{f^{m}_{res}}{f^{0}_{res}}\right] = \sqrt{\frac{\varepsilon^{m}_{effres}}{\varepsilon^{0}_{effres}}} \qquad (2)$$

$$\varepsilon_{effres} = k \cdot \varepsilon_{effsens} \qquad (3)$$

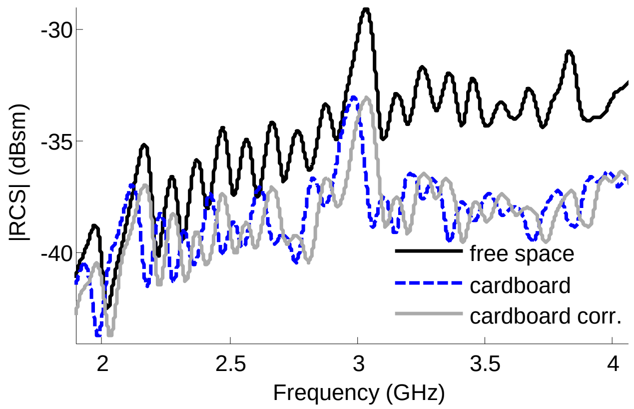
$$\left[\frac{f^{m}_{res}}{f^{0}_{res}}\right] = \left[\frac{f^{m}_{sens}}{f^{0}_{sens}}\right] \qquad (4)$$

$$f^{0}_{res} = \left[\frac{f^{m}_{res} \cdot f^{0}_{sens}}{f^{m}_{sens}}\right] \qquad (5)$$

If we define f^{m}_{res} (respectively ε^{m}_{effres}) as the frequency (respectively the effective permittivity) value of the resonator subject to the detuning effect of an object, and f^{0}_{res} (respectively ε^{0}_{effres}) its value in free space, we can divide both terms to find the equation (2). If using one resonator for coding and one resonator for calibration (the index *sens* is used to note this specific resonator), which is not used to encode information and its frequency changes only if the effective permittivity around it is varying, we can assume that the permittivity between the two resonators is linearly correlated with a constant value k as in (3). This is considered to be true whatever the surrounded environment. Based on this assumption, we can equate the two fractional equations as in (4). We obtain the equation (5) giving a relationship between the resonant frequency of a coding resonator in free space (f^{0}_{res}), and those measured on an unknown object for both the coding (f^{m}_{res}) and the calibration resonator (f^{m}_{sens}). In Fig. 2 (a) we present the measured frequency shift on the first resonant mode (at 2 GHz) of the 20 bits chipless tag as a function of the material, put in contact back to the tag, and for various thicknesses. One can notice a deviation up to 100 MHz for cardboard above 1 mm of thickness. As shown in Fig. 2 (b), the resonant modes of the tag are all shifted toward the lower frequencies to compare with the free space response. One can note that even though the magnitude of the EM response is not recovered, when we apply the



(a)



(b)

Figure 2. (a) Resonant frequency deviation of a single layer chipless tag as a function of the thickness and the permittivity of the tagged object. (b) RCS of the 20 bits based single layer chipless tag (see Fig. 1 (b)) in free space and on the top of a cardboard before and after compensation (measurements are done at 20 cm).

aforementioned post-processing technique on the detuned tag's response, all the resonant mode making the ID, get back to their initial frequency value.

3. Improving the isolation of the tag's response amid the background response

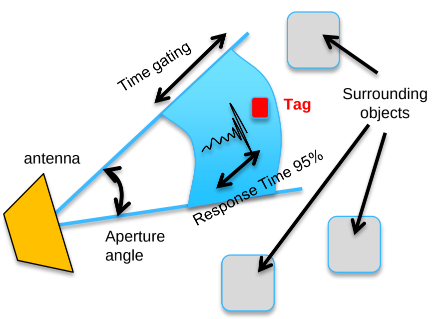
In chipped RFID, the tag backscatters two different powers by modifying dynamically its RCS between two states; meanwhile the response from the environment stays the same. Thus, the effect of the environment is mitigated by the detection of this power variation. A chipless tag sends only one static response making its extraction more difficult when we consider the EM responses of the surrounding objects. Extracting the weak tag's response amid the strong environment response is the biggest challenge in chipless RFID.

