2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Chipless RFID Threshold Temperature Sensor Compliant with UHF and ISM Radio Frequency

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Abstract

A new chipless RFID sensing concept compliant with Ultra High Frequencies (UHF) RFID and Industrial, Scientific and Medical (ISM) frequency bands is proposed. The concept is demonstrated with the design of a chipless threshold temperature sensor based on C-like scatterers. The variation of the substrate permittivity with the temperature enables the transduction of the temperature into a frequency detuning that is used to encode the temperature thresholds in a binary form.

1. Introduction

Sensing using chip-based radio frequency identification (RFID) tags has been the subject of a lot of focus in the recent years [1]. This is due to the advances in microchip technology for RFID chips which allowed the integration of sensing functionalities together with unique identification code as well as providing external sensor interfaces with the RFID chip [2]. In parallel to chip-based RFID sensing, the chipless RFID sensing is on the rise. It offers a completely passive sensing solution suitable for industrial applications that require long life cycle monitoring with zero power consumption due to the absence of electronic components [3].

One environmental parameter that is widely investigated by RFID research community is passive temperature sensing. This is due to the importance of temperature as a control parameter in many industrial processes such as food industry to monitor food quality, manufacturing industry to ensure a high quality level of the production line and in chemical engineering industry to control the chemical reactions as well as to monitor materials in storage for the safety of the employees. In addition, temperature sensors are vital to a variety of everyday products such as automobiles, aircrafts, computers, cell phones and many other items [4].

With the increasing popularity of the Internet of Things (IoT) concept for objects interconnectivity, passive wireless temperature sensing has been the area of recent research especially for chipless-based sensors [5,9]. Although various prototypes of passive chipless temperature sensor have been investigated, there are many challenges facing this technology. Among these challenges, two issues make the chipless technology not yet ready for a practical deployment in real scenarios. First, it requires in many cases a reference element that increases the size of devices, and technically introduces the problem of isolation between the chipless sensor and its reference [10]. Second, interrogating chipless sensors needs non-conventional reader protocols or a non-standard interrogation technique such as the use of RF signals which are not compliant with the RFID frequency bands regulations. This paper proposes a new sensing solution which overcomes the two aforementioned issues of chipless sensing. The proposed solution is a chipless sensor tag for temperature threshold measurement. It has the objective of detecting temperature conditions in terms of ranges and encodes them in a binary form. The sensor is based on C-like scatterers that are designed to operate in the dual commercial frequency bands: the 868MHz European Telecommunications Standards Institute (ETSI) RFID band and in the 2.4 GHz Industrial, Scientific and Medical (ISM) band simultaneously. The operation principle is based on transducing the temperature variation using the substrate properties. This causes a shift in the position of the resonance peaks of the backscattered signal from which the temperature thresholds are encoded in a binary format. Section two details the basic principle of the proposed chipless sensor with the presentation of its concept, design and simulation. Section three provides the experimental results demonstrating the sensing operation.

2. Sensor Structure & Simulation

The basic idea of the proposed chipless temperature threshold sensor is to take advantage of the substrate properties under the influence of temperature in order to detune the resonance frequency of C-like scatterers in the selected frequency bands. This can be explained using a generic relationship between a physical length L of a quarter-wavelength ($\lambda/4$) C-like scatterer and its resonant frequency

$$f_{res} = \frac{c}{4L\sqrt{\varepsilon_{eff}}} \tag{1}$$

where c is the speed of light and ε_{eff} is the effective permittivity of the structure. The choice of $\lambda/4$ scatterer has the advantage of having a smaller and compact size sensor structure. If ε_{eff} has temperature dependence $\varepsilon_{eff}(T)$, then, introducing a temperature variation affects the resonance frequency as

$$\delta f_{res} = \frac{-c}{8L\varepsilon_{eff}^{3/2}}\delta\varepsilon_{eff}(T) \tag{2}$$

