The Effect of Low Temperature on Passive UHF RFID Tags

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Abstract: - As radio frequency identification (RFID) systems are becoming more and more common in several industries, the requirements demanded of tag antennas are increasing. Especially in supply chain management, which is a major application of RFID, the operating environment is expanding all the time. Supply chains often encounter very cold environments: freezers with frozen food or geographically cold areas. The performance of the RFID technology must not deteriorate, even though the temperature drops. This paper studies the effect of low temperature (-20 °C) on passive ultra high frequency (UHF) RFID tag antennas. Besides the effect of a cold environment, that of snow and ice on the surface of the tag was tested. Tests were performed with both Gen1 and Gen2 tag antennas, and the results proved that passive UHF RFID tag antennas are usable at low temperatures.

Key-Words: - frozen tags, ice and snow, low temperature, passive UHF RFID, radio frequency identification, ultra high frequency

1. Introduction

In recent years, the RFID technology has become more and more common in several industries. Especially in logistics the interest in using RFID has grown due to the undeniable benefits it can offer to supply chain management [1]. This increasing use of RFID technology also expedites the requirements for tag antennas due to the various environments they confront during different types of supply chains.

One important environmental challenge is cold. When RFID is used in item identification during the supply chain, the tag antennas may be required to function at low temperatures in various situations. First, when tracking frozen food, the tracked item has to be at temperatures below freezing throughout the supply chain from the manufacturer to the end-user. Secondly, almost any product may need to be transported in a geographically cold environment, especially during winter, even though the product does not need to be frozen. Given these frequently occurring situations, it is important to ensure that tag antennas function without change and with no loss of performance at low temperatures.

This paper studies the functionality of passive UHF RFID tag antennas at low temperatures, which in this case means -20 °C degrees. Both Gen1 and Gen2 tags are tested [2]. Chapter 2 presents the basic theory of low temperature RFID, in chapter 3 the test methodology is described, and the measurement results are given in chapter 4. Chapter 5 concludes the paper.

2. Low temperatures and RFID

Low temperature has different effects on different parts of RFID tag functionality. This chapter describes the effect on the electromagnetic radiation and different components of the tag antenna. Also the effect of possible accumulation of snow and ice on the tag surface is discussed.

2.1 The effect of temperature on the electromagnetic radiation

In the atmosphere, not only the distance, but also the different types of gas molecules and particles, affects the propagation of radio waves. The electrical characteristics of the atmosphere depend on the amount of gas molecules, such as oxygen and water. Their polarization influences the refraction of the signal, and resonance of the attenuation. Although rain, snow and fog attenuate the signal due to scattering, its effect is not discussed here. [3, 4]

In the atmosphere the amount of oxygen is nearly constant, unlike the amount of water molecules, which is highly dependent on the temperature. The attenuation is directly proportional to the quantity of water molecules, which increases along with the temperature. At low temperatures, the amount of water molecules is low, but at 30 °C, the amount is similar to the total of other gas' volumes. The relevance of this attenuation increases with the frequency, and there is an effect in the RFID UHF band in the tested circumstances, but it is minor from the RFID point of view. [4, 5]

In antenna technology, temperature affects the level of thermal noise, which emanates from the antenna. In this study, where the temperature alteration is less than 50 degrees, this effect is, however very small. [6, 7]

2.2 The effect of temperature on the tag operation

Temperature affects tag operation through thermal expansion and thermal dependence of electrical characteristics.

The thermal expansion might cause problems when two materials with very different thermal expansion coefficients are coupled together. Thus the method of attachment is very important. The thermal expansion may also change the surface current of the antenna, due to changes in antenna size. However, in relatively broadband antennas, such as the antennas in this study, the effect is very small. [6, 8]

The IC chips used in RFID tags are usually based on CMOS technology, and they include semiconductors and passive components. The decreasing temperature has different effects on these components – the semiconductors' conductivity decreases. However at these temperatures due to the low capacitors' function temperature coefficient, the effect is negligible. Consequently, the resistors actually work better due to decreased conductivity. [9]

2.3 The effect of snow and ice on the tag surface

When the temperature drops below 0 °C, the effect of snow (i.e. frost) and ice must be taken into consideration. Even though the tags would mainly operate inside, the moisture, which turns into ice and frost, can be condensed on tag surfaces. The main characteristic of snow, when considered from the electromagnetic point of view, is the wetness. The scattering features of the snow are also influenced by density, particle size and form, thickness, and temperature of the snow layer. [10, 11]

Ice, as with snow, scatters the electromagnetic signal. This means, that radio waves disperse from the boundary of two mediums (surface scattering), or from the inner structures of each medium (volume scattering). In the case of a tag antenna covered with ice (or snow), the scattering occurs in three situations: 1) the boundary of the air and the ice, 2) within the ice itself, and 3) the boundary of the ice and antenna. The mutual ratio of these three scattering effects depends on the type and amount of snow, ice and water. [5, 12]

To summarize chapter 2, the effect of low temperature on UHF RFID will mostly be manifested in the form of the functioning of the IC chip and the attenuation of radio waves due to ice and frost on the tag surface.

