A Patch Antenna with Liquid Crystal Elastomer Switching for Passive RFID Temperature Sensing

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***Abstract*— The antenna design presented here supports a new generation of battery-free RFID sensing technology in which the antenna element dynamically conforms to the changing environment in a controlled manner. Specifically, we propose a sensing antenna that reversibly and repeatedly switches operating frequencies from 905MHz to 923.5 MHz based on a temperature threshold crossing. The developed antenna is a patch antenna matched to an RFID IC and integrated with a customized slot. The antenna shifts its operating frequency by using a novel thermal responsive polymer or Liquid Crystal Elastomer (LCE) which is programmable and operates reversibly. Furthermore, 4D printed LCE structures are to be coupled with an Ultra Subminiature Mechanical Switch (USMS) which shorts the slot when the LCE is activated. Finally, as the thermal excitation is removed, the switch returns to the open state. The short and open states of the switch will enable the frequency shift of the antenna structure. In this paper, the methodology of the frequency shift in the patch antenna and the novel LCE switch mechanism are described through simulation and measurements.**

Keywords— temperature sensor, RFID, patch antenna, slot, liquid crystal elastomer (LCE), cold supply chain

I. Introduction

Current RFID sensors for temperature monitoring, which communicate through backscattering modulation in the cold supply chain, consist of semi-passive and passive technologies. Semi-passive RFID sensors are limited to data-loggers that incorporate separate temperature-sensing ICs for monitoring temperature [1]. Therefore, they are complex, costly, require battery-replacement, and cannot provide temperature information in real-time. Conversely, passive RFID temperature sensors incorporate a new paradigm of sensing in which the antenna structure behaves as the sensing element [2]. These sensors are not pragmatic as they utilize shape memory alloys or shape memory polymers which require resetting after a single use [3].

The RFID antenna presented here is to be combined with an Ultra Subminiature Mechanical Switch (USMS) that has been customized to house the 4D printed LCE structure as shown below in Fig. 1 [4]. The switch is to be placed across the slot to provide the open and shorted circuit paths.

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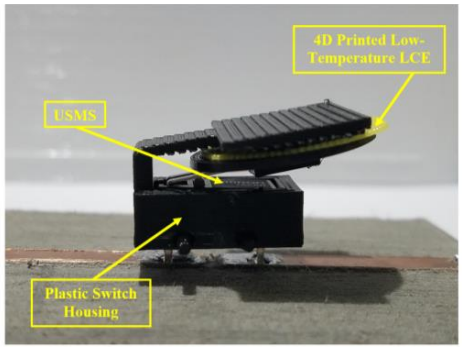

Fig. 1. The prepared USMS with plastic enclosure to enable actuation with the temperature dependent LCE.

LCEs are programmable and reversible polymers that change shape when stimulated and return to a relaxed state when the stimulus is removed, refer to (a) and (b) in Fig. 2, respectively. Thus, this provides the reversible operability in our design to repeatably detect temperature threshold crossings as the temperature varies.

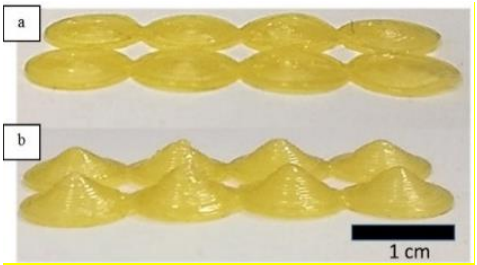

Fig. 2. Example of a 4D printed Archimedean spiral cells in the relaxed (a) and excited (b) states.

II. Antenna Design for the Temperature Sensor

A. Patch antenna design with an integrated slot

A patch antenna operating with the TM_{10} dominant mode has a surface current distribution as shown below in Fig. 3 (left).

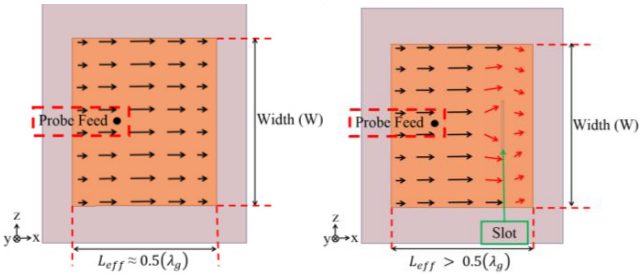

Fig. 3. Surface current distribution of the $\mathbf{TM_{10}}$ dominant mode without slot (left) and with slot (right).

