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Detection of water drop volume based on Chipless RFID radar approach

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Abstract- In this paper the principle of radar commonly used in chipless RFID is implemented to detect the presence of water in contact with a resonant radar target. It is shown how it is possible to determine very precisely the time at which the water on the tag has completely evaporated. Based on this observation, a method for determining the volume of a drop of water of a few μl on a resonant scatterer is introduced. The measurements carried out in a real environment are in very good agreement with the simulations and make it possible to consider the detection of the presence of water in contact with an RFID tag without a chip and to evaluate its volume.

Keywords- chipless RFID, radar, volume detection.

INTRODUCTION

The need for autonomous devices that can retrieve an identifier or a physical quantity and that are connected to each other, particularly via the Internet, is becoming increasingly important. For certain fields of activity, such as traceability, these autonomous devices must be wireless and, above all, not require a battery to operate [1]. From there, they can be either remotely powered, as in the case of UHF RFID, or totally chip-free, without any components, as in the case of chipless RFID. In the latter example, the tag is nothing other than a radar target specifically designed to backscatter a given EM signature, which will enable the tag to be associated with an identifier and thus perform the desired function [2]. In addition to reducing the cost of barcode-type solutions, which are still widely used, chipless RFID provides an answer to the problem of environmental protection. Indeed, as RFID systems with chips become more widespread around us, this means that billions of chips will be produced and, after what may be a relatively short period of use, will be thrown away. Chipless RFID is therefore a very good answer for all identification systems where the label is single-use with a short lifespan and no specific channel for its recycling.

Another advantage of chipless RFID lies in its operating principle which is based on a radar approach. Also chipless RFID sensors have been introduced, for example to measure humidity [3, 4]. In some cases, especially when the environment and therefore the reflections of objects potentially present around the tag are controlled, it is possible to carry out metrology-type measurements with a chipless tag [5]. For example, it has been shown that by working around 3 GHz, it is possible to measure chipless tag displacements of a few hundred microns [6]. Similarly, it is possible to characterise the thermal expansion coefficient of metals [7]. This is based on the measurement of the geometric dimensions

of the resonator shapes, which in this case have variations in the micron range. This results in variations of only a few MHz in the resonant frequency of the resonant scatterer. These figures show the very good measurement resolution that can be achieved with the measurement approach used in chipless RFID.

This article is a continuation of this work, namely to show the great potential of the chipless RFID approach for metrology and sensor applications. We are interested here in using the influence of water on a chipless resonator. The principle is based on the remote measurement of the evolution of the resonance frequency of such a device when it interacts with water. Indeed, the fact of depositing water, even in very small quantities, on a chipless resonator will instantaneously and very strongly modify its resonance frequency. By visualising the evolution over time of the signal backscattered by the resonator on which a drop of water has been deposited, it will be possible to determine very precisely when the water has completely evaporated. These observations allow, among other things, the detection of the appearance of dew or mist on the label. We will also see how it is possible to detect the volume of a drop from the moment we consider that the evaporation time of the drop is proportional to its volume. The analysis of the evolution of the resonance frequency or of the quality factor of the resonator can also make it possible to determine the type of deposit made on the resonator, for example if the drop has a semi-hemispherical shape, or if it is spread out on the resonator (like droplets).

PRINCIPLE OF OPERATION

The principle of a chipless RFID reading system is described in Fig. 1, which shows a mono-static configuration with a single antenna and the tag placed a few tens of centimetres away. The measuring device can either be a VNA or a dedicated impulse reader when taking into consideration the regulations on EM emission. For the proof of concept, we will focus on the study of a resonant scatterer composed of a rectangular loop without ground plane [8]. Insofar as, to obtain an identifier on several bits, a tag can be composed of several resonators of this type [2]. The results obtained for a single resonator can be extended to an entire tag. It should be noted that in this case, for sensor applications, the physical quantity to be measured is extracted for each resonator, so the fact of having several of them makes it possible to increase the accuracy of the measurement by averaging each of the values obtained independently, for each resonance frequency [6].