Under the assumption that the permittivity of the structure is linearly dependent on temperature such as $\varepsilon_{eff}(T) = \varepsilon_0 + kT$, where k is a constant depends on the substrate dielectric material, the variation of the permittivity will be $\delta\varepsilon_{eff}(T) = k\delta T$ and hence, (2) will take the form

$$\delta f_{res} = \frac{-kc}{8L\varepsilon_{eff}^{3/2}}\delta T \quad (3)$$

Since $\varepsilon_{eff}(T)$ depends linearly on the temperature, the detuning of the resonance frequency (3) has a linear proportional relationship to the temperature variation i.e $\delta f_{res} \propto \delta T$ as the rest of the parameters are held constant. In order to study the temperature effect on the resonance frequency, two C-like resonators C1 and C2 are designed to resonate in the allocated frequency bands, ETSI and ISM bands respectively.

Figure 1 represents the structure of the proposed threshold temperature sensor. In order to increase the amplitude of the backscatter signal in the ISM 2.4 GHz band, two of the C2 resonator has been used. The position of the three resonators is chosen to avoid spurious coupling between the scatterers.

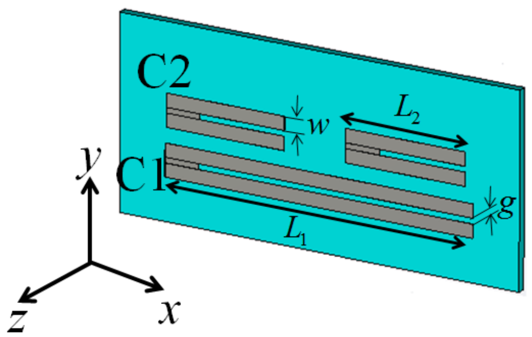

Figure 1. Temperature threshold sensor structure based on two C-like resonators and temperature sensitive dielectric substrate.

The structure has been degined using CST microwave studio simulator with Rogers RT/duroid 6010.2LM substrate (ε = 10.2, $tan\delta$ = 0.0023, h = 1.27 mm) which has k = - 425 $ppm/^{\circ}C$ in the temperatur range of -50 to 170 $^{\circ}C$. The dimension of the resonators are (L_1 = 46.2 mm, L_2 = 17.8 mm, g = 0.8 mm, w = 2 mm).

The structure was simulated using frequency domain method by illuminating the structure with a linearly polarized plane wave in y direction (x-z plane). The backscatter signal is collected by probes placed 10 centimeters away from the structure and the radar cross section (RCS) is used as metric for the performance evaluation. The temperature has been added as a parameter for parametric simulation under different values: 25, 50, 70, 80 and 100 °C. The simulation results are shown in Figure 2.

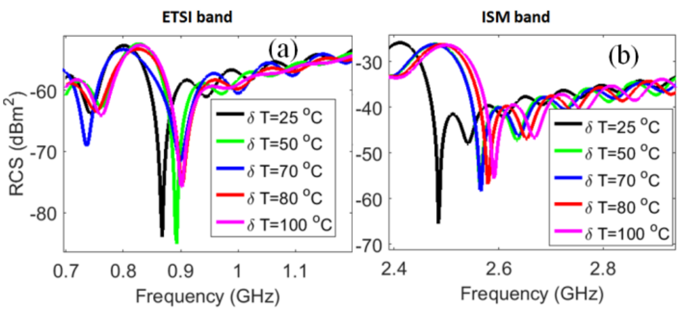

Figure 2. RCS simulation results for resonance under different temperature values in (a) ETSI band and (b) ISM band.

It is worth noting that in this simulation, the effect of temperature on the frequency detuning was taken only due to the variation of the permittivity of the substrate. However, variation in the dimensions of the structure due to temperature could also have a detuning effect of the resonance frequency as (1) predicts.

