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Micrometric Displacement Sensor Based on Chipless RFID

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***Abstract*— In this paper a chipless RFID tag has been used to realized displacement measurements. Displacements of 100 µm can be monitored with this technique coming from chipless RFID. Tagged objects can thus be identified and their displacements can be monitored at the same time with accuracy of a few microns.**

***Index Terms*— Chipless RFID, displacement measurement, radar cross section (RCS), sensor.**

I. Introduction

The opportunity to facilitate the interaction between objects, and after that with humans is a challenge in many applications, especially if the interaction happens without a direct human activity (see Fig. 1). RFID is based on the RF wave's transmission, which gives it lot of functionalities: the identification number (ID) capture is greatly facilitated and this technology is compatible with multi-tags reading in volume and rewritable data [1]. These functions are impossible to implement with a barcode. So, one might think that the barcode is inevitably overtaken. This is false because 70% of the items produced in the world have barcodes. The reasons for this huge market are simple: barcodes work very well and are extremely low cost. Based on this observation, Chipless RFID technology has been introduced [2], [3]. In comparison with classical RFID and barcode, this technology brings some advantages, and high accuracy sensing in one of those. Chipless RFID technology is a good means for displacement measurement (Fig. 1) due to its flexibility of use, low cost deployment but also its high measurement accuracy.

Several research works show that classical RFID tags, sold for identification purpose, can be used for applications in instrumentation. These sensing functionalities can be obtained by displacing sensitive coating materials or lumped components over the UHF tag antenna to achieve a specific response. Nevertheless, it is also possible to obtain these functionalities without adding any specific analog or digital components to the antenna or even the chip [4]. The most common principle is to exploit the sensitivity of tags to their environment. As is known to all, the performance of a UHF RFID tag is affected by the object on which it is attached. So, it is possible to make the connection between the tag performance changes and the environmental parameter variations (movement, temperature, pressure, etc.). This idea has been introduced in various works [4], [5] where it was shown that it is possible to use the standardized and mature UHF RFID communication protocol to achieve a wireless sensor. Based on this approach, applications in instrumentation such displacement measurement [5], [6] have been developed. The obtained accuracy is of the order of ten centimeters and could be too low for some applications. The performances are limited by the problem of chip sensitivity variations. Compared with chipless RFID, in UHF RFID, the chip provides flexibility as well as numerous functionalities, and most of them cannot be achieved without it. However, for sensing activity based on the processing of analog signals, chipless RFID can play a significant role.

Dedicated measurements systems have been developed for displacement sensors. Very good performance with resolution of few nanometers can be reached with optical interferometers [7]. However, a direct line of sight is needed. Less performance can be obtained with RF approaches based on radar systems even if sub-millimeter resolution can be reached [8]. Non-contact measurements are possible, but without any tag placed on the object to monitored, it is not possible to identify the object to monitor [9].

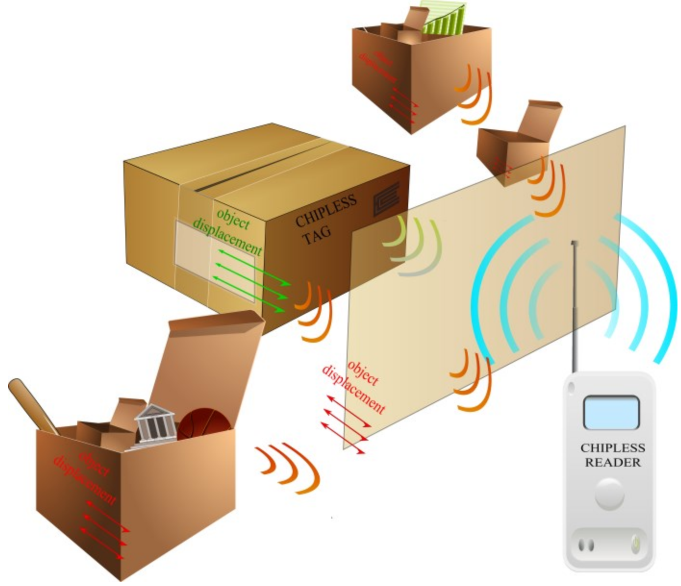

Fig. 1. Scheme of the tag-reader system for displacement measurements and the transmitted and backscattered signals. An environment with the presence of potentially movable objects and non-line-of-sight access are considered.

In this paper, the development of a chipless RFID system for displacement measurement sensor with sub-millimeter resolution is reported.