3.1 Technique of volume gating

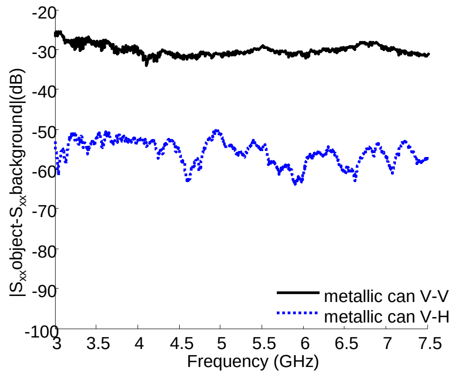
The first technique that we can use to lower the tag's response is based on time gating, which means that we limit the measurement time. When the measurement is done in the frequency domain, this technique can be applied by post-processing technique (convolution with the Fourier transform of a rectangle window for example). When combined with a narrow beam antenna we can introduce the concept of volume gating (see Fig. 3 (a)) for which a volume detection is defined by the traveled distance of the tag's EM response within the time gate and the aperture of the antenna. In the top of mitigating the response from the environment, this technique allows removing the multiple echoes of the tag's response, and performs the signal to noise ratio (SNR). However, a tradeoff should be found between the sharpness of the resonant peaks which can be detected and the SNR. As an example, a resonator having a 3 dB bandwidth of 50 MHz at 3.1 GHz delivers 95% of the stored energy in 20 ns, which corresponds to a 3 m roundtrip in free space. The minimum window size in this case is 20 ns for 50 MHz of frequency resolution. The curves shown in Fig. 2 (b) and in Fig. 3 (c) are obtained after having applied a time gating of 200 ns, which is enough in this case to remove ripples on the frequency response.

3.2 Using depolarizing scatterers

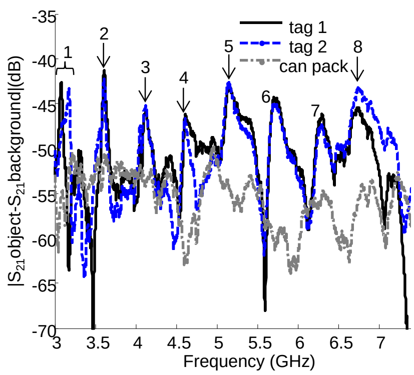
Another technique that we discuss here has been validated in [7] for some difficult cases, especially when the detection environment is composed with metallic objects or liquids. Indeed, because of their good conductivities and their huge size compared with a usual chipless tag, a metallic object or a bottle filled with liquid have large RCSs. When these objects are located in the same phase plane as for the tag, volume gating cannot be used to separate EM responses. For this case, the use of depolarizing scatterers may provide a solution to detect chipless tags. The reason comes from the fact that usual object such as a metallic plate or a water bottle don't depolarize. In other words, this means that when an EM wave impinges on their surface, they reflect a specific response in the same polarization (co-polarization). With a tag based on depolarizing scatterers, the reflected wave is shared between the co-polarization and the cross-polarization. A receiver which detects the cross-polarized response, as regard as the incident wave, will record mostly the useful EM response form the tag, isolated from the environment response. The environment commonly reflects the incident wave, mainly in the co-polarization. The curves in Fig. 3 (b) confirms this assumption showing the responses from the environment in co-polarization and in cross-polarization for a pack of metallic cans. In Fig. 3 (c) we can observe the EM response of a depolarizing chipless tag put on one of the metallic cans aforementioned. The eight resonant peaks can be detected and decoded in order to give the correct ID. This shows the high reliability of the design to compare with resonators generating a resonant mode only in co-polarization [4-5].



(a)



(b)



(c)

Figure 3. (a) Technique of volume gating to isolate the tag's response. (b) EM response of a pack of coffee cans in co (VV) and cross polarization (VH). (c) Tag's EM response of the depolarizing tag (see Fig. 1 (c)) on top of a pack of coffee cans for two different configurations (the first resonant mode only is varying) measured at 20cm.

