RFID-enabled temperature sensor system for packaging industry

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Abstract

Elevated temperature can have negative influence on many type of products during their storage or transportation. As a result, these products have to be thrown away and producers suffer losses. In order to avoid such situations temperature indicators or temperature loggers can be used but these solutions have many disadvantages. First of all, the indicators are controlled optically and thus, it is not possible to monitor storage conditions of a product continuously. Although the loggers read the temperature constantly, their life time is limited because of battery life and their price is much higher than for indicators. Many researcher are working now on passive RFID-enabled temperature sensors but these sensors often require complicated data processing, dedicated readers or their state is changes immediately after temperature exposure and hereby the occurrence of exposure can not be memorized.

All the disadvantages of the existing temperature control systems create the need for elaboration of new passive low-cost temperature control systems whose state will be read wirelessly and which will be able to memorize the occurrence of product’s temperature exposure. In this paper, such passive disposable RFID-enabled temperature sensor system for packing industry is presented. This system comprises UHF RFID reader and temperature sensor which changes its electrical parameters under influence of elevated temperature. It allows to detect product’s temperature exposure above 58°C with the maximum read distance 80 cm.

1. Introduction

Temperature is one of the key environmental factors which should be taken into account in many branches of industry and services. It plays crucial role in logistics where transported and stored products are often exposed to influence of elevated temperature. In consequence these products are spoiled and producers suffer losses.

Currently, identification of temperature exposure in logistics is carried out using indicators which changes their colour under influence of elevated temperature. Their main drawback is the optical way of reading and impossibility to place them inside a package [1].

There are also semi-passive RFID tags whose state is identified wirelessly. These tags are expensive and have limited life time because of battery life [2].

Because of many disadvantages of the existing temperature control systems many researchers are working now on a passive RFID-enabled temperature sensors. The sensor presented by Virtanen et al. [3] comprised UHF antenna, chip and temperature sensitive element. This element was distilled water whose relative electrical permittivity $\varepsilon_r$ depends linearly on temperature. The change of $\varepsilon_r$ causes variations in antenna capacitance which lead to the change of antenna power reflection coefficient ($S_{11}$). The analyze of $S_{11}$ makes possible to extract current temperature of a controlled product.

Another system was proposed by Amin and Karmakar [4]. It uses chipless RFID tags and consisted of spiral resonators coupled with a microstrip line which was connected to an antenna. Polyamide was applied as a substrate of one of these resonators. With the change of polyamide’s relative electrical permittivity the capacitance of this resonator was modified. This resulted in the change of a response of RFID tag and its analyze allows to determine current temperature of the monitored object.

Similar temperature control systems were reported in [5-10].

All the mentioned above systems are for multiple use and do not allow to memorize previous object’s exposure on elevated temperature. Moreover they indicate only current temperature.

In this paper, a passive low-cost RFID-enabled temperature sensor system is reported which is equipped with state memory, i.e. it is able to memorize previous exposure of a monitored product on elevated temperature.
2. System structure

The elaborated sensor system comprises standard UHF RFID reader and temperature sensor. This sensor consists of dipole antenna, chip and temperature sensitive unit (TSE) (Fig. 1).

3. Operation principle

The proposed sensor system operates on the basis of altering of RFID tag's work. When the impedance matching between antenna and chip is modified, it results in a change of power transfer between these two elements. This change can be associated with the occurrence of product's temperature exposure in the following way.

Before object's exposure to elevated temperature the power transfer between chip and antenna can be neglected. When temperature exceeds 58°C the solder alloy is transformed from solid to liquid state. In consequence, this alloy is spreading and the antenna and chip terminations become connected. As a results, the power transfer between antenna and chip is improved rapidly what makes the RFID tag readable and it can be interpreted as exposure of a controlled product to elevated temperature.

4. Experimental

A commercial paste PM-406 (Acheson), based on silver particles, was used for antenna manufacturing using a semi-automatic screen printer with a polyester mesh screen 68T. The antenna was printed on two types of flexible substrates, i.e. polyethylene naphthalate foil PEN (Teonex Q51; DuPont Teijin Films) and photo paper Everyday 180 g/m², and then cured in an oven in 120°C for 15 min.

An isotropic conductive adhesive reinforced with multi-wall carbon nanotubes, described in [11], was used for pad printing in the assembly process of RFID chip. When the chip was placed the produced sample was cured in an oven in 120°C for 15 min. To increase mechanical durability of the formed joints a thermoplastic adhesive 3762-LM (3M) was utilized for the chip encapsulation.

The temperature sensitive unit was manufactured with a low-melting solder alloy SnBiIn by its deposition on one antenna circuit termination. To prevent the alloy against external environmental factors it was covered with a piece of the PEN foil.

After the temperature sensor manufacturing its response time to the occurrence of elevated temperature was tested on a stand contained oven, multimeter and computer with the application for measurement data acquisition (Fig. 2). This time was measured for the sensor placed inside or outside of the wood, glass, plastic or paper packages (Fig. 3).

