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NFC/RFID sensor Tag for Wireless Temperature Monitoring in a Cold Chain

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Abstract. This work presents the design and validation of a temperature sensor tag, which can be queried either by a cell phone using the NFC protocol or an HF RFID reader. It will easily ensure the cold chain failures and the product integrity. The proposed recording sensor can be placed on the packaging box to measure the temperature of the product. This allows to observe and store its evolution in order to guarantee the products quality and to respect the applicable provisions during transport. Thanks to a cell phone with the NFC, this recording data can be easily available, contrary to existing tags on the market. The design of tag is summed up as the choice of components, and the size of the antenna. Then a program for data recording and processing is developed using C language. Indeed, to have a triple gain of place, speed, and cost; an optimization of values recorded is operated. The overall tag size is 5.1x4x1.6 mm³, and its operation has been validated by performing in a real scenario: the temperature monitoring of a water bottle inside a bag for at least 50 minutes. The results of this test will be presented and discussed.

1 Introduction

The objective of this study is to follow the cold chain throughout the product life cycle and especially during the transportation. In fact, it is really important that the cold chain does not break to ensure the product integrity.

Regulations exist about this matter [1]: First, the temperature measurement frequency has to be collected all 3 minutes to have an optimal tracking. Secondly, for hygienic purposes, the solution cannot always be in contact with food. This is the reason why regulation allows a measurement on the package instead of being placed inside where temperature difference is about +2°C. At last, the measurement accuracy must be about ±0.5 °C respecting the temperature ranges associated to different products.

Over the last decade, some works have been reported using RFID technology as in “Coin T” from Ela Innovation [2] or “PY RFID 100-120” from Jri [3]. These solutions require a specific equipment, which increase their cost. Indeed, it uses the UHF RFID which need a complementary reader at this frequency.

In order to further improve these technologies, this study¹ is focused on the realization of an NFC/RFID temperature sensor prototype. The operating frequency of this proposed prototype is 13.56 MHz which is easily remotely interrogate by an NFC-compatible cell phone or RFID reader to extract data. Moreover, a software (APP) is required to be installed which allows an automatically

data processing. Data as name or lot number are also stored in the memory to retrieve all the important information about the product. This will replace the paper delivery note on pallets. The block diagram of the developed wireless temperature monitoring system is shown in Fig. 1.

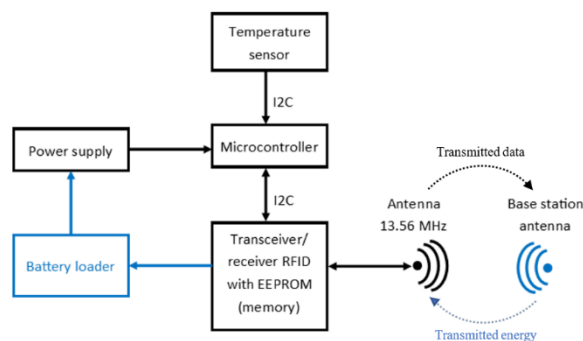


Fig. 1. NFC/RFID system block diagram developed for wireless temperature monitoring.

In the following section, we will present the methods we used to answer this matter by detailing the different choices. Then, we will focus on the obtained results following these choices.

¹ Study carried out, in 90 hours, in the framework of the RFID Projects, for the ESEO* Engineering Students, under the supervision of Mohamed LATRACH and Abdelaziz HAMDOUN.

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2 Design and prototyping

The studied and developed sensor tag consists of:

- a temperature sensor,
- an NFC/RFID device with EEPROM memory (ST25DV) to store the measured temperatures as well as product information,
- a microcontroller to collect and records temperatures from the sensor,
- a battery for supplying power all the circuit.
- the necessary electronics components,
- and an antenna to provide wirelessly the crucial information in applications such as a cold chain evolution.

Figure 2 shows the photos of both sides of the manufactured prototype, on a low-cost FR-4 substrate with a thickness of 1.6 mm, where the above-mentioned main components are clearly identified.

