Effect of different chemical compounds concentration in aqueous solution on UHF RFID readability

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Abstract

Radio frequency identification (RFID) technology could deserve an important role in food products automatic identification. The massive introduction of RFID tracking in food factories has been limited as technical challenges have to be overcome. Tag reading performances are affected by many factors, as product composition, packaging materials and some peculiarities of the production environment, which dramatically reduce RF identification reliability. This paper analyses the effect on RFID tag readability when in proximity of aqueous solutions of different chemical compounds chosen among molecules which are frequently contained in food or beverage (citric acid, sodium chloride, sucrose).

The effect of the concentration was evaluated measuring, in standardized conditions, the minimum power (P_{min}) to be delivered to different commercial UHF passive tags for their activation and effective identification by a RFID UHF (Ultra High Frequency) test bench system.

Keywords: UHF, RFID, tag detuning, tag performance, liquid bottle.

1. Introduction

In UHF RFID systems, the communication between tag and reader is governed by electromagnetic coupling where the reader antenna delivers an electromagnetic field which both provides to power electrically the tag and transmits coded signals which are then backscattered by the tag to the reader. In passive RFID tracking, which is the simplest RFID application, this mechanism is exploited to acquire information stored in the microchip of the tag (e.g. a serial number) which is attached to the item to be identified at a certain distance in the tracking system. In optimal conditions, as the reading range of UHF systems is very high (2-4 m) and allows easy management of multiple item detection even in dynamic conditions, this technique is considered very promising for food traceability. However, one of the limitations in applying UHF technology for passive identification of food items, and in particular of packed liquids, is the unreliability of the UHF systems which can fail in reading the tag due to the performance limits. This is caused by the presence of beverage in contact or nearby the tag reducing reading area and altering the electromagnetic tag-reader link.

In fact, while a UHF tag is readable in free space even at 2 or more metres by most of UHF readers, when a RFID tag is attached to a liquid-filled packaging dielectric properties of material surrounding the tag modify electromagnetic waves propagation. Indeed, a complex system is created whose dielectric properties are determined by the subsequent layers of materials of the packaging (glass, films, plastic materials) and the solution herein contained.

The effect is that reading range can be altered and the original performances requested for tracking food or e.g. other packed liquids (pharma products) are not maintained. Namely, when a tag adheres to a different material and composition, the parameters of the equivalent LCR electrical circuit of the antenna, constituted by an inductance, capacitance and resistance, change. This circuit should be tuned with the integrated circuit (IC) of the tag. In presence of materials of different composition in proximity of the tag the impedance is changed, causing detuning.

Another effect is a change in gain, efficiency and radiation pattern because of the currents induced in the material (Lorenzo *et al.*, 2011). The result is often the lowering of the efficiency in signal transmission and a reading range reduction that limit the possibilities of UHF systems use in food and beverage industry. This phenomenon has also been deployed to develop sensors based on RFID passive labels for sensing chemical change of food and beverage during conservation (Potyrailo *et al.*, 2012).

Sohrab and Huang (2010) specifically demonstrated that the presence of liquids in glass bottles led to impedance mismatching with a narrower bandwith and degraded return loss. Moreover, it has been reported that tag type has significant effects on reading performances of RFID labels attached to wine bottles (Expósito and Cuiñas, 2013).

The aim of the present study is to evaluate the reading performance of different models of tags attached to bottles filled with solutions of pure substances chosen among those which are often encountered in food products (salt, organic acids, sugars and alcohol). The objective is to compare the performances of existing commercial inexpensive UHF tags for a possible use under a label or attached to beverage goods, considering the limits imposed by each chemical constituent.

2. Materials and Methods

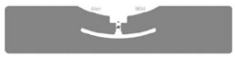
A test bench was setup using a commercial UHF RFID system composed by a Caen RFID R4300P standalone reader connected to a linear polarized antenna (Caen RFID, model Wantenna X007, 8 dB*i* gain) operating at a carrier wave at 866.6 MHz. The UHF passive tag under test was attached to a rectangular HDPE bottle filled with 500 ml of aqueous solutions of pure chemical compounds representative of food and beverage composition (sucrose, NaCl, citric acid) at different concentrations (% w/w). Solutions were prepared in laboratory deionized water. Electrical conductivity of the solutions was determined by a MicroCM2201 conductivity cell electrode Crison Instruments micro CM 2201 equipped with a platinum conductivity cell and temperature calibration (Crison 5292). The list of the Class 1 Gen2 compliant label-type passive UHF tags is reported in Table 1. Tag was placed at 500 mm fixed distance with respect to the reader antenna in frontal and in rear positions depicted in Figure 1. Tag was placed in frontal and rear positions with respect to the reader antenna at 500 mm fixed distance (Figure 1). The reader and the tag antennas were vertically aligned to minimize the polarization loss. Temperature was kept at 21±1 °C. In order to minimize electromagnetic wave reflection, any metal objects were kept away from the working environment.

