Thermally-Stable Passive Antenna Sensor for Strain and Crack Monitoring

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INTRODUCTION

An RFID patch antenna sensor can be used to wirelessly measure the strain and/or crack on a structural surface through the shift of its electromagnetic resonance frequency. According to electromagnetic theory, the resonance frequency f_R of a patch antenna has an approximately linear relationship with strain ε:

$$f_R = \frac{c}{2L(1+\varepsilon)\sqrt{\beta_r(T)}} \approx f_{R0}(T)(1-\varepsilon)$$

Here

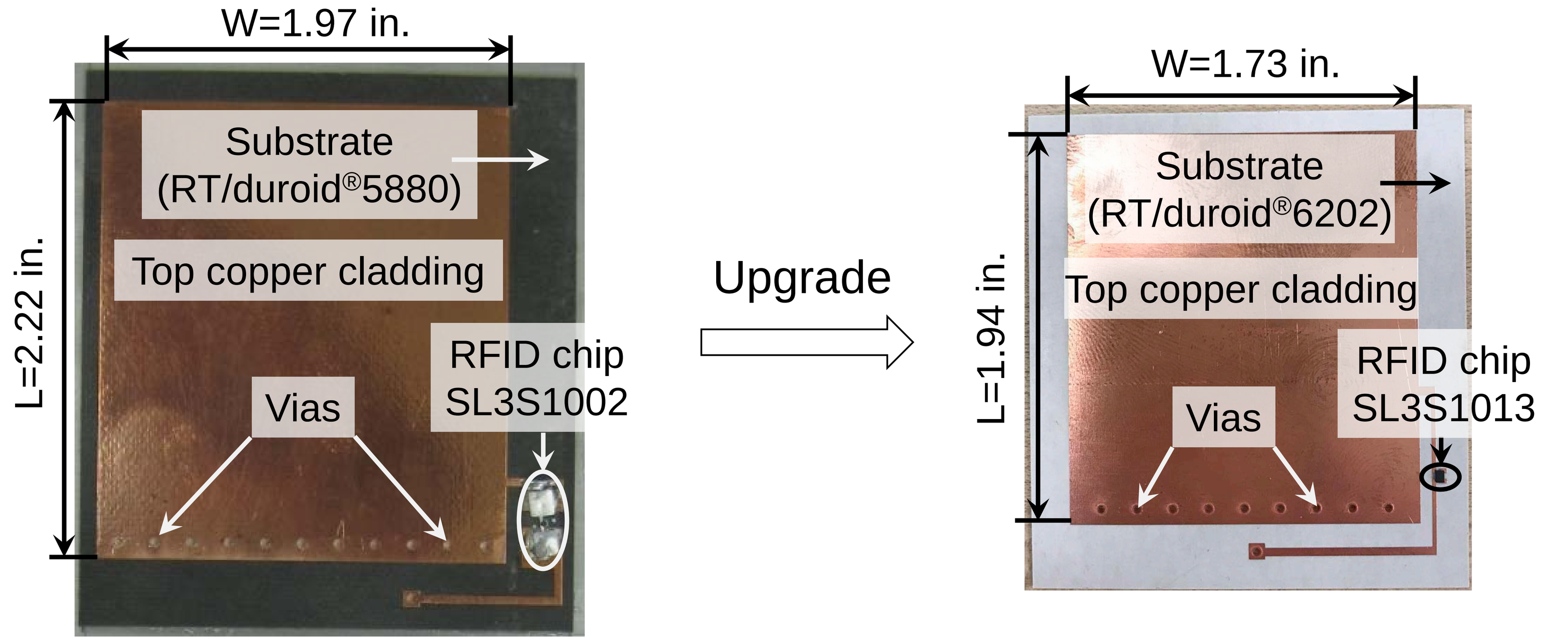
$$f_{R0}(T) = \frac{c}{2L\sqrt{\beta_r(T)}}$$

c -- Speed of light

L -- Length of the patch antenna

$\beta_r(T)$ -- Effective dielectric constant

Previous design of antenna sensor with Rogers RT/duroid® 5880 substrate is sensitive to temperature change. A new RFID patch antenna sensor with thermally-stable substrate material Rogers RT/duroid® 6202 is designed and tested through both numerical simulation and laboratory experiments. A new RFID chip with much smaller footprint is adopted in the new design.