![Fig. 1. Structure of the described sensor system.](image1)

![Fig. 2. Stand for measurements of the proposed sensor’s response time.](image2)

![Fig. 3. Wood, paper, plastic and glass packages used in the conducted investigations.](image3)
Maximum read distance (MRD) was also measured for the fabricated sensor using a stand described in [11]. The power of the RFID reader tt-8300 t+t netcom was 200 mW.

5. Results and discussion

The response time of the designed sensor system was investigated for the temperature of 80°C. For every case at least 6 samples was measured (Tab. 1).

It was revealed that the type of package have not an impact on the response time when the sensors fabricated on foil or paper were placed on the outer wall of the package. Such location of the tested samples did not cause any change in heating of TSE of the tested sensors.

Reverse behavior of the sensors’ response time was noticed when the samples were put in the package. In this way the real conditions of the designed system’s work in logistics were simulated in which the sensor is placed inside the box contained products under temperature control.

The biggest increase in the response time ($t_r$) was occurred when the sensor was put inside the glass package. For other once approximately double growth of $t_r$ was noticed. It was connected with the need to heat up the package and then air inside them. After that TSE of the measured sensor could be warmed up what resulted in the step resistance change of TSE. Therefore, it is worth to emphasize that in practical applications of the proposed sensor system it should be taken into account a type of package with product under temperature control because it has crucial influence on its properties.

$$\text{Tab. 1.}$$

**Response time (in [s]) of the sensors on the temperature exposure of 80°C.**

<table>
<thead>
<tr>
<th>Package</th>
<th>Substrate</th>
<th>foil</th>
<th>paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>paper</td>
<td>95 ± 5</td>
<td>83 ± 8</td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td>91 ± 5</td>
<td>82 ± 6</td>
<td></td>
</tr>
<tr>
<td>wood</td>
<td>92 ± 7</td>
<td>87 ± 5</td>
<td></td>
</tr>
<tr>
<td>plastic</td>
<td>94 ± 4</td>
<td>81 ± 9</td>
<td></td>
</tr>
</tbody>
</table>

The results of the MRD measurements for the investigated sensor system (Tab. 2) exhibited that its value varies from 36 cm to even 80 cm when the RFID reader and sensor are in line-of-sight. The biggest MRD was achieved for the wood package and the lowest one for the glass package. On this basis it can be stated that glass introduced the largest attenuation of electromagnetic field generated by the RFID reader among the tested package materials.

$$\text{Tab. 2.}$$

**MRD of the fabricated sensor system.**

<table>
<thead>
<tr>
<th>Package</th>
<th>MRD [cm]</th>
</tr>
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<tbody>
<tr>
<td>glass</td>
<td>36 ÷ 40</td>
</tr>
<tr>
<td>plastic</td>
<td>54 ÷ 61</td>
</tr>
<tr>
<td>paper</td>
<td>58 ÷ 69</td>
</tr>
<tr>
<td>wood</td>
<td>63 ÷ 72</td>
</tr>
<tr>
<td>free space</td>
<td>75 ÷ 80</td>
</tr>
</tbody>
</table>

From the practical point of view it is also interesting how the value of MRD varies depending on a read angle (an angle between reader and sensor). The MRD measurements, carried out for wood package (Fig. 4 and 5), showed that for the read angle from 0° to 80° and from 280° to 360° the larger maximum read distance was achieved than for the read angle range from 100° to 260°. It was resulted from the attenuation of electromagnetic waves introduced by the presence of the package where the designed sensor system was placed on.

The shape of the graph, presented in Figures 4 and 5, resembled the radiation pattern of the designed antenna which was 8-shaped in the horizontal plane. Moreover, in accordance to the results reported in [11] the value of MRD can be varied depending on the fluid type in bottles. This phenomenon should be also taken into consideration in the applications of the constructed sensor system for packaging industry.

![Fig. 4. Maximum read distance of the designed sensor system produced on foil, depending on a read angle.](image-url)
6. Summary

In this paper, a passive disposable RFID-enabled sensor system for packaging industry was described. The system comprised RFID reader and temperature sensor consisted of UHF antenna, chip and temperature sensitive unit whose electrical properties are changing permanently under influence of elevated temperature. This sensor was fabricated using screen printing technique.

The achieved results showed that the proposed sensor system is suitable for temperature control of many type of products, such as food or blood. Its response time to the exposure on elevated temperature depended on the location of the sensor. It was bigger when the sensor was placed inside a package, especially inside glass package.

Maximum read distance of the designed system revealed to be dependent on a type of package containing product under temperature monitoring. The largest MRD was obtained for wood box and the lowest one for glass package. It was also observed the lower MRD in the angle range from 100° to 260°.

In the next investigations, it is planned to elaborated sensor system which will be able to detect other type of exposure, such as humidity, UV or mechanical shocks.

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Bibliography


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