Reader was controlled by a custom software which generates tag interrogations at increasing carrier power levels, from 0 to 33 dBm, until tag identification. RF attenuators (3, 10 and 20 dB) were mounted on the antenna to obtain values in the reader operating range.

The minimum transmitted carrier power, in terms of Transmitter Power Output (TPO) which enabled a valid response of the tag was measured and indicated as P_{min} (dBm). The power ramp was stopped at 33 dBm while beyond this value the tag was considered technically unreadable in a real system implementation.

For each combination, five measures were repeated and the results were expressed as the mean of the five measurements.

Table 1. Tags tested.

Tag model	Integrated circuit	Nominal reading chip sensitivity	Antenna size width x length, mm	Inlay shape
Alien 9654	Higgs 3	-20 dBm	93 x 19	
Lab ID UH 101	NXP Ucode 7	-21 dBm	95 x 8	
Lab ID UH105	Impinj Monza 5	-20 dBm	91 x 18	

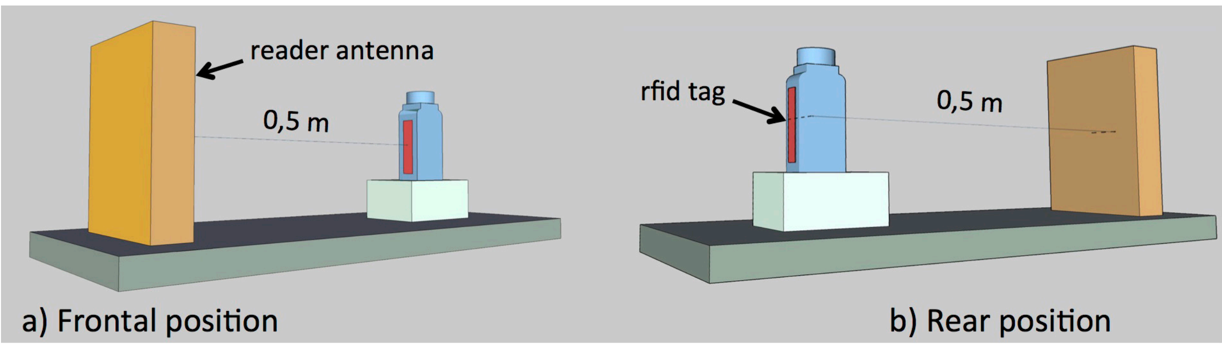


Figure 1. Scheme of the adopted positioning of the bottle, the tested tag and the antenna.

3. Results and Discussion

To verify the effect of the material of the bottle, minimum transmitted output power needed to activate the tag in the condition of the test bench, P_{min} was measured with the tag attached to the empty HDPE bottle (Table 2).

The HDPE is a material that interferes minimally on magnetic waves. Its dielectric constant at 1 MHz is about 2.3-2.4 and the dissipation factor is 1-10 x 10^{-4}. On the contrary, glass bottles strongly impact on readability (as demonstrated by

Expósito and Cuiñas, 2013), and therefore were not considered in this study even if are widely used in beverage packaging.

The tag LabID UH105 was detected at the lowest value of power emitted by the reader. In spite of the very high sensitivity of the integrated circuit (-21 dBm) the power level to activate the tag LabID UH101 was the highest. It has to be considered that the tag antenna geometry plays a role in readability also for the different dimension of the area in contact with the bottle surface. In tag design, constructors try to minimize the negative effects of detuning and gain penalty due to the contact with other materials, but in practice of RF tracking, materials in contact with the tag are very heterogeneous. The success of a passive tag relies on their easiness of use on various materials.

When bottle was empty, the position (frontal or rear) didn't modify the power level to activate the tag.