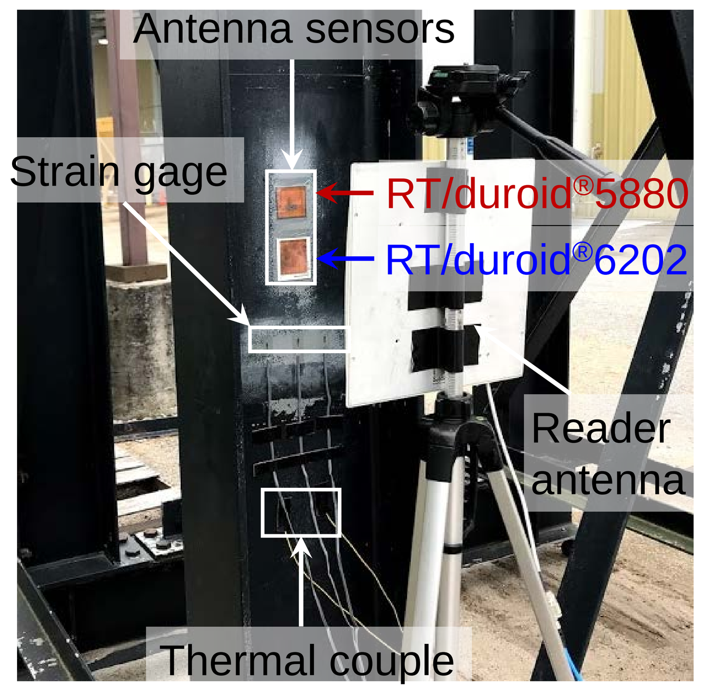
Previous Design

New Design

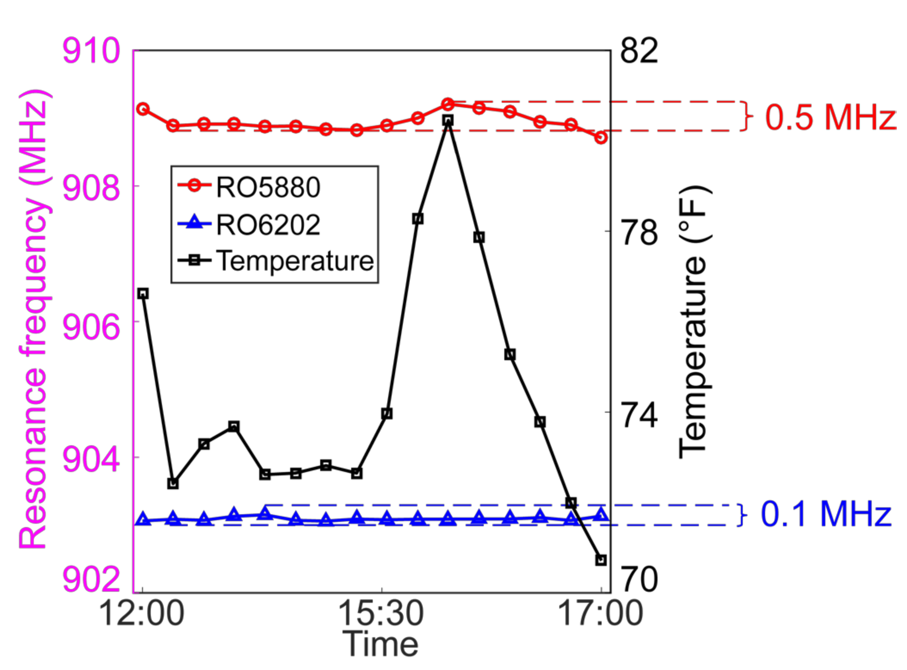
METHODS & RESULTS

- Outdoor Temperature Test

Thermal influence on the new substrate material RT/duroid® 6202 is investigated through a day-long outdoor test. Frequency change caused by temperature fluctuation is much less than previous sensor with substrate material RT/duroid® 5880.