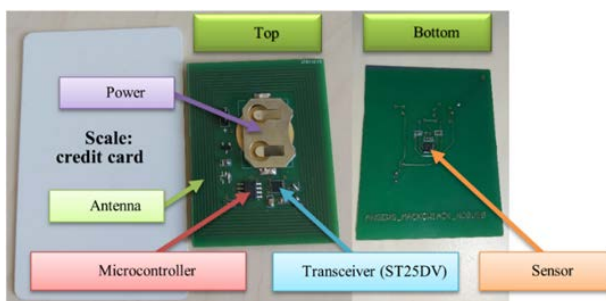


Fig. 2. Photographs of the realized prototype.

The principle of use is simple: the microcontroller collects the temperature every three minutes to respect the regulation and write it into the memory. When the user wants to collect all the data, he has to connect on an APP on his phone and get closer to the sensor tag with activating the NFC. When the RFID chip receives the interrogation signal, all information (recorded temperature and product ID) automatically sent to the user's smartphone and formatted by the APP to be simply read by users.

2.1. Frequency choice

As a first step, the 13.56 MHz frequency has been chosen because it is the worldwide standardized RFID frequency and it used by NFC technology via mobile end devices such as cellphones, tablets and notebooks for data exchange purposes. At this frequency, the operating area is almost short, around ten centimeters. This allows the user to make a visual control on the merchandise during the data recovery.

In addition, as NFC is associated to most cellphones, all users around the cold chain can easily and quickly access to the tag to monitor the product; contrary to competing solutions [2][3] which use an 868 MHz frequency which requires specific equipment.

2.2 Components' selection

All components have been chosen to reach a trade-off between their consumption and their performance in accordance the specifications. For example, the temperature sensor which is referenced as Si7054 [5] has an average consumption of 60.55nA in our application (measurement all three minutes) and an accuracy of $\pm 0.4^{\circ}\text{C}$.

In addition, the ATtiny212 [6], 8-bit microcontroller, has been chosen for its low-power consumption ($7\mu\text{A}$ in executive mode and 100nA in low mode) and its low-cost. Indeed, it has just 6 input/output and 2 Kbytes of memory, which is enough for this application to transfer and convert data. The recording data is realized in the ST25DV [7], NFC/RFID device, which offers a high memory accessed by the RF part.

2.3 Antenna Design

Most commonly used antenna type for the HF RFID and NFC applications is planar coil single or double sided, on the intended substrate, due to easy and flexible design capability of the antenna size and low cost. The inductivity of a planar coil depends on the geometrical data of the coil outline size, space, the number of turns, their spacing and the trace width in the PCB. The equivalent impedance module of such an inductance shall be equal to the impedance module presented by the internal capacity of the RFID chip.

In this study a single sided planar coil has been designed, on FR-4 substrate, with an online tool proposed by ST microelectronics [4]. This last allows to obtain, as a first approximation, the target inductivity based on the geometrical data of the coil.

The first step on the design of the used coil antenna is to determine the input RFID device capacitance, then calculate the inductance value to achieve resonance at 13.56 MHz by considering the relation 1. Knowing the RFID device (ST25DV) capacitance input value (28.5 pF), it is easy to find the inductance value ($L=4.8\ \mu\text{H}$) at the resonance by following the equation 1. Based on the obtained inductance value and by using the ST microelectronics tool, the antenna dimensions are easily determined.

$$\omega = 2\pi f = \frac{1}{\sqrt{L.C}} \quad (1)$$

The overall tag size was deliberately chosen to be $5.1 \times 4 \times 1.6\text{ mm}$ to minimize its loss and facilitate its attachment to the packaging box. That equals to half credit card size (Fig.2) in order to gain a place on a packaging. Indeed, the tag must replace the paper form. This solution is thinner (around 8 mm instead of 11 mm for competitors [2][3]) which eases its integration. Consequently, as the surface of tag is wide, the antenna size can be large with the same surface of the tag (5.1 cm by 4 cm). The designed coil antenna had 8 turns with both 0.5 mm as conductor width and spacing between windings.

