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Temperature and Position Effect on Readability of Passive UHF RFID Labels for Beverage Packaging

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The radio frequency identification (RFID) of food items improves production process efficiency as well as optimises the management of the monitoring and the logistics along the production chain (Barge et al., 2014).
Moreover, interest in UHF RFID tags adoption is growing in particular applications such as anti-counterfeiting systems. The readability of passive UHF RFID tags is well known to be critical when applied to products at high water content. Nevertheless, the effect on readability of solutions of water and other organic (e.g. ethanol, sugars, organic acids) or inorganic (salts) compounds, which are typical of food and beverage composition, has not yet been studied. Furthermore, as in the case of beverages that must be chilled for their conservation (i.e. fruit juice, fresh milk and other pasteurised beverages), the temperature can compromise tag readability.
RFID systems efficiency may also be affected by tag-to-reader antenna misalignment, which often occurs for cylindrical section containers.
Experimentation has been conducted to evaluate the effect of temperature, different solute type and tag orientation on the readability of a commercial passive RFID UHF tag (Lab Id UH100) applied to a HDPE (High-density polyethylene) bottle. To compare readability, the minimum transmitted power output that allows the tag-backscattered signal (P_{min}) to be acquired by the reader was measured in standard controlled conditions.
It was observed that solution temperature strongly affected the readability of passive UHF RFID labels. The correlation between temperature and readability was observed being positive or negative depending on the adopted solute type. In particular, an improvement in readability was detected for deionized water, sucrose and ethanol solutions when temperature was increased from 4°C to 25°C. Readability decreased for citric acid and NaCl solutions in the same temperature range.
Reading performance was highly influenced by bottle rotation along the vertical axis, which caused both the misalignment of the tag-to-reader mutual orientation and the radio wave reflection and absorption phenomena due to the presence of the considered solutions in different positions.

1. Introduction

The choice of integrating UHF passive identification systems to improve logistic and traceability is due to the long reading range and the possibility of detecting items without line of sight and even in dynamic conditions. However, while LF and HF frequency band have already been deployed in food and alive animal sectors (Barge et al., 2013a), UHF technology can be strongly limited by low performance due to the food item composition, and in particular by liquid products at high water content as beverage (Barge et al., 2013b).
As dielectric properties of material surrounding the tag can modify electromagnetic waves propagation, the type of packaging and the distance among the liquid-filled packaging and the tag can strongly influence reading distance.
The aim of the present study is to evaluate the reading performance of different tag models 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 effect of other conditions (temperature and position) that can occur during the normal handling of liquid packed food and beverage in food processing and storage was further analysed.

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2.Materials and methods

The RFID test bench consisted of a commercial linear polarised UHF antenna (Caen RFID Wantenna X007, 8 dBi gain) connected to a Caen RFID R4300P ETSI standard compliant standalone reader. The RFID system operated at 866.6 MHz central frequency.

