RFID Thermal Seal: Radio-Sensor Integrating Shape-Memory Alloys

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***Abstract*— Beside the logistic usage of RFID Technology, new interesting applications come from the possibility to augment the labelling information with physical information about the tagged object itself, according to the promising low-cost pervasive sensing paradigm. In this context, the paper proposes a dual-chip UHF tag embedding Shape Memory Alloys (SMA) able to transform the variation of the tagged items temperature into a permanent change of antenna radiation features. A general design methodology for the resulting two-ports tag antenna is here introduced and then applied to prototypes able to work at low (around $0°C$) and high ($80°C$) temperatures.**

I. Introduction

The passive UHF tag is often considered, in the RadioFrequency Identification (RFID) context [1], as a digital device which, when interrogated and energized by a reader, may send back its own ID or other resident information through a backscattering modulation of the incident continuous wave. Beside this common usage, RFIDs is now imposing as a leading key-technology in low-cost pervasive sensing within the context of Internet of Things. The labelling information may be augmented with physical information about local agents, as well as about the change in the tagged object itself. Among the various parameters which could be sensed, maybe the most attractive one is the temperature due to the so many implications in pharma and food supply-chain, as well as in hospitals and industrial processes in general.

This paper considers a particular case of temperature RFID logger, e.g. a "seal" or "fuse" which could be able to tell the final user if the tagged item has been exposed to a temperature higher than particular thresholds, as it is useful for the quality assessment of vaccines and other drugs, blood bags and frozen-foods [2]. The RFID device has to store this information all along the supply chain even in absence of continuous interrogation by a reader. The over-temperature flag needs moreover to be unchanged even if the tag temperature falls down the critical value. A possible approach to this problem is to embed into the RFID tag a temperature-sensitive material which modifies its chemical-physical status depending on the local thermal boundary conditions, and force the RFID response to be affected by this material. In this work, shape-memory-alloys (SMA) are considered as sensitive materials for their capability to change their shape when the local temperature exceeds a transition level. It is described how the SMA can be used to develop a thermal switch which will be inserted into a two-chips ad-hoc designed tag. The idea is illustrated in the following by computer simulations and experimental characterization on fabricated prototypes.

II. Shape Memory Alloys and Rationale of the Radio Sensor

The particular SMA here considered are Nickel-Titanium (NiTinol) compounds, subjected to proper annealing process [3]. Nitinol is characterized by two crystallographic phases, a *martensitic* one and a *austenitic* one, in which the structural and mechanical properties of the alloy greatly change. In typical embodiments, these alloys will be particularly malleable in *martensitic state*, while they will return to the original annealing shape when the *austenitic phase* takes place. The transition between the two states is determined by a temperature threshold: when the alloy is exposed to a temperature higher than this threshold, it will change its cristallographic structure, entering the austenitic phase. It is worth mentioning that the threshold is tunable, by changing the alloy percentage composition: therefore, transitions can be obtained in a very wide range of temperatures, i.e. between $-30°C$ and more than $100°C$.

The scheme of the conceived RFID tag is shown in Fig.1. The tag is provided with two RFID microchips connected to a same antenna. The first microchip (Chip-1) is expected to communicate the object unique identifier (ID-1) in any temperature condition, while the second microchip (Chip-2) will wake up only when the local temperature exceeds a given threshold and hence its identifiers (ID-2) will provide the *thermal status* of the tagged object. To this purpose Chip-2 is connected in parallel to Nitinol switch which is generally closed (Chip-2 is short-circuited and does not respond) while it opens above the temperature threshold.

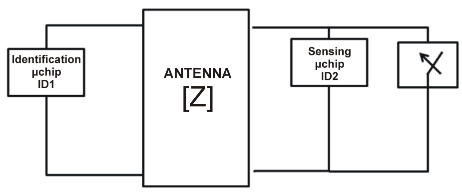

Fig. 1. *Scheme of the two-chip sensing tag embedding a temperature "fuse"*

The considered implementation of the switch includes a Nitinol wire segment having straight shape in the austenitic state. In the martensitic state the wire is shaped to realize a curved bond between two copper terminals: in particular one of the wire termination is softly glued to one of the antenna conductor by means of a conducting paint, while the other is strongly crimped to the other one (as shown in the inset of Fig.2. When the wire enters the austenitic phase, because of a temperature increase, the wire tends to return to its original straight shape and the soft bond is broken therefore interrupting the ohmic link between the switch terminals. Accordingly, a very high impedance condition is achieved as required to activate the Chip-2.