II. Principles of Operation

In [9], a displacement sensor approach has been introduced and it has been shown that the method is compatible with the use of depolarizing chipless tags (see Fig. 2). Indeed, the response of the tag in cross-polarization allows to detect its displacements even when other objects are placed around the tag (see Fig. 1). Also, it has been shown that using (1) the tag's displacement d_C can be extracted from the cross-polarization scattering term of a chipless tag with three measurement results, which are I_{vh}, ${S_{21}}_{vh}^{(0)}$, and ${S_{21}}_{vh}^{(d_C)}$.

$$d_C = \frac{1}{2k} ln\left(\frac{{S_{21}}_{vh}^{(0)} - I_{vh}}{{S_{21}}_{vh}^{(d_C)} - I_{vh}}\right). \qquad (1)$$

where, I_{vh} is the direct coupling between antennas, also called isolation measurement. k is the phase constant. ${S_{21}}_{vh}^{(0)}$ and ${S_{21}}_{vh}^{(d_C)}$ are the S-parameters corresponding to the cross-polarization tag's scattering respectively at a position of reference 0 and after a displacement d_C. A typical measurement bench that could be used for such acquisition is shown in Fig. 2.

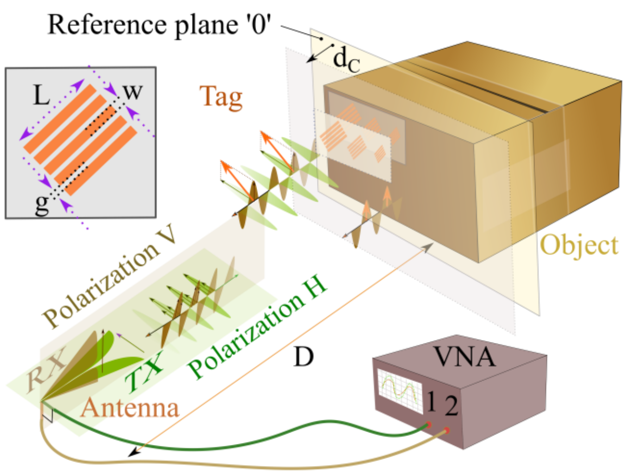

Fig. 2. Principle of the chipless RFID system used to monitor deformations. The TX antenna sends a signal in vertical polarization while the RX antenna operates in horizontal polarization. Representation of two positions of the tag: the displacement between these two configurations is d_C.

The validity domain of (1) has been studied in [9]. One significant result is that (1) can be used even when the tag is surrounding by multiple unknown objects that can move. To implement (1) in practice, the process is simple: we first have to measure the direct coupling from the reader's transmitting to receiving antenna in cross-polarization I_{vh}. Then d_C will be directly computed form (1) based on the measurement of the backscattered wave from the tag at different times.

III. Measurements Results

Measurements have been done in the frequency domain with the Agilent PNA Network Analyzer N5222A. The power delivered by the vector network analyzer (VNA) is -5 dBm in the frequency band from 2 GHz to 8 GHz. The horn antenna has a gain of 12 dBi in the frequency band of interest. The measured quantities correspond to the S_{21} parameter. The tag is placed at a distance of 20 cm from the antenna. The measurement is performed inside an anechoic chamber. The tag with shorted 45° dipoles introduced in [10] has been used for the experimentation (see Fig. 3). The measurements S_{21} with the tag for different distances and the I_{vh} or background (empty-room scene) without the presence of the tag have been performed.

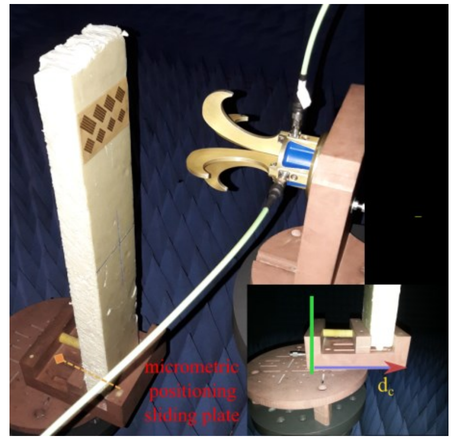

Fig. 3. Photograph of the measurement setup for displacement measurements in an anechoic chamber: micrometric positioning sliding plate and the depolarizing tag based on shorted dipole [10].

The objective of the paper is to determine the minimum displacement distance that can be measured. A displacement of 100 µm has been assessed (5 times less than in [9]). Fig. 4 shows the measured $|S_{21}|$ parameter for four displacements of the tag. Note that the 5 curves (with the reference one) look similar. When the peak apexes are considered (see the zoom in Fig. 4), the variations observed are not correlated to the displacement. These very small variations are clearly not linked to displacements but to measurement noise.