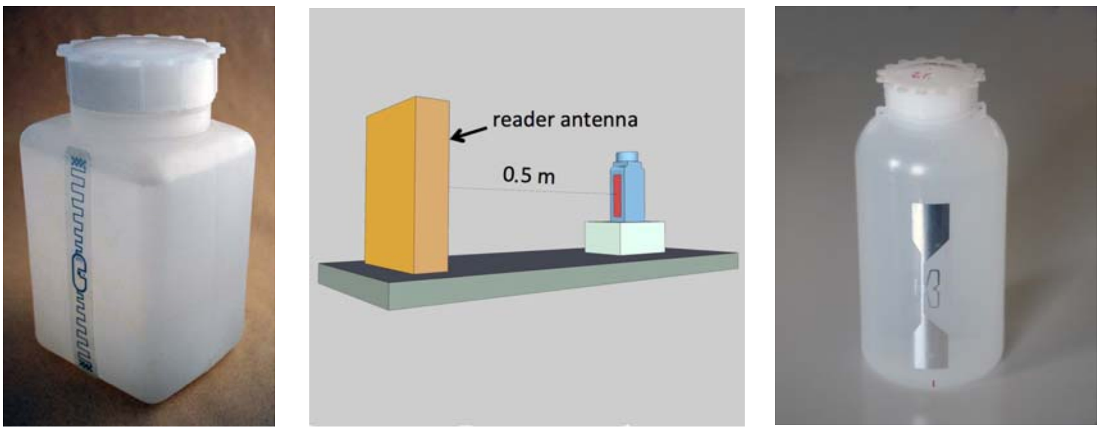
2.1 Temperature effect assessment test

A label-type passive UHF tag (Class 1 Gen2 compliant) was used, which specifications are reported in Table 1 (tag B). Tags were attached on rectangular HDPE bottles (Figure 1A), each containing 500 ml of a pure chemical compound solution prepared in deionized water. HDPE flasks were used as its interaction with radio-frequency electromagnetic field can be neglected. Six different aqueous solutions were used in this trial: 0.15% and 2% NaCl, 1% sucrose, 2% citric acid and 4% ethanol. Pure deionized water was used as reference. Glass bottles were not considered in this study as this material has been proven to strongly affect readability (Expósito and Cuiñas, 2013).

Table 1: Specifications of the passive UHF Class 1 Gen2 compliant tags.

Tag	Commercial name	Integrated circuit	Nominal read chip sensitivity	Antenna size width x length, mm	Inlay shape
A	Dog Bone	Impinj Monza 3	-15 dBm	93 x 23	
B	Lab ID UH100	Impinj Monza 4	-17.4 dBm	94 x 7.8	
C	Lab ID UH105	Impinj Monza 5	-20 dBm	91 x 18	

The filled flask was then refrigerated to 3°C and placed at 0.5 m distance with the tag vertically aligned and centred with respect to the reader antenna to minimise polarisation and misalignment losses (Figure 1B).
Solution temperature was measured by a DeltaOhm HD9215 digital thermometer. The test was performed outdoor to minimise possible electromagnetic wave reflections caused by the presence of metal objects in the working environment. A white polystyrene box was used to cover the bottle to avoid any effect of direct sunlight on the tag that can interfere with its optimal operation. The polystyrene box also allowed to minimize the heating of the solution due to the sunlight exposition.



A *B* *C*

Figure 1: A – Rectangular HDPE bottle used for tag B temperature effect assessment; B – RFID system setup for temperature effect assessment; C – Circular HDPE bottle used for position effect assessment with tag C.

RFID reader was controlled by a custom C# software that allowed tag interrogations at increasing carrier wave power levels, in the range from 0 to 2000 mW, until tag identification. RF attenuators (3, 10 and 20 dB) were used to maintain measurements in the reader operating range.
The minimum reader Transmitter Power Output (TPO) that enabled a valid tag response was measured and indicated as P_{min} (mW). Tag was considered unreadable for a real system implementation when identification

did not occur within the 2000 mW TPO maximum power. Three consecutive measures were repeated and results were expressed as the mean of the measurements. The trial was carried out until the aqueous solution reached the environmental temperature.

2.2 Position effect assessment test

Specifications of the three tags used for the assessment of the effect of position on P_{min} are reported in Table 1. Tags were stuck on a circular HDPE bottle (Figure 1C) containing 0.15% NaCl solutions in deionized water. Temperature of the aqueous solutions was maintained constant at 21°C. The bottle was initially placed in the same position adopted for the temperature effect assessment test. P_{min} of the tag attached to the flask was then measured after a rotation step of 10 degrees around the bottle vertical axis, in the range 0-360°. The trial was carried out in outdoor conditions and the direct sunlight exposure was avoided by means of a covering by a white polystyrene box, which also allowed to maintain the temperature of the solution relatively constant during the test run.