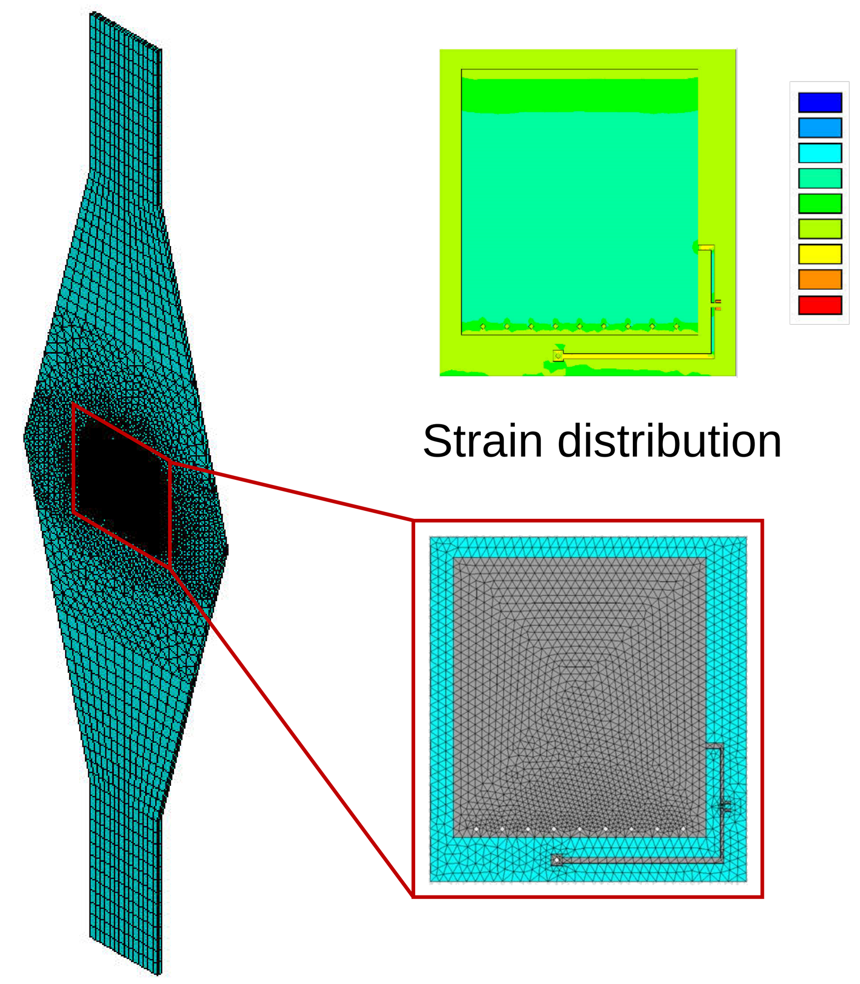
Experimental Setup

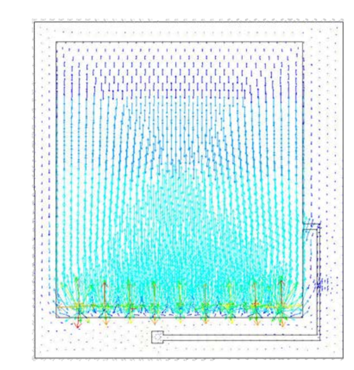


Resonance Frequency Change

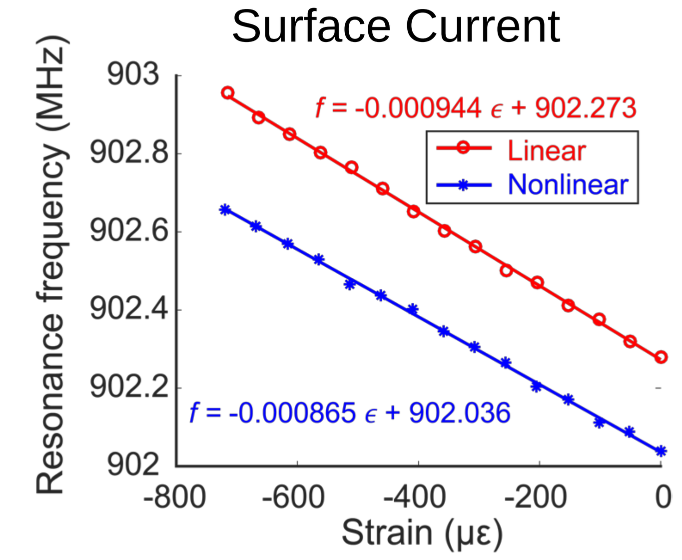
- Multi-Physics Simulation

Mechanical simulation with linear constitutive properties and nonlinear constitutive properties is conducted. Resonance frequency of deformed antenna sensor is then calculated. Strain sensitivity is calculated as –944 Hz/με using linear constitutive properties, and –865 Hz/με using nonlinear constitutive properties.