Table 2. Minimum transmitter power output which activates the tag when attached to the empty HDPE bottle

Tag	P_{min} (dBm)
Alien 9654	0.97
Lab ID UH101	2.08
Lab ID UH105	0.71

The nature and the concentration of solute in aqueous solutions affected the P_{min} and consequently the reading range of the radio frequency identified bottle. The effect of the P_{min} on the reading range is depicted in Fig. 2 where is reported the P_{min} of the tag attached to the HDPE bottle filled with an aqueous solution of 0.15% w/w NaCl measured at different tag-to panel antenna distances in the range 200-1000 mm. This means that, in this condition, to read the item at 1 m distance, a power of about 29 dBm (which is highly above the maximum power level allowed in RFID systems) should to be delivered.

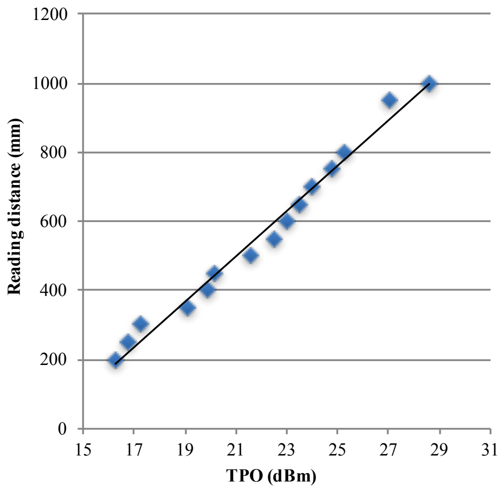


Figure 2. Maximum reading distance of tag Lab ID UH 105 tag placed on a HDPE bottle, in frontal position, filled with a 0.15 (% w/w) of NaCl.

The electrical conductivity of the tested solutions is reported in Table 3. The increase in NaCl concentration has been demonstrated to reduce read range on UHF RFID tags also when tag is not attached to the solution but only in its proximity (Yu et al., 2015). As the electromagnetic wave penetrates in the high conductivity NaCl solution, ions charge form eddy current and part of the power is dissipated. This phenomenon results in gain penalty which reduces read range. Other ionic substances as organic acid (e.g. citric acid) are low electrolytes and may have the same effect on power loss. Sucrose solution conductivity is similar to deionized-grade laboratory water.

In fig. 3 and 4 are reported the P_{min} recorded in the experiment with different chemical compounds; we specify that in the graphs where lines are interrupted the tag is not detected in the power range considered (up to 33 dBm). As could be seen, for all tag types and compounds, the P_{min} requested for tag activation increased for more concentrated solutions both in frontal and rear position.

For NaCl, the position of the tag had a considerable impact on the P_{min} values as well as on the curve slope. For low

NaCl solutions concentration, the tag was easier detected in the rear position. On the contrary, for NaCl concentration higher than 0.2%-0.5%, even a small variation in salt concentration lead to a very strong increase in the power requested for tag activation.

Table 3. Electrical conductivity of the tested solutions (μS/cm).

	Conductivity μS/cm		
Concentration (% w/w)	NaCl	Citric acid	Sucrose
0.025	466		
0.05	904		
0.075	1355		
0.1	1773	831	
0.15	2160		
0.2	3420	1239	2.15
0.5	8040	1966	2.81
1	15460	2820	2.64
2	29300	3930	
2.5			3.82
5	63800	4450	5.83
10			8.04
25			12,37

In the case of NaCl, at concentration above 0.2-0.5 % w/w, some of the tags couldn't be detected, while they are still readable in frontal position. For example, for all the tags the best position to be activated is the rear position when NaCl concentration is lower than 0.2% w/w, while above this value the frontal position is more convenient for tag detection.

As already seen for the empty bottle, also for all the considered chemical compounds and at all the concentrations tag UH105 gave the best results as could always be activated at lower power levels.

Comparing the P_{min} values obtained in frontal position, the gap among the three tags was highly influenced by the chemical compound. For example the difference between the P_{min} of UH105 and UH101 can reach about 7 dBm for NaCl (at 0.2 % w/w concentration), 4 dBm for citric acid (at 0.5 % w/w) and less than 2 dBm in the case of sucrose (in the range 0.2-5%).