3. Results

3.1 Temperature effect

The effect on P_{min} of pure deionized water and 1% sucrose solutions is depicted in Figure 2, while the cases of the 2% citric acid and 4% ethanol solutions are reported in Figure 3.
In the case of pure deionized water (Figure 2), temperature increase seems to lead to a quite constant P_{min} reduction in the temperature range 4 – 29°C as well as in presence of 1% sucrose, even if in the latter case the P_{min} value is in general slightly higher. These results confirm data presented in a previous work using a similar tag (Barge et al., 2016) where sucrose concentrations solutions up to 5% were observed to give no considerable effect on P_{min}. Similarly, in the case of 4% ethanol aqueous solution, the temperature increase improves tag readability (P_{min} decreases, Figure 3). On the contrary, P_{min} grows at increasing temperature in the case of 2% citric acid aqueous solution (from 125 mW at 5°C up to 162 mW at 23°C).
The results of P_{min} assessment for tag B when the bottle was filled with 0.15% or 2% NaCl solutions are depicted in Figure 4.
Both temperature as well as NaCl solution concentration affect tag B functioning (Figure 4) and power has to be significantly increased to read correctly the tag at a higher NaCl concentration. At 0.15% NaCl, P_{min} is quite constant (about 105 mW) when temperature is in the range 4 – 20°C and then sharp increases, reaching 143 mW at 25°C. In the case of 2% NaCl solution, P_{min} is always higher and the curve is similar, but the inflection point is left shifted of about 10°C.
These results could be ascribed to the influence of solution with different electrical conductivity on tag readability as already found by Barge et al., 2016. In fact, sucrose and ethanol have a low electrical conductivity which is similar to deionized-grade laboratory water, while citric acid aqueous solutions contain low electrolytes that slightly affects tag readability. This was found also by Potyrailo et al. (2012) who employed RFID sensors for milk spoilage detection exploiting the effect on readability of the lactic acid produced by bacteria.This effect is clear for NaCl solutions where dissolved charged ions dissipate part of the power of the electric wave which impinges on the tag, reducing reading range. This is confirmed by the enhancement of the requested power for tag activation at higher temperature.

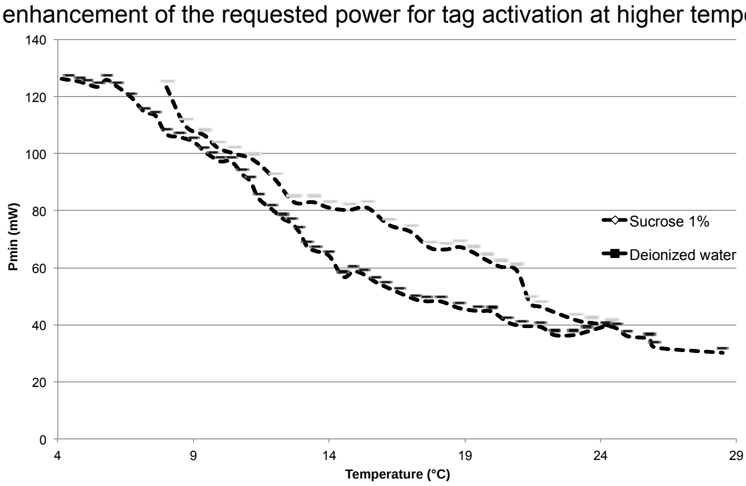


Figure 2: Temperature effect on P_{min} (mW) of tag B (UH100) stuck on HDPE bottle filled with pure deionized water and 1% sucrose aqueous solution.

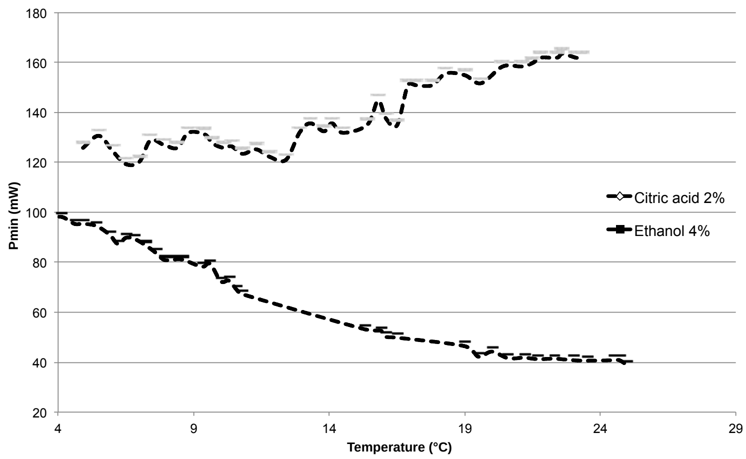


Figure 3: Temperature effect on P_{min} (mW) of tag B (UH100) stuck on HDPE bottle filled with 2% citric acid and 4% ethanol aqueous solutions