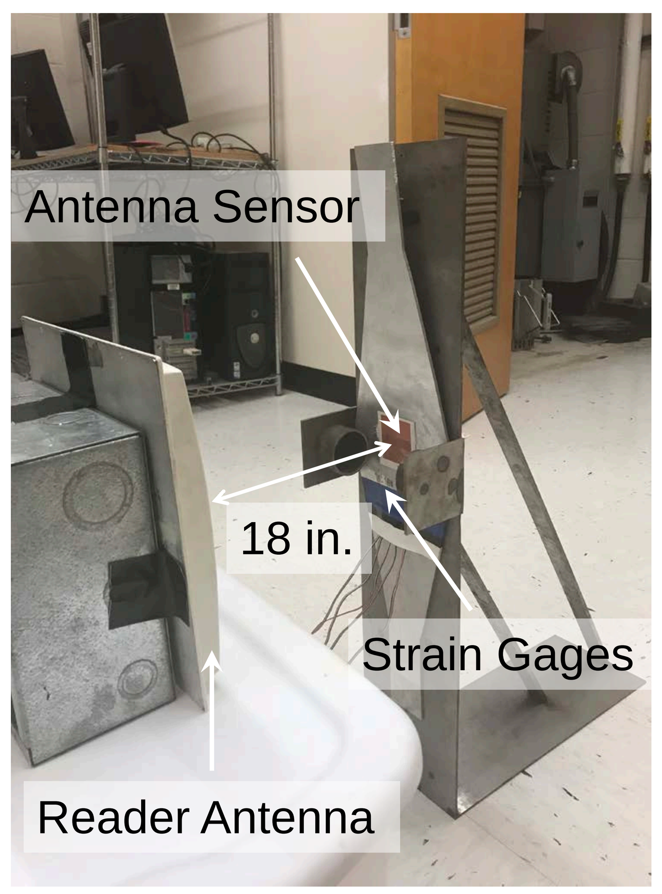
Finite Element Model



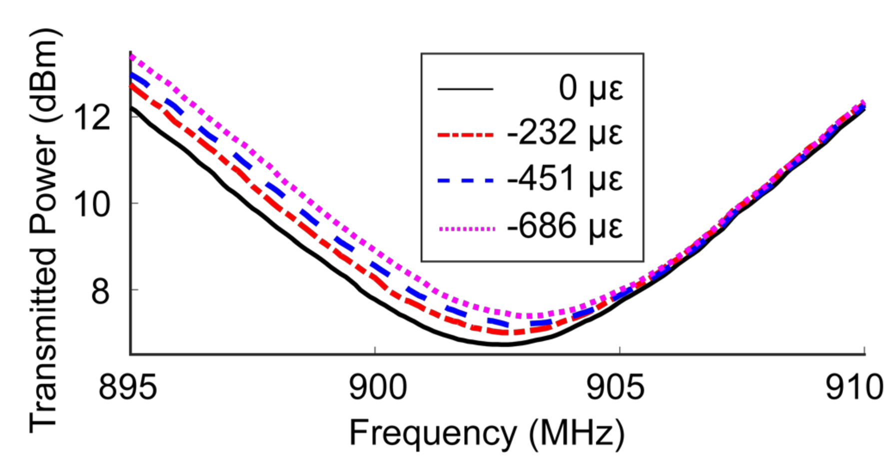
Resonance Frequency Change

- Strain Sensing

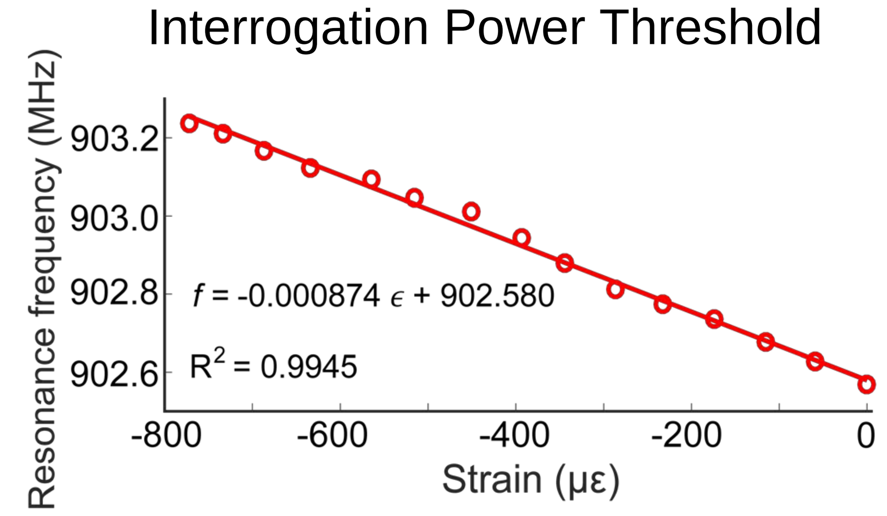
Compressive strain is generated from zero to –750 με, at an increment of –50με per step. At each strain level, an interrogating device wirelessly sweeps the interested frequency range for power threshold measurement. From each curve, the resonance frequency is extracted. The strain sensitivity is measured as –874 Hz/με. The approximately linear relationship between resonance frequency and strain is experimentally confirmed.



