proceedings

*Abstract*

# Ecoresorbable Radio-Frequency Platform for Humidity and Temperature Sensing †

**James Bourely [1], Jaemin Kim [1], Xavier Aeby [2], Gilberto Siqueira [2], Gustav Nyström [2], Oleksandr Vorobyov [3], Christian Beyer [3], David Schmid [3] and Danick Briand [1,*]**

1 Soft Transducers Laboratory, Ecole Polytechnique Fédérale de Lausanne, CH-2000 Neuchâtel, Switzerland
2 Cellulose & Wood Materials Laboratory, EMPA, Swiss Federal Laboratories for Materials Science and Technology, CH-8600 Dübendorf, Switzerland
3 Wireless Embedded Systems, CSEM, Centre Suisse d'Electronique et de Microtechnique SA, CH-2000 Neuchâtel, Switzerland
* Correspondence: danick.briand@epfl.ch
† Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

**Abstract:** Aiming to reduce electronic waste in sensing applications, we report on an eco-friendly printed microstrip line to sense relative humidity (RH) and temperature. The device is made of zinc resonators on paper used as transducers, which are coated with beeswax as an encapsulant, and uses konjac as a humidity sensitive coating. The multi-resonating structure, operating in the S-band, shows reproducible temperature and humidity sensing from 15 °C to 35 °C and 30% to 70% RH with sensitivities up to 1.9 MHz/°C and 2.0 MHz/%RH, respectively. This combination of transducing and sensing materials is promising for the realization of disposable environmental sensors.

**Keywords:** ecoresorbable electronics; humidity; temperature; sensors; radio frequency; chipless

check for updates

**Citation:** Bourely, J.; Kim, J.; Aeby, X.; Siqueira, G.; Nyström, G.; Vorobyov, O.; Beyer, C.; Schmid, D.; Briand, D. Ecoresorbable Radio-Frequency Platform for Humidity and Temperature Sensing. *Proceedings* **2024**, 97, 74. https://doi.org/10.3390/proceedings2024097074

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 22 March 2024



## 1. Introduction

The monitoring of environmental parameters is essential for the safety of perishable goods' and to prevent waste. With the increase in connected devices for IoT applications such as tracking the logistics of products, the need for a more eco-friendly approach to reduce electronic waste is of importance. Compared to the state of the art [1], we report on a study conducted to measure temperature and relative humidity using a chipless approach implemented with entirely biodegradable materials.

## 2. Materials and Methods

A sensing platform composed of a multi-resonator, operating at a radio frequency from 1 GHz to 4 GHz, was developed using eco-friendly and degradable materials. A zinc microstrip line made of three resonators was screen-printed using 500 nm zinc nanoparticle ink on an 800 µm thick paper substrate and sintered using a hybrid sintering process [2] to reach high conductivity. The transducers were then encapsulated using beeswax melted at 80 °C to prevent interference from moisture. One of the resonators was used for temperature sensing, another was coated with the mucilage of a super absorbent plant-based polymer (Konjac Glucomannan) at 10% concentration in deionized water for humidity sensing, and the last one was used as reference. The most appropriate resonant frequency of the microstrip resonator for sensing temperature was determined and the position of the coating giving the highest humidity sensitivity was identified. The temperature and RH sensing data were acquired using a Vector Network Analyzer (VNA) with the device under test having a copper-tape ground plane and the device was placed in a climatic chamber plane with a commercial humidity and temperature sensor used as reference. The temperature sensitivity of the eco-friendly sensing platform was assessed from 15 °C to 35 °C and the humidity characterization was conducted from 30% up to 70% RH.

## 3. Results and Discussion

Each resonator acted as a stopband filter resulting in specific resonance frequencies along the recorded frequency spectrum. The S12 signal across the fabricated sensing microstrip line was recorded under varying temperature and humidity levels. Temperature detection was achieved by exploiting how the electrical conductivity of the microstrip line changed with temperature, with a temperature coefficient of resistance (TCR) of ~0.0032 ppm/°C for the zinc layer [2], leading to a shift in the resonance peak. The achieved sensitivities to temperature were 0.7 MHz/°C, 0.8 MHz/°C and 1.9 MHz/°C for the resonator at 1.2 GHz, 2.0 GHz and 3.3 GHz, respectively, as seen in Figure 1a.