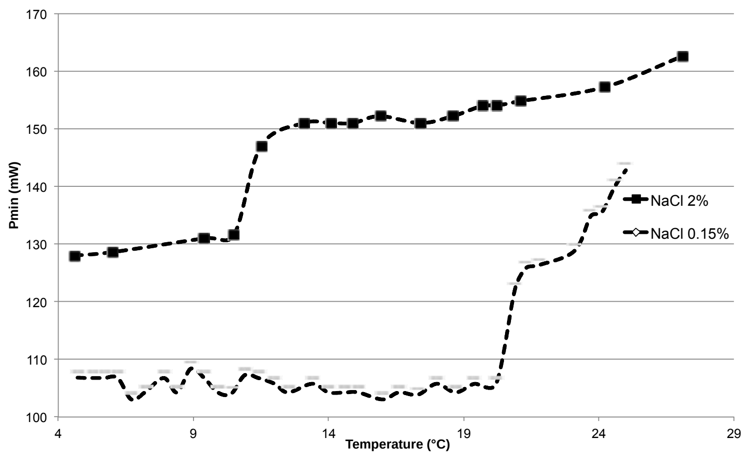


Figure 4: Temperature effect on P_{min} (mW) of tag B (UH100) stuck on HDPE bottle filled with two NaCl aqueous solutions concentration.

3.2 Position effect

When the tag is applied to an empty flask (e.g. tag C in Figure 5), the power requested for tag activation is very low (1.4 mW) and, as can be seen in the graph, the orientation does not affect readability when the bottle is rotated. On the contrary, in critical conditions as with the bottle filled with a 0.15% solution of NaCl, the shape of the reading zone of the tag due to rotation of HDPE did not result symmetrical. The shape of the graph appears to be very similar for all the studied tags, even if the size is different. This area, characterized by two clearly visible lobes and a minimum value of the P_{min} in the rear position (180° rotation), is probably due to the asymmetry of the tag antenna shape.
In the case of UH100 (tag B), P_{min} value is higher than 2000 mW in the range 80-140° and 240-290° of rotation and therefore the tag is technically not readable. On the contrary, Dog Bone (tag A) results to be readable in any position, with a minimum P_{min} value when the bottle is at 180° and a maximum at 110°. Also tag C (UH105) is readable in any position with respect to the reader antenna, but the overall P_{min} values are considerably lower and then it appears to be the easier readable tag.

