3D printable Chipless RFID sensors

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1. Introduction

Chipless RFID sensors overcome some of the issues of traditional sensors [1]:

- Passive, no chip needed
- Low manufacturing cost, can be 3D printed
- Lower maintenance/recovery costs if made with eco-friendly materials

The working principle is that the resonant frequency of the RFID tag is a function of the substrate's permittivity.

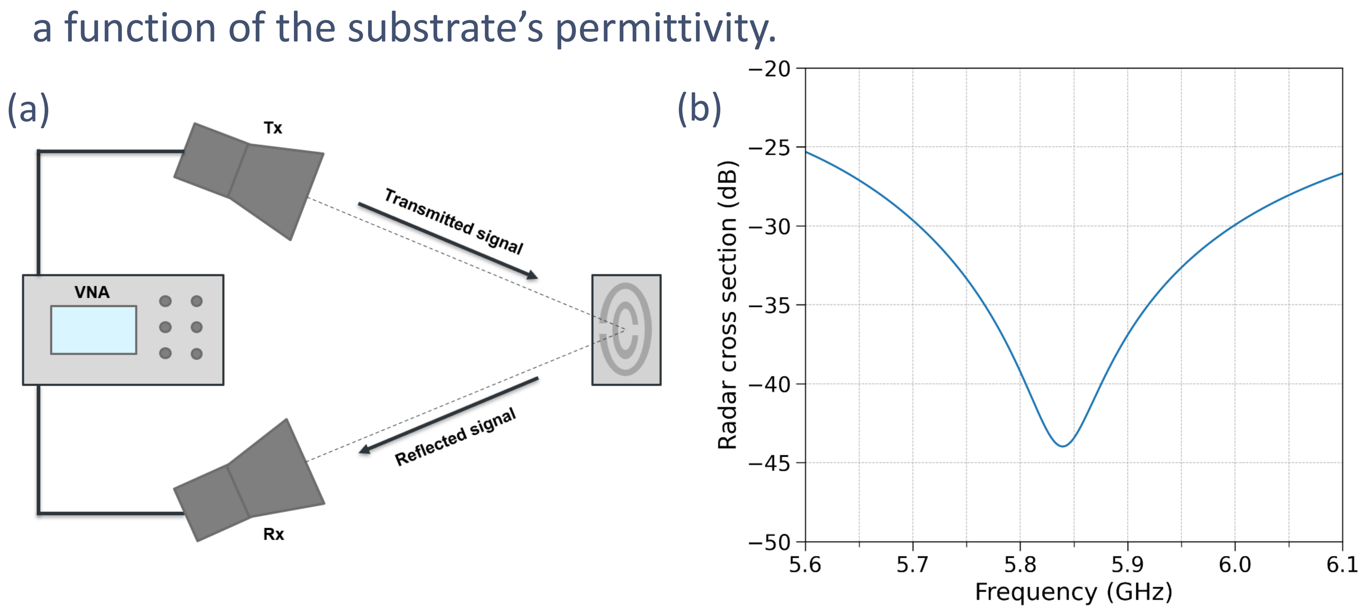

Figure 1 – (a) Chipless RFID sensor measurement and (b) frequency response (RCS)

Specifically, we study lightweight (LW) polylactic acid (PLA), a biocompatible 3D-printable cellular material, which has already been studied for energy harvesting applications [2]. We expect cellular PLA to have a faster response to temperature, as well as a better response to humidity, due to the numerous microscopic cavities.