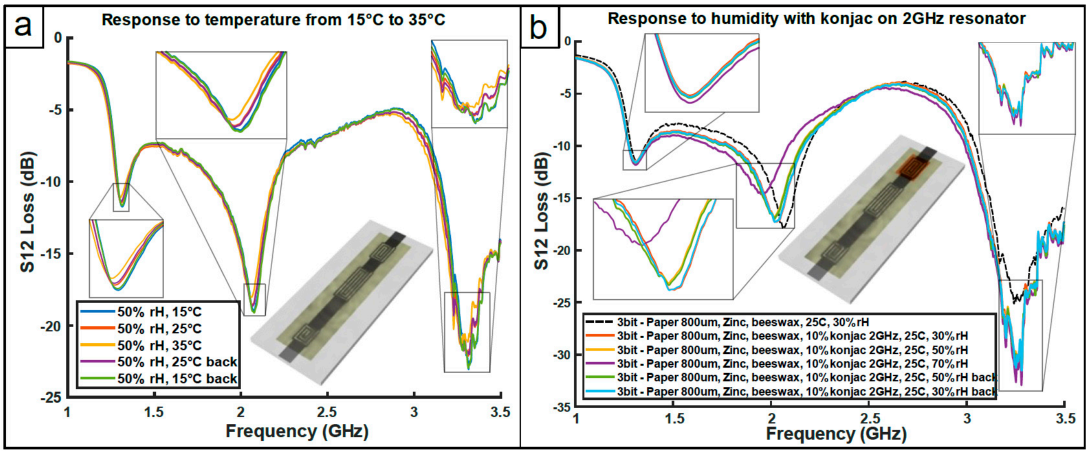


**Figure 1.** S12 signal of the ecoresorbable microstrip platform (noise at 3 GHz due to climatic chamber operation. (**a**) S12 temperature response of the multi-resonating structure cycling from 15 °C to 35 °C and down, with device schematic; (**b**) S12 relative humidity response of the multi-resonating structure cycling from 30% RH to 70% RH and down, with device schematic.

Similarly for humidity, konjac coated on higher-frequency resonators led to higher average sensitivity: 0.85 MHz/%RH, 2.0 MHZ/%RH and 2.2 MHz/%RH for 1.2 GHz, 2.0 GHz and 3.3 GHz resonators, respectively. Since the temperature sensitivity at 3.3 GHz was twice that at 2.0 GHz while only a small increase was observed for humidity, the 2 GHz resonator was chosen to be coated with 30 µm thick konjac. As humidity increased, water molecules were adsorbed into the coating, locally changing the dielectric properties and thus the dielectric permittivity near the resonator. This change in permittivity resulted in a change in the resonant frequency proportional to the capacitance of the structure. We found a sensitivity ranging from 0.5 up to 6.8 MHz/%RH from 30% to 70% RH for the coated resonator, while the beeswax encapsulation prevented the two other resonators' resonant frequency from shifting, as seen in Figure 1b.

**Author Contributions:** Conceptualization, J.B., J.K., G.N., O.V., C.B. and D.B.; methodology, J.B., O.V. and C.B.; validation, G.N., C.B. and D.B.; formal analysis, J.B. and C.B. data curation, J.B.; writing—original draft preparation, J.B. and D.B.; writing—review and editing, J.B., J.K., X.A., G.S., G.N., O.V., C.B. and D.B.; visualization, J.B.; supervision, C.B. and D.B.; project administration, D.S., O.V., D.B. and G.N.; funding acquisition, D.S., O.V., G.N. and D.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Swiss National Science Foundation and the Innosuisse BRIDGE Discovery Program for the project "GREENsPACK—Green Smart Packaging", grant number 187223.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data supporting the conclusions of this article will be made available by the authors on request.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Subrahmannian, A.; Behera, S.K. Chipless RFID: A Unique Technology for Mankind. *IEEE J. Radio Freq. Identif.* **2022**, *6*, 151–163. [CrossRef]
2. Fumeaux, N.; Briand, D. Zinc hybrid sintering for printed transient sensors and wireless electronics. *Npj FlexElectron* **2023**, *7*, 14. [CrossRef]