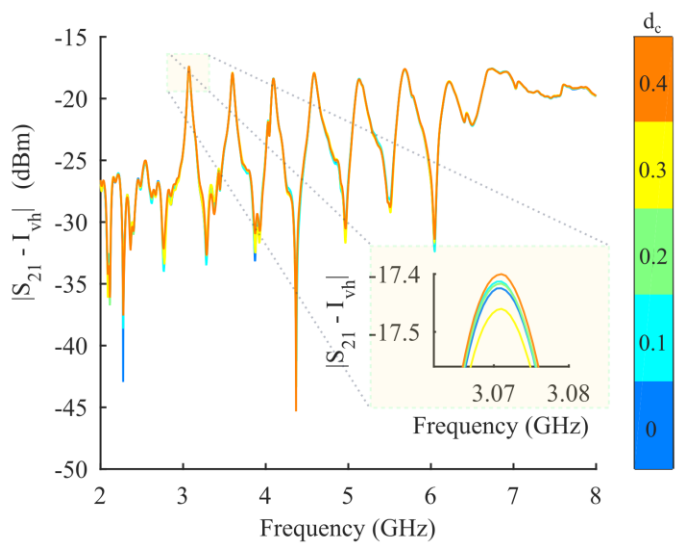

Fig. 4. Measured $|S_{21}|$ for the tag (shorted dipoles at 45°) with the background subtraction inside an anechoic chamber. The distance between the tag and the antenna is 20 cm. Five positions (d_C from 0.1 mm to 0.4 mm) have been plotted.

The Fig. 5 shows the extracted displacement values d_C form the same measurement results but using (1). Contrary to the results of Fig. 4, (1) gives accurate results of the measured displacements, especially around the tag resonance frequencies [see Fig. 5(b)]. With this tag, 8 values of d_C can be extracted simultaneously, so to increase the accuracy, the mean value can be computed. The relative error is -37.5% for d_C=0.1 mm (worst case), and 3.7% for d_C=0.4 mm (best case). Note that the latter corresponds to an error of 15 µm.

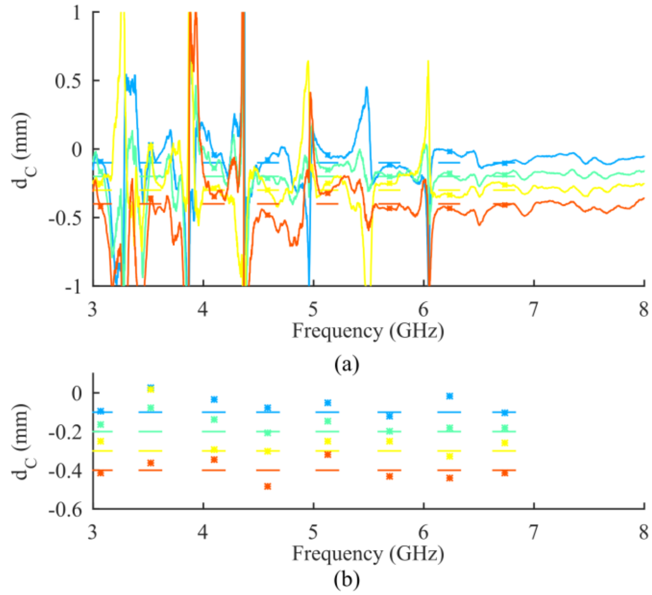

Fig. 5. Displacements of a depolarizing tag (8 scatterers) based on shorted dipoles oriented at 45°. (a) d_C is derived from the measurement of S_{21} parameter using (1). (b) Same than (a) but with only the expected values and the extracted values (asterisks) at the tag resonance frequencies. Four displacements (from 0.1mm to 0.4mm, with a step of 0.1mm) have been measured.

It is interesting to evaluate the effect of the distance between the tag and the reader antenna. Fig. 6(a) shows the measured $|S_{21}|$ parameter when the distance is 80 cm.

A lower signal to nose ratio [see the zoom in Fig. 6(a)] increases the relative error. However, up to 100 cm the obtained error remains acceptable (less than +-15%). The extracted displacement versus the distance in the range 20 cm to 100 cm is plotted Fig. 6(b). To have resolution of 30 µm, a maximum read range of 40 cm has to be chosen.