4. Reducing the interferences from concurrent wireless systems

In many cases, except in an anechoic chamber, concurrent wireless systems using ISM bands may disturb the chipless tag system utilizing the same frequency bands. In chipless technology, there is no intelligence embedded in the tag, so no modulated signals and no anti-collision management are implemented. However the EM response of the tag is supposed to be always the same whatever the interrogation time or the power (a chipless tag is a linear device). Thus, we can use multiple measurements in order to increase the SNR of the desired tag's response. For that, we make the assumption that modulated signals of concurrent systems sharing the same frequency bands vary randomly as a function of the time to compare with the chipless tag response. To remove the effect of the concurrent signals we can apply an averaging filter on N measurements as in (6) in which $Tagresp_i(k)$ is the sample k of the tag's response and $Srf_i(k,t)$ is the environment response of the sample k took for the starting time t. When the number N is large enough (N>10), the term $Srf_i(k,t)$ is mitigated so that it can be considered as null (like in (7)) to compare with the tag's response which remains the same whatever the starting time of the acquisition. We performed the measurements shown in Fig. 2 (b) and in Fig. 3 (c) based on an averaging on 10 measurements in an indoor environment surrounded by WIFI and GSM wireless systems. We didn't observe the resonant peak at 2.45 GHz due to the WIFI showing the validity of the technique.

$$Tagresp_{ave}(k) = \sum_{i=1}^{N} \frac{Tagresp_i(k)}{N} + \sum_{i=1}^{N} \frac{Srf_i(k,t)}{N} \quad (6)$$

$$Tagresp_{ave}(k) \approx \sum_{i=1}^{N} \frac{Tagresp_i(k)}{N} \quad (7)$$

5. Conclusion

In this article, several techniques are studied and implemented in order to perform the detection reliability of chipless tags in real environments. To address the problem of detuning, we introduced and successfully validated an auto-compensation technique that relies upon the use of additional calibrating resonators. To make the detection of chipless tags possible in a real environment we studied the concept of volume gating combining the time gating to control the detection depth and the aperture of the antenna. In the case when highly reflective objects such as metallic plates or bottle of water are in the same phase plane, we proposed a design based on depolarizing resonators allowing an efficient separation of environment and tag's response. Finally, using repetitive measurements and with the utilization of an averaging filter, it was possible to detect chipless tags amid concurrent wireless communication systems.

6. Acknowledgments

The authors are grateful to the University of Montpellier 2 and University of Grenoble Alpes for supporting this research.

7. References

1. F. Costa, S. Genovesi, A. Monorchio, "A Chipless RFID Based on Multiresonant High-Impedance Surfaces," IEEE Transactions on Microwave Theory and Techniques, vol.61, no.1, pp.146,153, Jan. 2013.
2. C. Mandel, M. Schüßler and R. Jakoby, "A wireless passive strain sensor," IEEE Sensors Journal, pp.207-210, 28-31 Oct. 2011.
3. E. M. Amin, S. Bhuiyan, N. Karmakar, B. Winther-Jensen, "A novel EM barcode for humidity sensing," IEEE International Conference on RFID, pp.82-87, April 30 2013-May 2 2013.
4. A. Vena, E. Perret, S. Tedjini, G. Eymin-Petot-Tourtollet, A. Delattre, F. Garet, Y. Boutant, "Design of Chipless RFID Tags Printed on Paper by Flexography," IEEE Trans. on Antennas and Propagation, vol.61, no.12, pp. 5868 - 5877.
5. A. Vena, E. Perret, S. Tedjini, "A fully printable chipless rfid tag with detuning correction technique," IEEE Microwave and Wireless Components Letters, vol. 22, n°4, pp. 209-211, 2012.
6. A. Vena, E. Perret and S. Tedjini, "Design of compact and auto-compensated single-layer chipless rfid tag," Microwave Theory and Techniques, IEEE Transactions on, vol. 60, no. 9, pp. 2913-2924, Sept. 2012.
7. A.Vena, E. Perret, S. Tedjni, "A Depolarizing Chipless RFID Tag for Robust Detection and Its FCC Compliant UWB Reading System," IEEE Trans. on Microwave Theory and Techniques, vol.61, no.8, pp.2982,2994, Aug. 2013.
8. K. Finkenzeller, "Rfid handbook: fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication," Wiley, 2010.