An antenna-based RFID expansion joint monitor

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***Abstract*—We present the design and preliminary test results from an RFID-based sensor used for expansion joint gap monitoring. Discrete increments in gap length are related to a change in signal response of an array of RFID tags. We demonstrate that our sensor can be reliably used to monitor gap increments of 1 inch over a read distance of at least 0.5 m. Prospective design improvements and future research directions are also discussed.**

I. Background

Passive RFID has gained much traction as an object identification technology for high volume asset tracking. Passive RFID tags today can be manufactured in high volumes at 7-15 US cents per tag [1]. Furthermore, RFID offers several key features such as non-line of sight operations, improved read range and automated inventory management [2]. We are thus presented with an ideal wireless communication infrastructure for pervasive sensing.

Researchers have successfully developed pervasive sensors to measure parameters such as displacement, strain and cracking in structural health monitoring using ordinary RFID tags [3], [4], [5]. In all these sensors, changes in the parameter of interest are related to a change in tag signal response.

Gaps are present in structural elements to allow room for the material to expand and contract under different temperature conditions. The gap length is an important design parameter, especially in the railroad industry [6]. Gaps that are too small can lead to mis-alignment of rails while gaps that are too large compromise structural integrity. It is therefore important to select an optimal gap length and ensure that fluctuations are within tolerances. We propose the design of an expansion joint sensor that monitors expansions in discrete increments of 1 inch. Changes in displacement are correlated to a change in the signal response of an RFID tag. In the following sections, we discuss the design principle, present sample measurements and directions for future work.

II. Design Principle

We make use of an array of inductively coupled loop antennas as seen in Fig.1(a). We observe that each of the antennas has a 1 mm slit in the middle of the radiating element. As seen in Fig. 2, splitting the radiating element in half severely detunes the antenna and causes a 9 dB difference in tag signal response. We make use of this property in the sensor design.

As seen in Fig. 1, the antenna array is anchored to a fixed reference frame (one part of the structural element) and a part of the structural element bearing the expansion joint slides behind the antenna array. As an example, the structural element could be a rail-road track which slides relative to the antenna array depending on whether the expansion joint is expanding or contracting. As seen in Fig. 1 (b), a through hole connects the radiating element of the antenna to the underside of the substrate material. Also, as seen in Fig. 1 (b), a conductive strip, at a slight offset, is present on the surface of the sliding structural member.

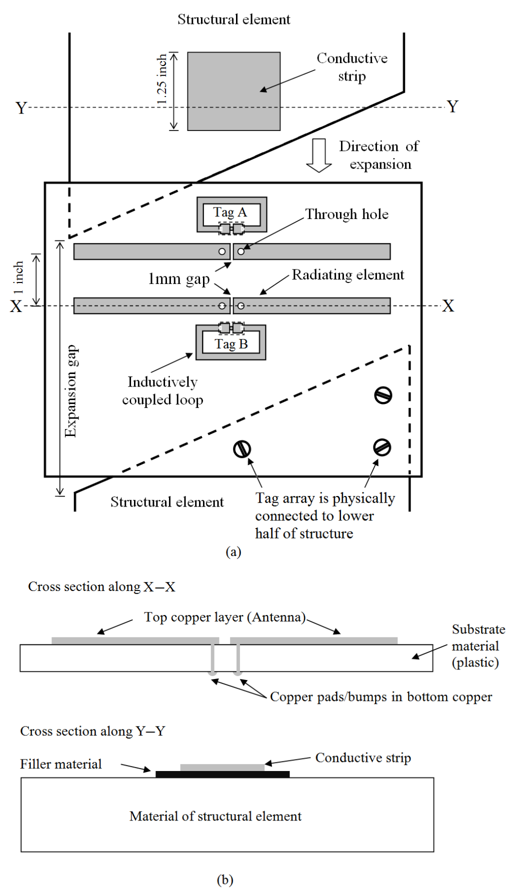

Fig. 1. (a) Sensor having two RFID tags deployed in an expansion joint (b) Cross sections along X–X and Y–Y.

Consider the two tags *A* and *B* shown in Fig. 1, located a distance of 1 inch apart. Consider the structural element with an expansion joint located behind the sensor array. When expansion occurs moving the conductive strip so that it is located behind tag *A*, the conductive strip electrically connects the two halves of the radiating element of tag *A*. Thus tag *A* would respond with a much higher signal strength to reader interrogation than tag *B*. On the other hand, if the joint expands further, the conductive strip now moves to a position behind tag *B* improving it's signal response. Therefore, by observing the relative signal responses of the tag array, it is possible to predict the expansion of the structural element in increments of 1 inch.