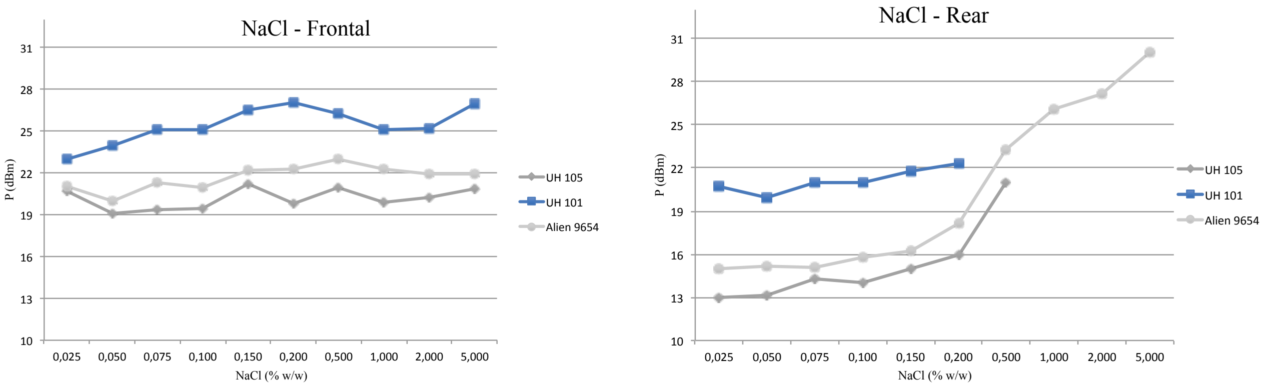


Figure 3. Effect of NaCl concentration (% w/w) on the minimum power requested for tag activation (P_{min}, dBm in frontal and rear position).

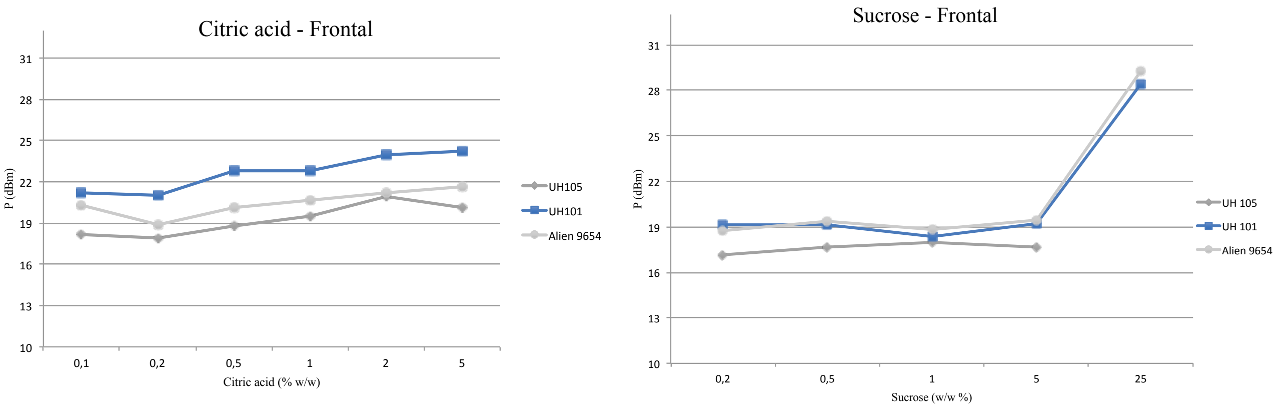


Figure 4. Effect of citric acid and sucrose at different concentrations (% w/w) on the minimum power requested for tag activation (P_{min}, dBm, in frontal position).

For sucrose, the readability was very poor at 25% w/w. For this substance this high concentration has been chosen as could be found in many food products (e.g. jam, syrups, juice). This could be explained also by the conductivity enhancement of the sucrose solution at 25% w/w concentration

4. Conclusions

It has been shown that shape of the antenna and chip type have a great effect on sensing tag attached to critical materials as liquids. The nature of the food products, here expressed as concentration of some compounds, as e.g. NaCl, can highly affect reading performances and should be seriously taken into account when designing RFID traceability systems. For this reason, tag performance benchmarking is very useful to suggest best practices and solutions for RFID systems user when solving problems of missed authentication by radio-frequency devices.

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