Finally, this configuration allows to place components inside the antenna. However, the battery size modifies the

radiating surface of the antenna and absorbs the flux which impoverishes the magnetic coupling performance as explain in the followed part in this paper.

2.4 Temperature sensor placement choice

For a first prototype, the SMD components have been chosen to save space while being easily weldable manually. To ensure a good temperature measurement, the temperature sensor is placed on the opposite side of the coil antenna. At this position, it is in direct contact with the package. Fig. 3 shows the components placement on the printed circuit board (PCB).

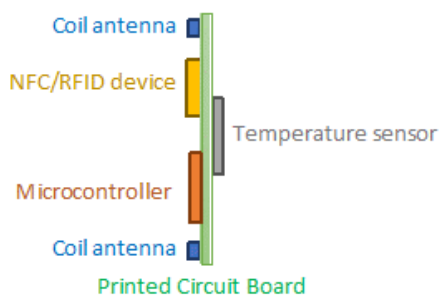


Fig. 3. PCB profile view.

2.5 Data recovery

To reduce the size of the sensor temperature data and increase their transmission speed, an optimization of the data storage is realized.

Firstly, the real value from the sensor – temperature in Celsius – is converted to an integer. Knowing that we can have a precision of +/- 0.5 °C, this new value is simply the integer of the double of the real temperature illustrated on the equation (2). This step has a twofold benefit: reduce the size of the value and increase the operated speed of the microcontroller. Indeed, an integer operation is speedier than a float operation. In addition, the multiplication by two is easy for the microcontroller working in base two.

$$T_{conv} = Integer(2 * T_{real}) \quad (2)$$

Where : T_{conv} = converted temperature and T_{real} = real temperature.

Secondly, always to lower the size, the difference between the converted value and the optimal temperature is also converted. Naturally, the result of this subtraction is a converted temperature as described above (equation (2)) and represents the derivation around the optimal value.

Thirdly, this new value from the subtraction, recorded into the memory, is limited to five bits. This size is adequate for the tag application. Indeed, in these five bits, there are one bit for the sign, one bit for the 0.5 accuracy and three bits for the integral part. Thus, the tag records a derivation around the optimal temperature (-8 °C to 7.5 °C).

The size gain in memory can easily be shown in the case of a three-day measurement example. If each temperature is recorded on one byte, in three days, the size of the

memory will achieve around 1.5 Kbytes. Yet, if each temperature is recorded on five bits and three temperatures on two bytes, the size will achieve around 0.98 Kbyte.

Moreover, in order to simplify and speed up memory erasure, a counter is inserted in the list header. Thus, the new values replace just the old values after the reset.

3 Experimental data analysis and results

3.1 Antenna impedance and memory reading tests

The verification of antenna impedance (inductance) is a primordial step to ensure the correct operation of the sensor.

In a first step, the calculated inductance of the coil antenna must be equal to 4.8 μH to allow a maximum power transfer, at the resonance frequency, between antenna and NFC/RFID device. The measured value, by an impedance analyzer, is 5.3 μH. Such a difference lies in the manufacturing process and the accuracy of the measurement.

In a second step, a reading of the memory is done with the cell phone. This one carried out correctly despite the very long reading time. Indeed, the prototype is powered by a button cell battery placed in the middle of antenna. That induced a large ground plane which will decrease the antenna radiating surface and absorb a part of the magnetic flux. Thus, memory has less energy to send its data to the base station (the cell phone in our case). The following pictures (Fig.4) shows the communication disturbance due to the cell phone. Indeed, the inter-components connection tracks receive part of the signal transmitted by the phone.

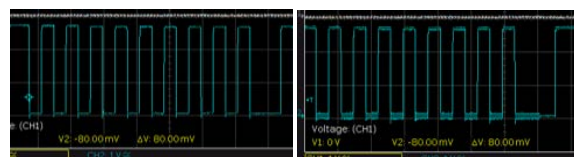


Fig. 4. Writing in the memory without phone reading on the left and with it on the right.