3. Sensing Principle and Coding

Based on the simulation results the two resonance frequencies can be used in the proposed compact C-like scatterers as two bits encoder for temperature ranges. Logic '1' is represented by a resonance lies within the band, while logic '0' is represented by a resonance outside the band. The temperature is transduced through the substrate properties into a resonant frequency shift spanning the ETSI and ISM bands. Since these bands do not have the same bandwidth, one expect that the resonance shift will not be the same and hence allowing different bit combination to be assigned to ranges of temperatures. Figure 3 illustrates the principle of temperature threshold coding.

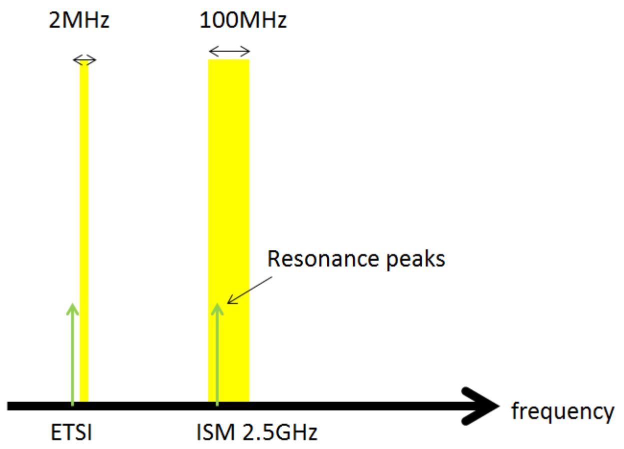

Figure 3. The spectrum of the frequency bands illustrating the principle of temperature threshold coding.

Different bit combinations are assigned to represent the desired temperature threshold. It is worth noting that for this study two threshold values are obtained however, the different bit combinations could be obtained either by choosing the position of the resonance peak in or outside the frequency bands or by extending temperature range to incorporate negative temperatures.

4. Experimentation and Demonstration

The experimental setup is shown in Figure 4. The purpose of this measurement is to evaluate experimentally the effect of temperature variations on the resonance frequency in both ETSI and ISM bands.

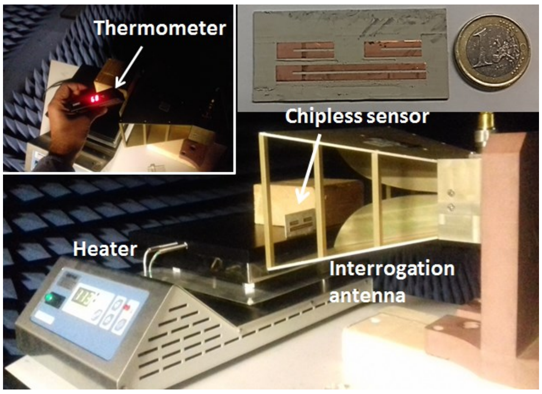

Figure 4. Measurement setup for characterizing the chipless temperature threshold sensor structure.

The measurement platform is monostatic which consists of a linearly polarized horn antenna connected to a port of the vector network analyzer PNA-X Series N5222A and used as the transmitting and receiving antenna. The frequency range of the network analyzer has been chosen to be in the ETSI and ISM bands. The interrogation distance between the antenna and the chipless sensor is set at a fixed value of 10 centimeters. The structure has been heated using a controllable hot plate and an infrared thermometer has been used to get the temperature value at the sensor position. Figure 5 shows the measurement results of the resonance frequency for different temperature values.

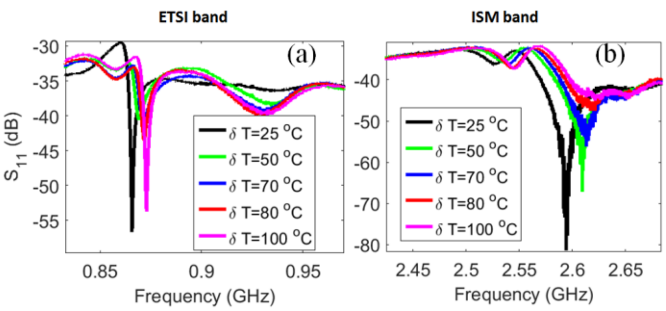

Figure 5. Measurement results of the temperature effect on resonator detuning for: (a) ETSI band; (b) ISM band.