The principle of the approach is as follows: at time t_0 a drop of water is deposited in the centre of the rectangular loop (see Fig. 2a), i.e. in the area where the electric field is maximum at the resonance frequency. The water gradually evaporates, and its interaction over time on the resonator is obtained from the backscattered signal. A second type of deposition is also studied, namely the case where the drop is spread over the entire surface inside the metal loop (Fig. 2b and 2c). In order to best describe the evolution of the backscattered signal as a function of time due to the evaporation of water, two simulations are carried out in the case of the spread drop: 1- the thickness of the water deposit decreases as a function of time (Fig. 2b), the surface of the deposit remaining constant. 2- The thickness remains constant, but the surface of the deposit is reduced as a function of time (Fig. 2c).

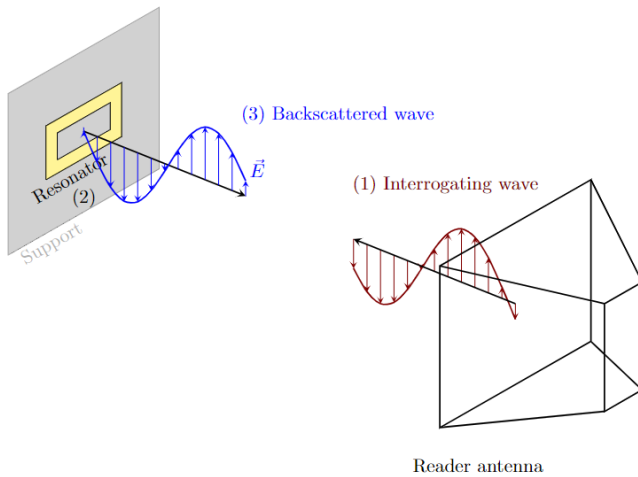


Fig. 1 Illustration of the Operation's Principle. A transmitting antenna will emit an electromagnetic wave towards the target (1). The target will receive and reflect part of this wave (2). The reflected wave will then be able to be captured again by the receiving antenna (3).

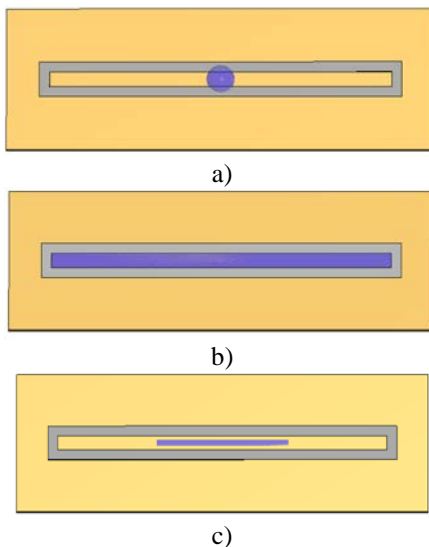
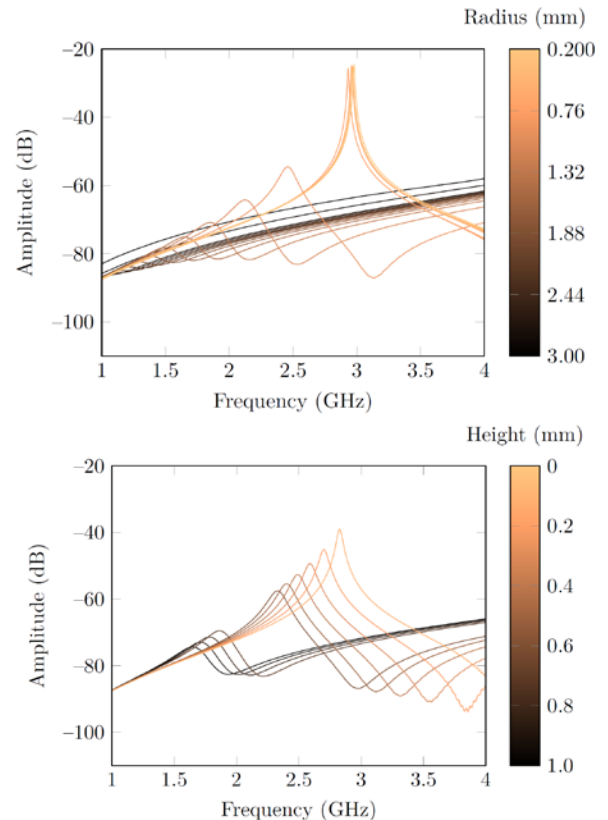


Fig. 2 Resonant scatterer used in the study with three different water deposition: a) semi-hemispheric drop, b) surface deposition with water thickness variation, c) surface deposition with water surface variation. Dimensions are: gap =2.07mm, arms width=1.43mm and gap length=50.8mm.