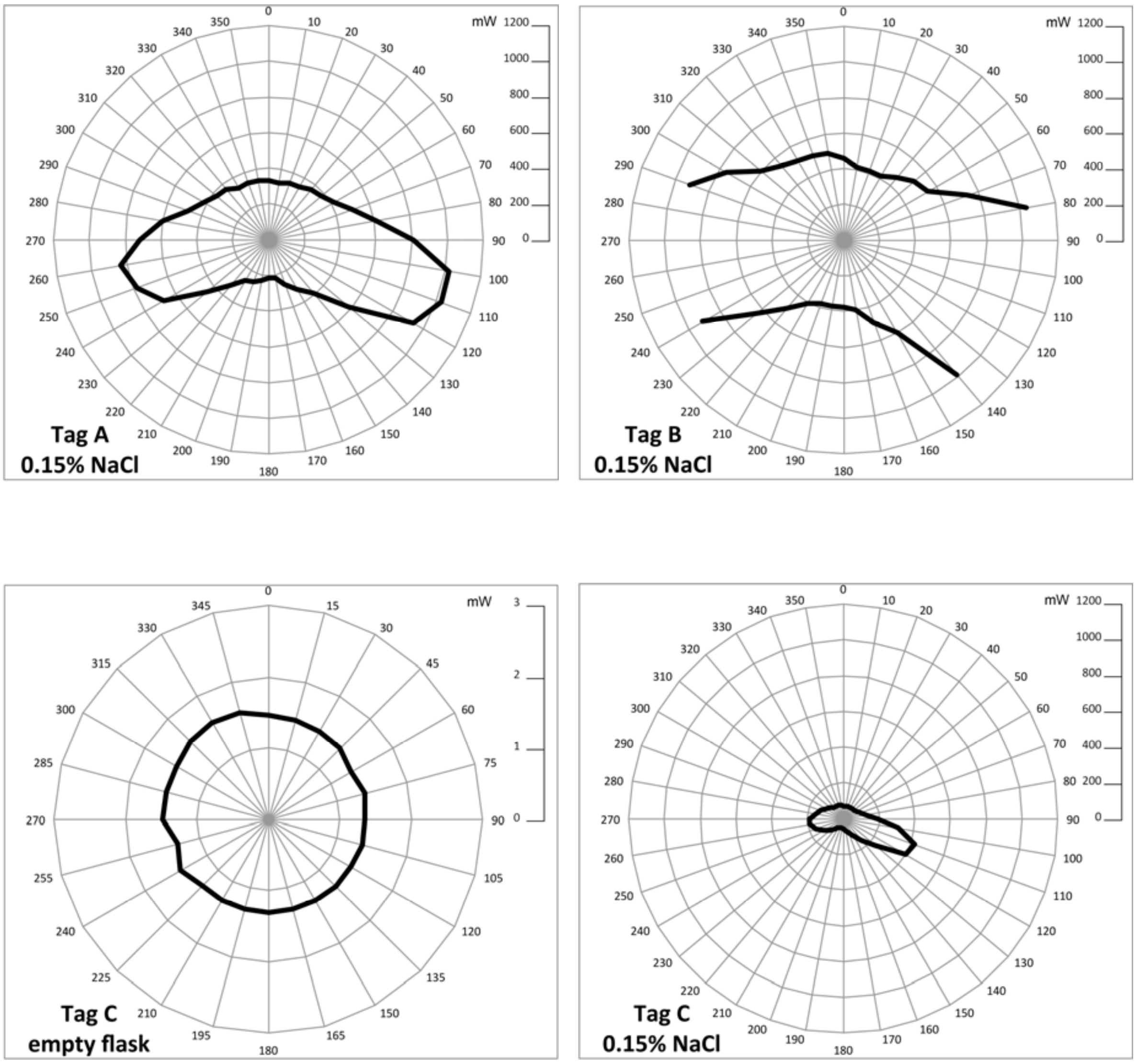


Figure 5: Position effect on P_{min} of tag A (Dog Bone), tag B (UH100) and tag C (UH105) stuck on circular HDPE bottle containing 0.15% NaCl aqueous solutions or void.

4. Conclusions

For packed items which contain food at high NaCl content, like salty liquids and brine, radio frequency identification resulted unsuitable as the readability of the attached tags is strongly impaired. This is particularly true for devices operating in UHF band.

An improper tag positioning can also give rise to very critical reading conditions, leading to complete inability of tag detection by actual commercial UHF RFID systems. This problem can be solved e.g. using tag at high sensitivity that require a lower RF power to obtain a correct identification and/or positioning the packed item in a more favourable orientation (Barge et al., 2017).

The presence of other organic compounds dissolved in water (sucrose, ethanol) had not a strong effect on tag readability at the considered concentration. Nevertheless, among organic substances, dissolved week acid molecules impaired RFID functioning, especially at room temperature.

During the handling of the product to be identified the best positioning of items should be adopted avoiding orientation which can limit electromagnetic coupling in sub-optimal reading conditions. In this paper some recommendations for tag orientation on packed liquid products were presented.

Further work is envisageable to assess the effect on readability of other tag models when attached to packed water solutions of other compounds typical of food composition at different concentrations. The effect on tag readability of acqueous solutions of mixtures of different chemical compounds should also be considered. Moreover, it could be interesting to determine the effect of temperatures above those of room environment.

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