The resonant frequency, f_r , of the patch antenna inversely depends on the effective electrical length, L_{eff} , of the patch metallization as approximated by [5]:

$$L_{eff} \approx 0.5\left(\frac{c}{f_r}\right)\left(\frac{1}{\sqrt{\varepsilon_{eff}}}\right) = 0.5(\lambda_0)\left(\frac{1}{\sqrt{\varepsilon_{eff}}}\right) = 0.5(\lambda g) \quad (1)$$

Furthermore, L_{eff} can be increased by introducing a slot in the metallization of the patch. As a result, the resonant frequency of the patch antenna decreases since the surface current now has a longer path to travel [6], refer to Fig. 3 (right).

B. *Fabricated design and measurements*

The concept patch antenna with the integrated slot was fabricated and is shown in Fig. 6. The design was placed on a specialized stand. The stand enabled the testing of the antenna by applying and removing a conductor (a short) at the slot through minimal human interference.

Fig. 6. Fabricated patch antenna with integrated slot on test stand to apply and remove the short across the slot.

Moreover, the performance (reflection coefficient) of the fabricated design when the slot is shorted and opened is compared with the simulation design in Fig. 7. A favorable correlation is obtained. The black and red traces represent the operation of the antenna at 923.5 MHz (slot is shorted) and 905 MHz (slot is left opened), respectively. Currently, we are characterizing and modifying the USMS (Fig. 1) to operate properly on our antenna structure. This involves the design of input and output matching networks.

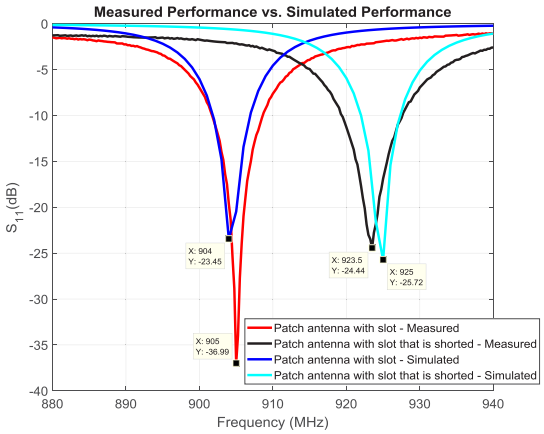

Fig. 7. Measured and simulated S_{11} of RFID antenna.

III. Conclusion

The intended application for this antenna is to sense temperature threshold crossings by switching its operating frequency in the RFID UHF band. The antenna consists of a calculated slot that is shorted to switch its operating frequency. An Ultra Subminiature Mechnical Switch (USMS) is used to ensure a passive (battery-free) design. The USMS is coupled with novel temperature responsive LCEs which enable reversible and repeatable operability. In this paper, we confirmed with simulation and measurement that shorting the slot provides the desired frequency shift. Further research in the integration of the USMS and miniaturization of the design is to be presented at the conference.

References

[1] P. Kumar, H. Reinitz, J. Simunovic, K. Sandeep and P. Franzon, "Overview of RFID Technology and Its Applications in the Food Industry", Journal of Food Science, vol. 74, no. 8, pp. R101-R106, 2009.

[2] C. Occhiuzzi, S. Caizzone and G. Marrocco, "Passive UHF RFID antennas for sensing applications: Principles, methods, and classifcations," in *IEEE Antennas and Propagation Magazine*, vol. 55, no. 6, pp. 14-34, Dec. 2013.

[3] S. Caizzone, C. Occhiuzzi and G. Marrocco, "Multi-Chip RFID Antenna Integrating Shape-Memory Alloys for Detection of Thermal Thresholds," in *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 7, pp. 2488-2494, July 2011.

[4] C. P. Ambulo, J. J. Burroughs, J. M. Boothby, H. Kim, M. R. Shankar, and T. H. Ware, "Four-dimensional Printing of Liquid Crystal Elastomers," ACS Applied Materials & Interfaces, vol. 9, no. 42, pp. 37332–37339, Nov. 2017.

[5] R. Garg, *Microstrip antenna design handbook*. Boston, Mass.: Artech House, 2001, p. 266.

[6] Fan Yang and Y. Rahmat-Samii, "Patch antenna with switchable slots (PASS): reconfigurable design for wireless communications," *IEEE Antennas and Propagation Society International Symposium (IEEE Cat. No.02CH37313)*, San Antonio, TX, USA, 2002, pp. 462-465 vol.1.