SIMULATION

The loop shown in Fig. 2 was simulated with CST MW by considering as excitation a plane wave propagating at normal incidence on the loop, with an electric field oriented perpendicular to the long side of the loop so as to excite its fundamental mode [8]. The backscattered field in the direction of the incident wave (see Fig. 1) is obtained with an E-farfield probe defined in CST. The simulation was done for different volumes of water drop on the loop in order to describe an evaporation phenomenon. In the case where the water is completely evaporated, the classical behaviour of a resonant loop is found, characterised by a resonance frequency of 2.9 GHz and a quality factor of 180. The results for the half-hemispherical drop configuration of variable radius (between 0 and 2.2 mm) are shown in Fig. 3a. It can be clearly seen that a 2.25 μl drop of water (radius 2.2 mm) positioned in the centre of the loop cancels the resonance of the device. By progressively reducing the radius of the drop, the appearance of the resonance can be seen. As expected, there is an increase in resonance frequency with decreasing volume and an increase in the quality factor. This study was carried out for different drops spreads within the loop as shown in Fig. 2b,c. The results are shown in Fig. 3b and c. The same trends are observed. However, it should be noted that the evolution of the curves (resonance frequency and quality factor) as a function of volume are not identical, especially with the case where the drop is not spread.

Through these simulation results, it is also shown that it is possible to detect very precisely the instant at which the water is completely evaporated. It corresponds to the end of the variation in time of the resonance frequency or the quality factor. If we take the frequency, it is sufficient to detect the instant for which it becomes constant. Taking all the results shown in Fig. 3, we are also able to determine through these time evolutions, the shape of the initial deposit, i.e. whether it is a localised drop or spread over the structure.



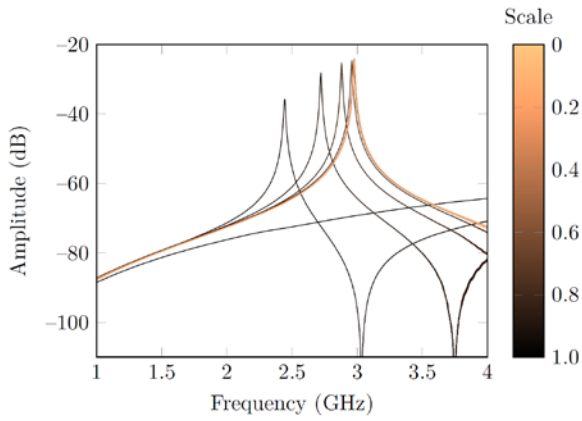


Fig. 3 Simulation of the electric field backscattered by the resonant structure for different water deposits. a) localised drop with variable radius, b) spread drop with variable thickness, c) spread drop with variable surfaces.

MEASUREMENT RESULTS

The following protocol was implemented to evaluate the performance of the approach in practice. A drop of water was deposited with a micro pipette at a time t_0 . In the case of the spread drop, we moved the tip of the pipette over the surface of the loop so as to spread the water once the drop was deposited. From there, acquisitions on a VNA (Keysight P9375A) connected to an antenna (Satimo QH2000) as described in Fig. 4 were performed at regular time interval (2 seconds time stamps).

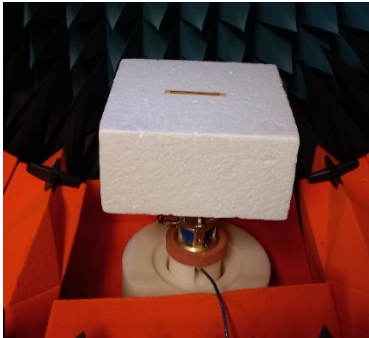


Fig. 4 Photo of the measuring bench.