3. Test methodology

The tests were performed in a frost warehouse, where the temperature was -20 °C. The warehouse had metal walls and roof, but the distance to them was set to several metres to nullify their effect. Two types of tests were performed: Gen1-tests, and Gen2-tests. In Gen1-tests the tags were EPCglobal UHF Class1 air interface specification –compliant, and in Gen2-tests, the tags satisfied the newer specification, UHF Class1 Gen2.

In Gen1-tests, the used RFID-reader was Alien ALR-8780, with one Huber+Suhner SPA 860/65/9/0/V -antenna. The test set-up can be seen in figure 1. The tested tags were self-made bow-tie type tags, with Alien IC-strap. One tag can be seen covered with ice in figure 2. The height of the antenna and the tag was 0,66 metres from the concrete floor, and the distance between tag and reader antenna was variable (see table 1).

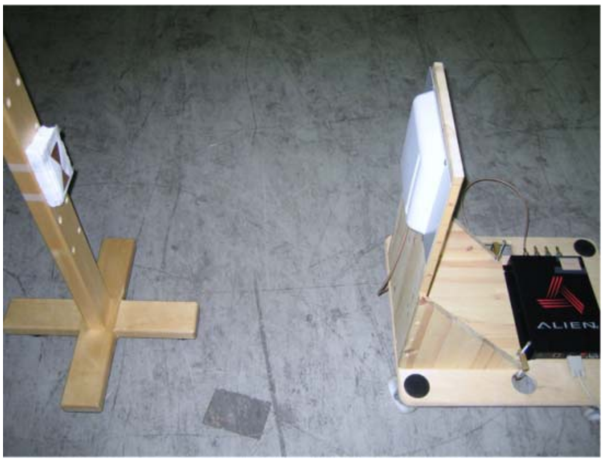


Fig.1. The test set-up for Gen1 tag measurements

As shown in figure 1, with the aforementioned configuration, the maximum reliable read range (MRRR, continuous 1 minute identification with over 75% of maximal reads-per-second rate) [5, 13] was measured, for five different tag types, in three different circumstances – at a temperature of +15,6 °C, at -20°C, and at -20°C with tags covered with ice and frost, as in figure 2. These temperatures were chosen, because they were easily available at the measurement site. The chosen five tag types were:

- *Printed (4 tags)*: 4 different kinds of silver paste antennas, paper or cardboard underlay, glued IC-strap.
- *Cu/paper/tape (5)*: copper antenna, paper underlay, IC-strap attached with tape.
- *Cu/paper/glue (5)*: copper antenna, paper underlay, IC-strap attached with conductive glue.
- *Cu/transparency/tape (5)*: copper antenna, transparency underlay, IC-strap attached with tape.
- *Cu/transparency/glue (5)*: copper antenna, transparency underlay, IC-strap attached with conductive glue.

Each tag was measured three times at three different temperatures, and the mean values are presented in the results.

Fig.2. The Gen1 tag covered with ice and frost

In Gen2-tests, the used testing equipment was Voyantic Ltd's Tagformance™ Lite –measurement device with two Huber+Suhner SPA 860/65/9/0/V –antennas. The distance between the antennas and the tag was 1 m. The set-up is presented in figure 3.

Fig.3. The test set-up for Gen2 tag measurements in cold circumstances

Tagformance™ measured the threshold power in the 860-870 MHz frequency span in cold (- 20°C) and in warm (+20°C) circumstances. When measured in the cold, the tags (Alien ALN-9540 Squiggle) were covered with 5-6 mm ice/frost, as seen in figure 4. The warm-measurements were performed after the ice had melted and the tags were entirely dry. In total three different kinds of underlay-types were tested: paper, transparency and cardboard. Cardboard underlay was added to the list of materials because it is in wide use in different kinds of packages, even though it was not tested in previous measurements with Gen1-tags.

