A Novel Passive RFID Temperature Sensor Using Liquid Crystal Elastomers

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***Abstract*— A passive RFID temperature sensor is presented. This sensor design utilizes a patch antenna integrated with a customized slot. Using a novel Liquid Crystal Elastomer (LCE) switch, the slot is shorted when the temperature reaches a specified threshold. When the temperature decreases below this threshold, the switch retracts to the original position. As a result, the antenna operates at one of two states corresponding to a controlled shift in frequency within the RFID band. Additionally, a single impedance matching network is designed to accommodate a favorable match between the two antenna states and the RFID IC.**

Keywords*— temperature sensor, RFID, patch antenna, slot, matching network, liquid crystal elastomer (LCE)

I. Introduction

A variety of essential foods and medicines must be maintained within a temperature range to avoid spoilage [1]. Therefore, a sensor design using real-time and battery-less technology is proposed. Moreover, due to standardized communication protocols, high proliferation, and non-line-of-sight communication, RFID technology is incorporated.

The proposed sensor will use a patch antenna with an appropriately designed slot. When the slot is shorted with a switch the antenna operates at a different state corresponding to a different operating frequency [2]. The switch is designed using Liquid Crystal Elastomers (LCEs) and it extends and retracts based on the temperature [3]. Moreover, as the antenna switches states, the input impedance changes as well. For this reason, a customized matching network is designed to provide a good match to the RFID IC in both shorted and non-shorted slot states. Finally, the sensor design is verified using ANSYS HFSS.

II. Antenna Design for the Sensor

A. The proper antenna selection

The proposed sensor is to detect a temperature above a certain threshold. This is accomplished through a designed frequency shift within the narrow RFID bandwidth of 902-928 MHz. For this reason, the patch antenna with an inherently high-Q factor is selected [4].

B. Slot design theory

According to [2], the addition of a slot in the patch antenna effectively increases the electrical length of the antenna. As a result, the resonant frequency of the antenna decreases. When the slot is shorted, the electrical length decreases and the resonant frequency increases. Moreover, the frequency of the antenna when the slot is shorted will always be slightly less than the original design frequency of the antenna [2], this relation is depicted in Fig. 1 below.

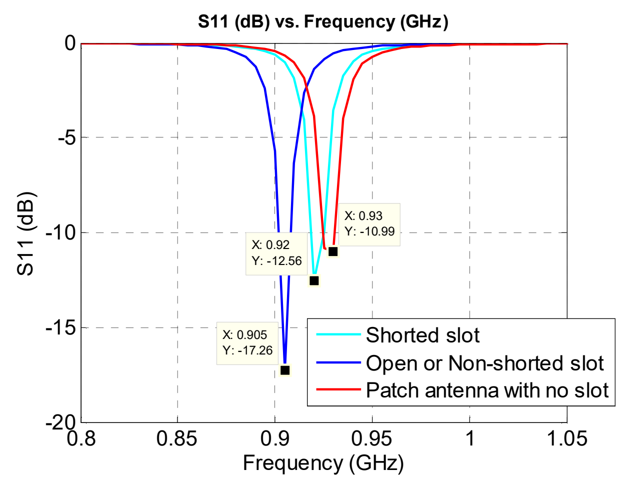

Fig. 1. S_{11} of patch antenna with a shorted and non-shorted slot.

In reference to Fig. 1, the following is a generalized design procedure for the sensor patch antenna:

1. Determine the desired operating frequency of the patch antenna with the shorted slot (cyan).
2. Design a patch antenna at a slightly higher frequency than the frequency determined from step 1 (red).
3. Determine the position and length of the slot so that the antenna resonates at the lower end of the RFID band (blue).
4. The position determined in step (3) should allow the antenna to resonate at the frequency determined in step (1) (cyan) when the slot is shorted.

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Moreover, the layout of the patch antenna with the slot is depicted in Fig. 2.