These chronograms comparison (Fig. 4) shows the influence of the wave sent by the cell phone during the reading of the memory when the microcontroller communicate with the memory. They represent the clock (blue signal) of the I2C writing. As we can see, the cell phone presence disturbs the clock signal (thicker signal on left figure 4) which will disturb the communication and so the information transportation. This result was predictable as phone sends RF waves that will disturb the microcontroller during the data writing.

Moreover, the ground plane induced by the battery is important compared to the tag antenna size. Thus, this ground plane will absorb a part of signal sent by the

phone. For better reading, the mobile phone should be positioned in front of the opposite side, where the temperature sensor is located (Fig. 3).

3.2 Temperature recovery

In addition to the measurements list, a header is inserted in order to record information about the product. The header is illustrated with below example.

The fictive product:

- Name: “sorbet cassis 550 mL” – Size: 20 bytes equal to 20 characters.
- Lot number: “3 574 100 075 093” – Size: 6 bytes.
- Optimal temperature: 25°C – Size: 1 byte.
- Maximal temperature: 30°C – Size: 1 byte.

So as to easily read the information sent by the tag, a treatment is required on the phone. To do it, a Python’s script is used because it is an ideal language to develop a prototype. In this first prototype, it is realized on a computer because Python is not implemented on our phone. Nevertheless, in future version, an Android application will be created to conjugate the reading and treatment. The process of this treatment is based on two operations: the header reading and the shaping of the temperature derivations list around the optimal value.

In the first step, the program read the header with the name product, its lot number, etc. and print them on the user’s screen. For instead as previously, the identity of the product is rediscovered (Fig. 5). The following figure shows the result after processing the read values in the RFID sensor memory. Data have been retrieved from the cell phone and sent to a computer to then process them with a Python software.

```
Nom du produit : sorbet cassis 550 mL
Numero du produit : 3574100075093
Temperature opt : 25.0 °C
Temperature max : 30.0 °C
```

Fig. 5. Extract of the processed data

In the other step, the software extracts, thanks to the values number in the memory, the list of temperature derivations and then calculates the real temperature by reversing the conversion shown above (Fig. 6). Moreover,

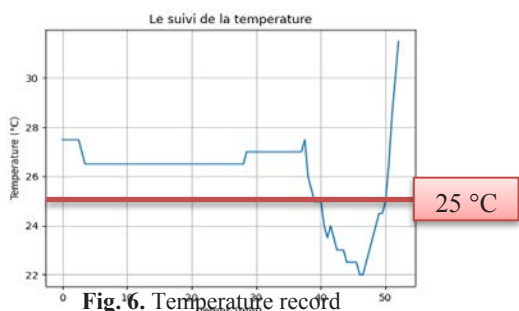


Fig. 6. Temperature record

it formats in a graphic these values in order to easily represents a change in temperature. For example, the optimal temperature is read and a change of +/- 2°C at 38 minutes is emphasized. Indeed, at this moment, the water bottle goes from a 27°C room to a cellar and then to the sun ten minutes later. In this experimentation, the product is rather a water; therefore, there are no consequences to a health. But if the liquid is a milk, the consequences could be disastrous.

4 Conclusion

The objective of this study is to monitor the temperature at regular intervals. To do this, an NFC/RFID sensor tag has been studied and realized. This sensor also processes information to simplify the transporters work, especially during the refrigerated products transport. To answer this matter, the sensor employs an NFC technology to use the cell phone as a base station. The most important step was the antenna design. This one is rectangular and surrounds electronics components. Despite rather satisfactory results (the temperature recovery is done), reading time is relatively too long. This is due to the battery-induced ground plane. In a future release, we need to review the location of the different components associated with the printed planar coil antenna.

This prototype also should be improved on the energy saving part. Currently, it is a button cell battery which powers all the system as competing systems [2][3]. In a future version, a rechargeable battery would be needed. The system will harvest the sent phone RF energy, during the memory information reading, to recharge the battery. For this prototype, we printed the antenna on a FR-4 substrate, but we can imagine a similar product printed on a flexible material. This will allow, for example, to adapt to human skin to recover the patient’s temperature during an operation.

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