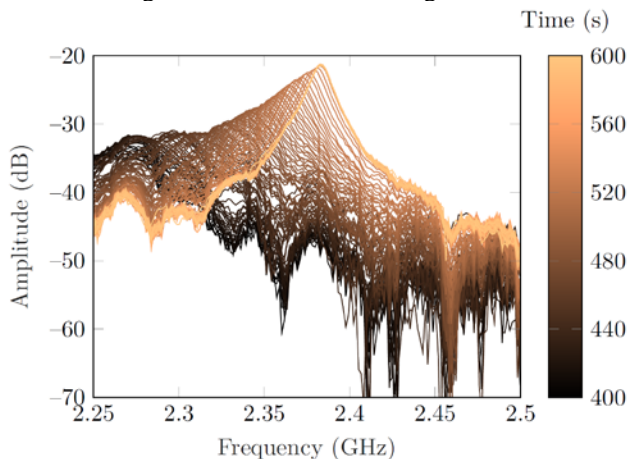


Fig. 5 S11 parameter measured as a function of time for the configuration described in Fig. 2a.

A. Time determination when water is evaporated

The S11 parameter as a function of time thus obtained are shown in Fig. 5. The same trend as that observed in the

simulation in Fig. 3 can be seen, i.e. an absence of resonance for times close to t_0 , followed by the appearance of resonance and the attainment of a maximum frequency that is stable over time. To highlight the fact that it is possible to obtain with great precision the moment when the water droplet has completely evaporated, the extraction of the quality factor from all the measured curves has been carried out as a function of time. The results are presented in Fig. 6a for the localised drop and Fig. 6b for the spread drop. In the absence of resonance (instants close to t_0) the extraction of the quality factor is not precise and results in chaotic variations. However, from 240sec, a trend appears and a very rapid evolution can be observed between 300 and 340sec. After that, a plateau is observed, which is characteristic of the achievement of a stationary phenomenon and in this case of the end of the evaporation process. It is thus understood that the appearance of the resonance frequency only occurs when the surface of water remaining on the loop is extremely small, which is shown by a very rapid evolution just before the appearance of the plateau. Both of these elements make it possible to determine very precisely by this method the time when the water has completely evaporated. By comparing Figs. 6 and 3, more exactly the curves after 240sec, it is possible to differentiate between the two cases, i.e. whether the drop was deposited in a localised manner, or whether it was spread out. Indeed, it can be seen that when the drop is spread out, the evolution towards the equilibrium state and therefore the total evaporation is much faster.

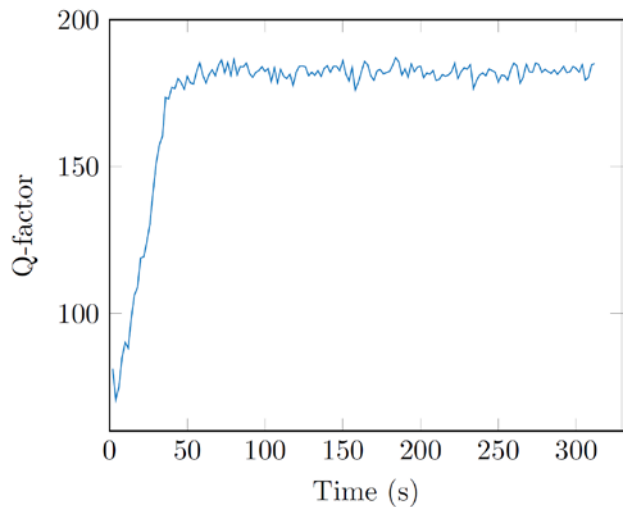
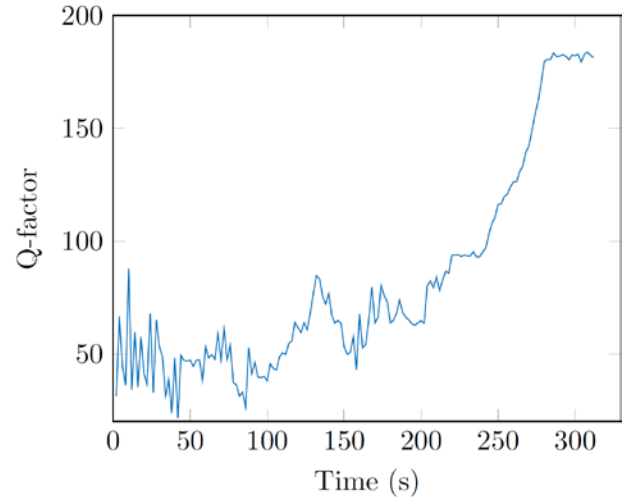


Fig. 6 Evolution of the Q-factor as a function of time, a) localised drop, b) spread drop.