In order to study the threshold behaviour of the proposed sensor, the measured frequencies detuning are plotted versus the temperature in Figure 6. with the ETSI and ISM bands. It is worth noting that the frequencies in Figure 6 (b) have been corrected by a shift of 0.1 GHz, this is due to fabrication error which detuned the frequency of the fabricated sensor to be outside the ISM 2.4 GHz band.

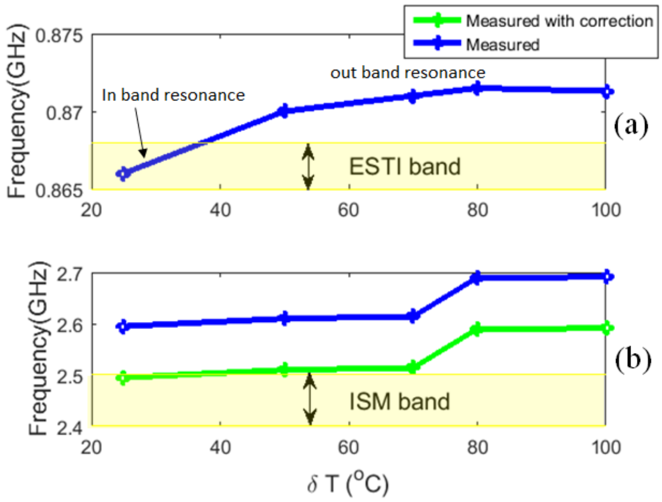

Figure 6. Measurement of the shift of the resonance peak inside (a) ETSI band (b) ISM band.

Using the ETSI and ISM frequency bands as references, different temperature threshold can be obtained corresponding to whether the resonance peak is inside the frequency band or not. Since there are two frequency bands, a two bits binary number is used to designate the threshold values of the temperature. In this case, logic '1' is represented by a resonance lies within the band, while logic '0' is represented by a resonance outside the band. Table I summarizes the different binary code associated with the measured resonance that could be used to represent the measured temperature thresholds.

TABLE I
TEMPERATURE THRESHOLDS ENCODED IN BINARY FORM

Temperature threshold range	ETSI band	ISM band
0 < T < 33.3 °C	1	1
33.3 < T < 37.5 °C	1	0
35.7 < T < 100 °C	0	0

This encoding depends on the bandwidth and the amount of resonance shift due to temperature variations. Since the ETSI and ISM bands do not have the same bandwidth, one expects that the resonance shift will not be the same and hence allowing different combination of binary code to be assigned to ranges of temperatures. This can be done by frequency resonance peak engineering through the adjustment of length of the C-shape scatterers which results in having different binary code or adding different temperature thresholds.

4. Conclusion

In this paper the concept and realization of a threshold temperature sensor using chipless configuration are presented. The operation principle relies on temperature transducing as a frequency detuning in multiple radio frequency bands. Depending on the number of frequency bands used, the threshold information can be encoded in a binary format. For this study, the proposed chipless sensor is realized to have responses in ETSI RFID UHF and ISM 2.4 GHz bands resulting in two bits binary code. The results are promising in terms of overcoming the problem of chipless RFID sensing compatibility with standard communication protocols. Otherwise, in perspective this concept could be extended to other geographical standards such as Federal Communications Commission (FCC) (902-928 MHz) band which has larger bandwidth. The FCC band could be divided into many sub-bands and therefore have more than two bits encoding.

5. Acknowledgements

This work has been supported by the European Rise project ChiplEss MultisEnsor Rfid for GrEen NeTworks EMERGENT" project – GA n. 547761.

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