Note that the displacement information is not related to the data encoding capacity, it is an additional feature that is totally independent. Indeed, contrary to some other approaches [3], there is no compromise between the sensing capability and the data capacity. Thus, if a tag having a plurality of resonators and operating in cross-polarization is used for an identification application, with the same tag it is possible to retrieve information about its movement and this by exploiting all its resonators.

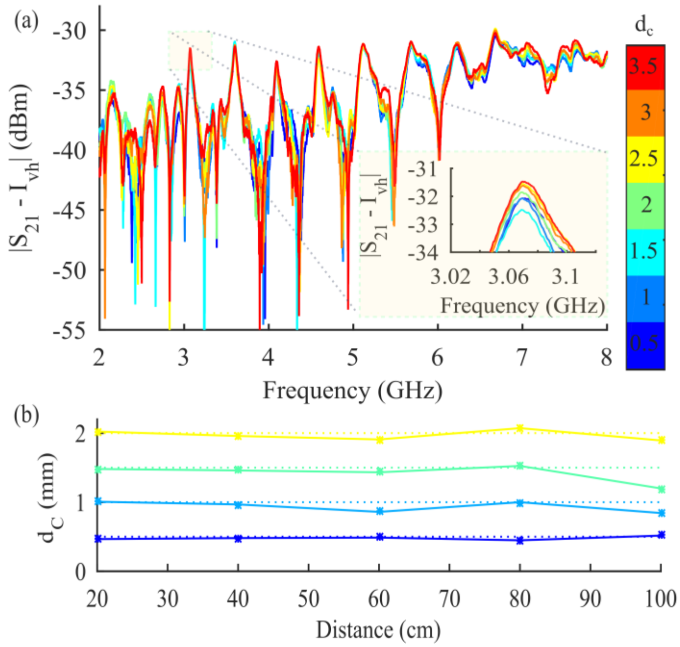

Fig. 6. (a) Measured |S21| for the tag with the background subtraction inside an anechoic chamber. The distance between the tag and the antenna is 80 cm. Seven positions (d_C from 0.5 mm to 3.5 mm) have been plotted. (b) Impact of the distance on the displacement d_C extraction (0.5 mm to 2 mm).

IV. Conclusion

The introduced solution based on cross-polarization interrogation signals provides higher signal to noise ratio, which directly contributed to improve the robustness, and the stability of the chipless tag analog response. From this study, it is shown that a displacement of 100 µm can be measured with a chipless RFID approach. It is possible to reduce the error by averaging the independent information extracted from each of the tag's resonators. The best resolution is obtained for displacements higher or equal to 400 µm where an error of 15 µm has been obtained.

Acknowledgment

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References

[1] K. Finkenzeller, RFID Handbook: Fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication, 3rd Edition: Wiley, 2010.

[2] I. Jalaly and I. Robertson, "RF barcodes using multiple frequency bands," in IEEE MTT-S International Microwave Symposium Digest 2005, 2005.

[3] E. Perret, Radio Frequency Identification and Sensors: From RFID to Chipless RFID: Wiley-ISTE, 2014.

[4] G. Marrocco, L. Mattioni, and C. Calabrese, "Multiport sensor RFIDs for wireless passive sensing of objects—Basic theory and early results,"

Antennas and Propagation, IEEE Transactions on, vol. 56, pp. 2691-2702, 2008.

[5] R. Bhattacharyya, C. Floerkemeier, and S. Sarma, "Low-Cost, Ubiquitous RFID-Tag-Antenna-Based Sensing," Proceedings of the IEEE, vol. 98, pp. 1593 - 1600, Sept. 2010.

[6] S. Caizzone and G. Marrocco, "RFID-grids for deformation sensing " in IEEE International Conference on RFID, 2012, Orlando (USA), 2012, pp. 130 - 134.

[7] L. Xinqun, W. Clegg, D. F. L. Jenkins, and B. Liu, "Polarization interferometer for measuring small displacement," IEEE Trans. Instrum. Meas., vol. 50, pp. 868-871, 2001.

[8] K. Seoktae and N. Cam, "A displacement measurement technique using millimeter-wave interferometry," IEEE Trans. Microw. Theory Techn., vol. 51, pp. 1724-1728, 2003.

[9] E. Perret, "Displacement Sensor-based on Radar Cross-Polarization Measurements," To be published in IEEE Trans. Microw. Theory Techn., 2017.

[10] A. Vena, E. Perret, and S. Tedjini, "A Depolarizing Chipless RFID Tag for Robust Detection and Its FCC Compliant UWB Reading System," IEEE Transactions on Microwave Theory and Techniques, vol. 61, pp. 2982 - 2994, 2013.