B. Measurement of the volume of the evaporated drop.

To demonstrate the measurement accuracy of the method, we carried out drop deposits of variable volume, i.e. between 1 μl and 2.5 μl in steps of 0.5 μl . The measurement procedure remains the same as that previously explained, we note $t_0 = 0$ s the instant when the drop was deposited. The measurement results are shown in Fig. 7a. It can be seen that there is a very significant difference in the extracted evaporation time for the different volumes. Indeed, it is perfectly possible, and with precision, to differentiate the different volumes of drops. To get an idea of the reproducibility of the measurement, for volumes 1 μl and 2 μl , the measurements were repeated, i.e. all the deposits as well as the measurement itself. We can see a very good correspondence in these same measurements, with evaporation times very close to each other and also very different from those obtained for different volumes. Through the results of Fig. 7a one can claim to differentiate variations of the order of 0.1 μl in this way. Fig. 7b shows the evaporation time for each of the different drop volumes. One can see a proportionality between the two quantities. Assuming this trend, especially from reference measurements such as those shown in Fig. 7b, it would be possible to trace the volume deposited on the resonator from the evaporation time measurement. Here again, an error of the order of 0.1 μl seems achievable.

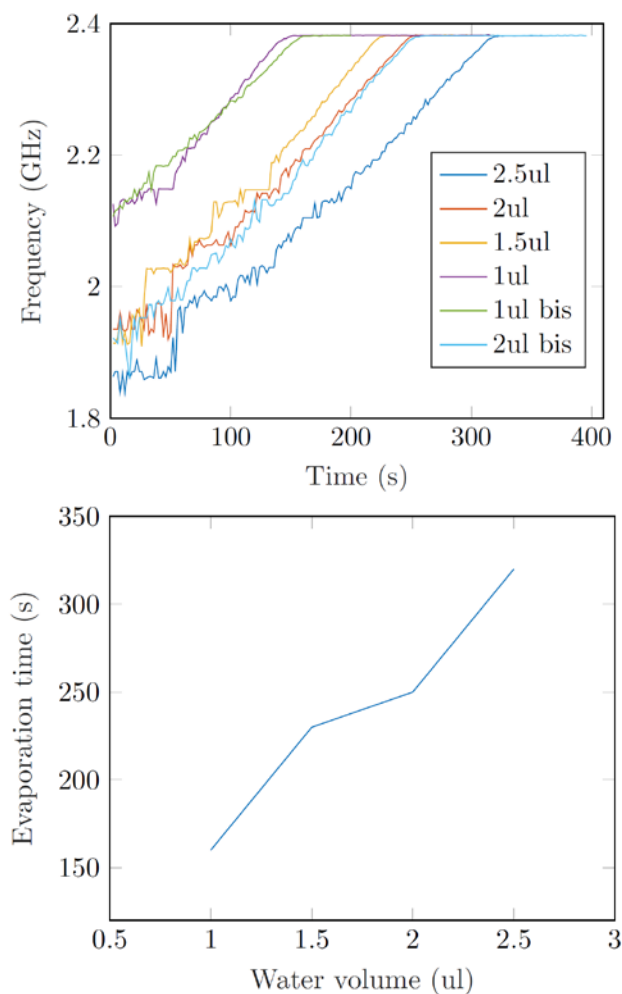


Fig. 7 Measurement of the deposited drop volume. a) Evolution of the resonance frequency as a function of time, b) drop volume vs obtained evaporation time from Fig. 7a.

CONCLUSION

The chipless reading approach has been applied to the detection of the presence of water on a resonant scatterer. With this method, it is possible to remotely detect the time at which the water has completely evaporated. From there, in terms of application, it is possible to estimate the distribution of water on the surface of the resonator or to measure the initial volume of water. This technique could be of interest in agriculture to better control the water needs of crops in relation to rainfall.

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