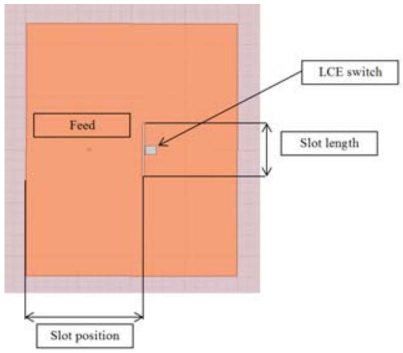

Fig. 2. Patch antenna with the slot and LCE switch.

C. *The LCE switch*

In order for the antenna to shift operating frequencies, a mechanism to short the slot must exist. A switch using a novel LCE is proposed [3]. When the temperature reaches a certain temperature level the LCE switch extends and shorts the slot thereby changing the operating frequency of the antenna. Also, when the temperature drops below this temperature level the switch retracts and brings the antenna to its original geometry and operating frequency, refer to Fig. 3. Therefore, this temperature sensor can be used repeatedly as the LCE actuation is reversible.

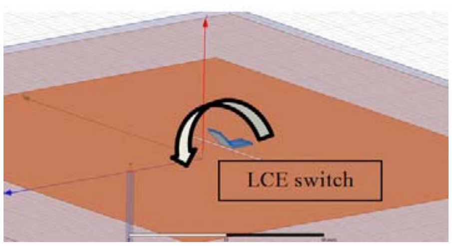

Fig. 3. The proposed LCE switch actuation.

III. Matching Network Design

The proposed antenna shifts its operating frequency states from 905 MHz to 920 MHz when the temperature reaches a certain high temperature. At each of these states the input impedance varies from Z_{ANT1} to Z_{ANT2}, respectively. Accordingly, an impedance matching network must be designed to provide a favorable match to the RFID IC impedance (Z_{IC}) in both states, refer to Fig. 4.

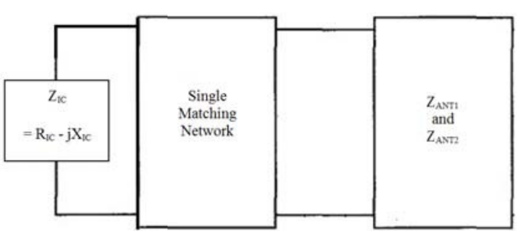

Fig. 4. A single matching network to accommodate two antenna impedance states.

A. *Impedance matching technique*

For ease of fabrication, it is important to realize a matching network using microstrip transmission line. A short-circuited stub technique was used to achieve the needed matching. Our design provided a favorable match with minimal losses at both antenna operating frequencies of 905 MHz and 920 MHz. The performance of the match is measured by the insertion loss (IL) and depicted in Fig. 5.

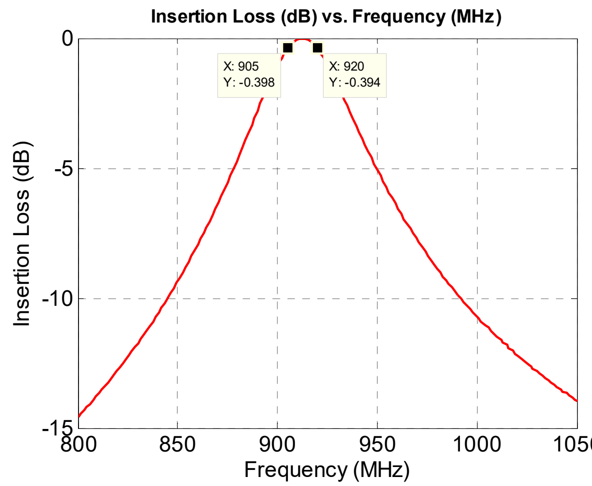

Fig. 5. The performance of the proposed matching network.

IV. Conclusion

A novel temperature passive RFID sensor using LCEs is presented. The sensor consists of a patch antenna with a slot. The sensor can detect when the temperature is higher or lower than a set temperature level by shifting its operation between two frequencies in the RFID band. This frequency shift is achieved with a novel metalized LCE switch that extends to short the slot when the temperature is higher than a certain level. When the temperature falls below this level, the LCE switch retracts thereby removing the short and returning the antenna to its initial operation state. Therefore, this temperature sensor can be used repeatedly as the LCE actuation is reversible. Additionally, a matching network is designed to accommodate both the antenna states and provide a favorable match to the RFID IC.

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