III. TAG DESIGN

A first prototype of RFID thermal seal consists of a dipole-like tag in Fig.2 originated from a planar dipole partly folded to reduce the overall size. The port impedances are controlled by the aspect ratio of two symmetric T-match circuits [4]. The T-match circuits are assumed of equal sizes (a, b) to be determined by imposing the following conditions:

$$switch \text{ ON:} \quad \begin{cases} \tau_1^{ON} \to \max \\ \tau_2^{ON} \to 0 \end{cases} \tag{1}$$

$$switch \text{ OFF :} \quad \begin{cases} \tau_1^{OFF} \to \max \\ \tau_2^{OFF} \to \max \end{cases} \tag{2}$$

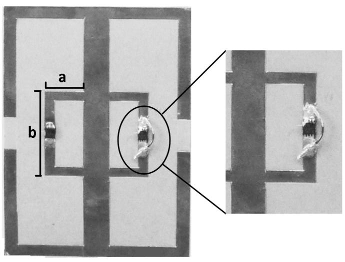

Fig. 2. Proposed dipole-like tag

where $\tau_{1,2}$ are the power transfer coefficients at the two ports which rule the power scavenged by each microchip from the incoming interrogation field emitted by the reader. The optimum solution for the T-match size (a, b) is such to minimize the following fitness function

$$F = w_1|\tau_1^{ON} - 1| + w_2|\tau_1^{OFF} - 1| + w_3|\tau_2^{OFF} - 1| + w_4\tau_2^{ON} \tag{3}$$

where w_k are constant weights and the various power transfer coefficients are numerical evaluated by an FDTD code. The resulting T-match size are $a = 12mm$, $b = 27mm$.

IV. THERMAL CHARACTERIZATION OF THE TAG

The proposed RFID sensor has been tested in real conditions in order to verify the effective communication and sensing performances. Two different scenarios have been reproduced: a first one characterized by a high-temperature environment and a second one with a very low-temperature condition as for the logistics of frozen items. The Nitinol switch has been accordingly fabricated with wires of nominal transition temperature $A_F \simeq 80°C$ and $A_F \simeq 0°C$, respectively.

Examples of collected data in both the experiments are shown in Fig.3 and Fig.4.

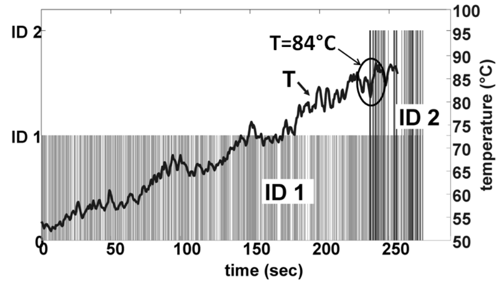

Fig. 3. Digital response from sensing tag with $A_S \simeq 80°C$ versus temperature raise and time.

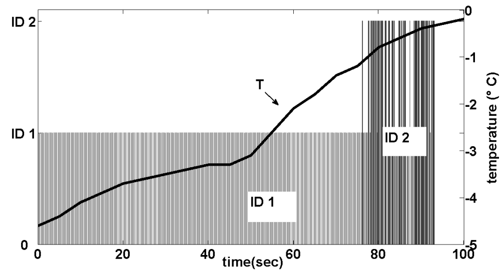

Fig. 4. Digital response from sensing tag with $AF \simeq 0°C$ versus temperature raise and time.

In both cases at low temperature only the ID-1 is collected by the reader since chip-2 is short circuited by the Nitinol switch. When the temperature is close to the threshold value the switch changes status and also the second ID is received hence providing the status information of the thermal seal.

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