Experimental Setup



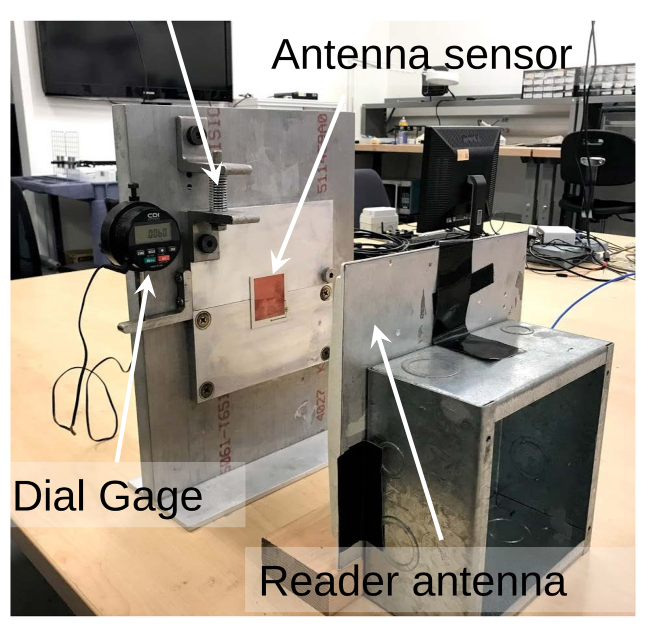
Interrogation Power Threshold



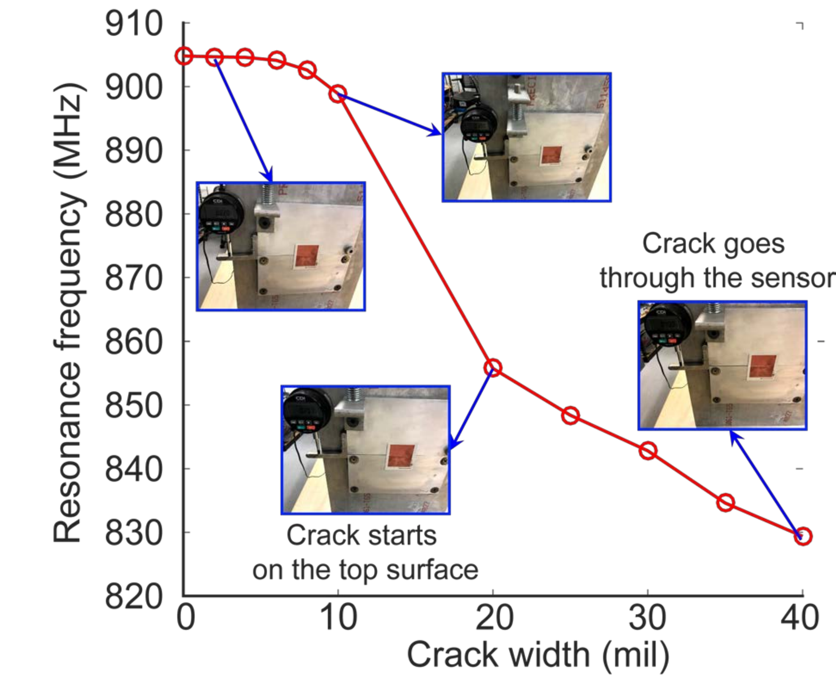
Resonance Frequency Change

- Crack Sensing

Surface crack, from 0 to 40 milli-inch, is generated by an emulated crack device. At each crack level, the resonance frequency of the antenna sensor is measured. The antenna resonance frequency is shown to reduce gradually when the size of the crack opening increases.



Experimental Setup



Resonance Frequency Change

CONCLUSIONS

A thermally-stable passive antenna sensor has been developed for measuring strain and surface crack on structures. Extensive numerical simulation and laboratory tests lead to following conclusions:

- The sensor with RT/duroid® 6202 substrate is shown to be more stable under outdoor environment disturbance compared with previous sensor with substrate material RT/duroid® 5880.
- Multi-physics simulation can accurately model behaviors of the antenna sensor. Incorporating nonlinear constitutive properties in the model can improve the accuracy of the simulation results on strain sensitivity.
- The antenna sensor is capable of estimating small strain changes on structures. The resonance frequency of the antenna sensor increases as the compression strain is applied.
- The antenna sensor can detect surface crack. As crack propagates, the resonance frequency of the antenna sensor reduces as expected.

REFERENCE

Li, D., and Wang, Y. (2018). "Strain sensing rosettes using passive patch antennas." Proceedings of SPIE, Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring Denver, CO, USA, March 4-8, 2018.

ACKNOWLEDGEMENTS

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