Fig.4. The Gen2 tags covered with ice

4. Results

The results of the Gen1 and Gen2 measurements are presented in tables 1 and 2, respectively. Table 1 shows the MRRR values of five different tag types at three different temperatures. Table 2 shows the threshold power, i.e. minimum reader transmission power levels, which enabled the reading of the tag, in the 860-870 MHz frequency span. Three different types of underlay were tested (transparency, paper, cardboard), each with and without the ice coverage.

Table 1. The MRRR for different Gen1 tag types in different circumstances [cm]

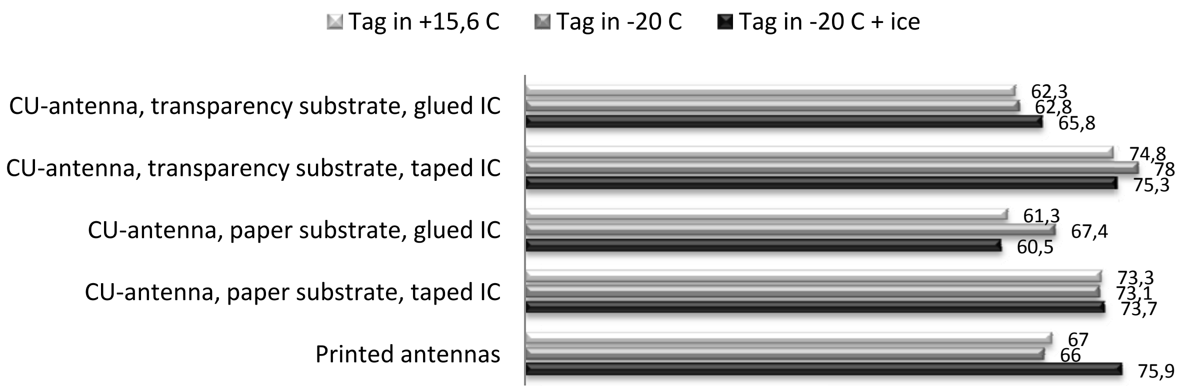
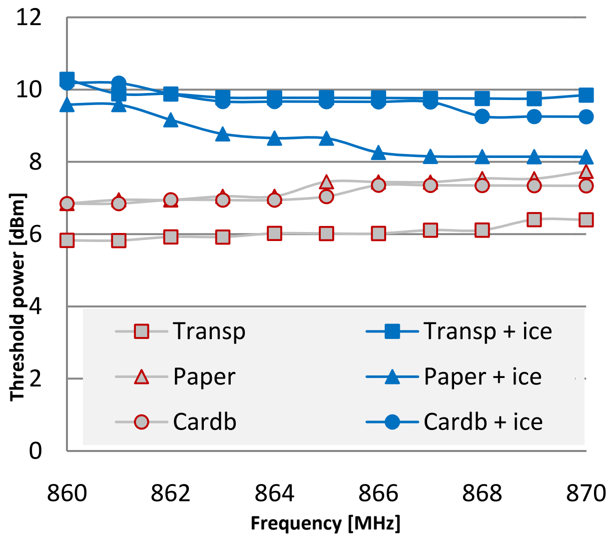


Table 2. The threshold power for Gen2 tags with and without ice coverage [dBm]



5. Conclusions

When analyzing the results, it is not essential to concentrate on the magnitude of the values, but on changes to them in different circumstances. This is due to the fact that Gen1 tags were designed to work under a thick layer of paper, so they were not in their optimal environment to reach the maximal values in the MRRR.

As can be seen in table 1, the effect of temperature, and also the ice coverage, on the MRRR is small. The tags worked well in cold environments, as well as with the ice/frost coverage on the surface. In some of the cases, the MRRR was even higher with ice, due to the similar permittivity values of the paper and the snow/ice. When examining the differences between the tag types, it can be seen that tape attachment between the IC strap and the antenna provided slightly better values than conductive glue.

From table 2 it can be seen that when tags were covered with ice they required a notably higher transmission power level with each of the tested underlay-types. In some of the cases the power needed to “wake up” the ice covered tag was twice as high as without the ice. It is also notable that the effect of ice and snow declines as the signal frequency is increased. However it must be remembered, that Gen2 tags were not optimised to work under paper or ice, and the ice layer was clearly thicker than in the Gen1 measurements

From these results, it can be concluded, that UHF RFID tags work well at the tested temperatures. They also work well when they are covered with ice/frost, but if the ice layer is very thick, for example over 10 millimetres, more transmission power is needed.

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