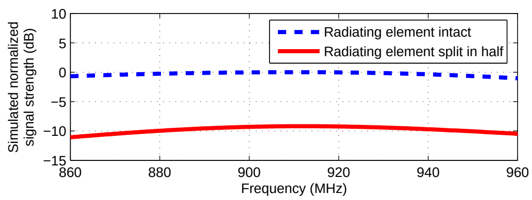

Fig. 2. Simulated normalized signal strength for the two cases (i) the radiating element is intact and (ii) the radiating element split in half (normalization is performed with respect to the maximum strength recorded in either case).

III. Measurement results

We experimentally verify the sensor design principle using an array of two tag-sensors as shown in Fig. 3. The structural element, with the conductive strip, is emulated using a cardboard sliding element as labelled in the figure. We examine the response from both RFID tags as the conductive strip slides relative to the tag array. We made use of an Impinj Revolution RFID reader [7] and conducted the measurements at a reader-tag separation of 0.5 m.

Measurements were obtained for four discrete cases as

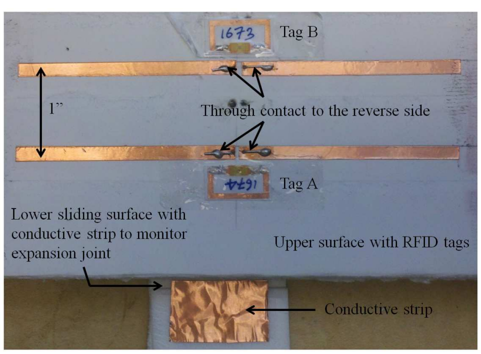

Fig. 3. Expansion joint monitor consisting of two RFID tags.

listed below:

1) Neither tag is connected to the metal strip.
2) Tag *A* is connected to the metal strip.
3) Both tags are connected to the metal strip.
4) Tag *B* is connected to the metal strip.

The results are shown in Fig. 4. The results make logical sense. When neither tag is in contact with the conductive strip, the response from both tags is poor. When only one tag is connected, the connected tag responds with a strong signal strength. When both tags are connected, both tags respond with a strong signal strength.

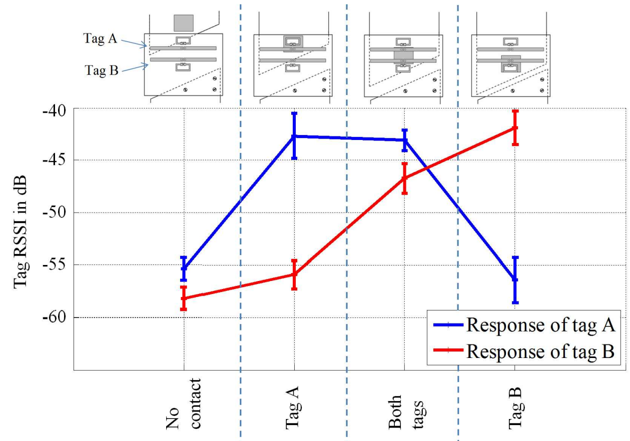

Fig. 4. Measured received signal strength indicator (RSSI) of tags *A* and *B* as the structural element expands into the expansion gap.

These results confirm that the design principle is feasible and the sensor can be used to monitor expansions in discrete increments of 1 inch. Furthermore, it is interesting to note that the separation of 1 inch between the two tags is sufficient to avoid undesirable coupling effects between the two tags.

IV. Conclusion and Future Work

We presented the design concept of an antenna-based RFID expansion joint sensor. We demonstrated that an array of inductively coupled loop antennas could be used to monitor expansions or contractions in discrete increments of 1 inch over a read distance of 0.5 m.

As part of future work, we intend to examine, and possibly extend the maximum read range from the sensor array. We also intend to optimize the array so that the precision of the sensor can be reduced to less than 1 inch. Finally, we hope to conduct pilot tests in the field to monitor expansion joints in rails and bridges. This would require that we address the challenges of deploying the sensor in an RF hostile environment containing snow and rain, abrasion and acid attack and potentially large cycles in temperature.

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