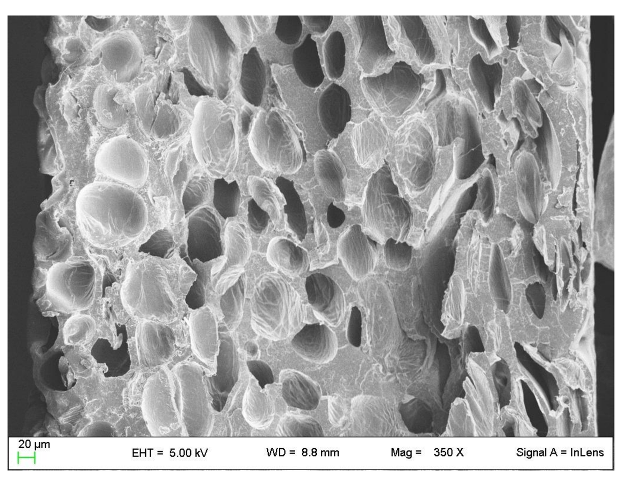

Figure 2 – SEM image of cellular PLA [2]

The first step towards developing RFID sensors is characterizing the material's permittivity, which predicts the sensor's response to RF signals.

2. Permittivity

Complex permittivity was measured using a rectangular waveguide (WR90) in the X band (8.2-12 GHz). The permittivity is obtained by simulating the same waveguide in COMSOL and comparing the results for the S parameters. This was done for different foaming levels, i.e. different extrusion temperatures.

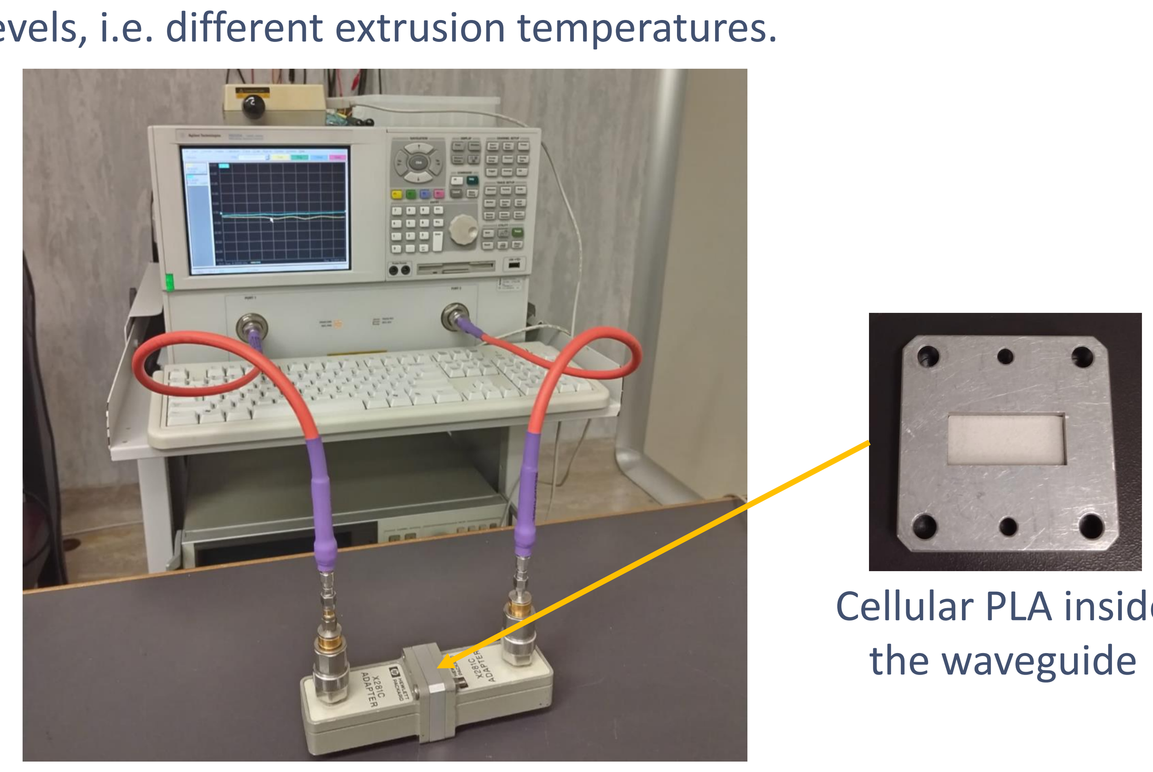

Figure 3 – Measurement setup with VNA and WR90 waveguide

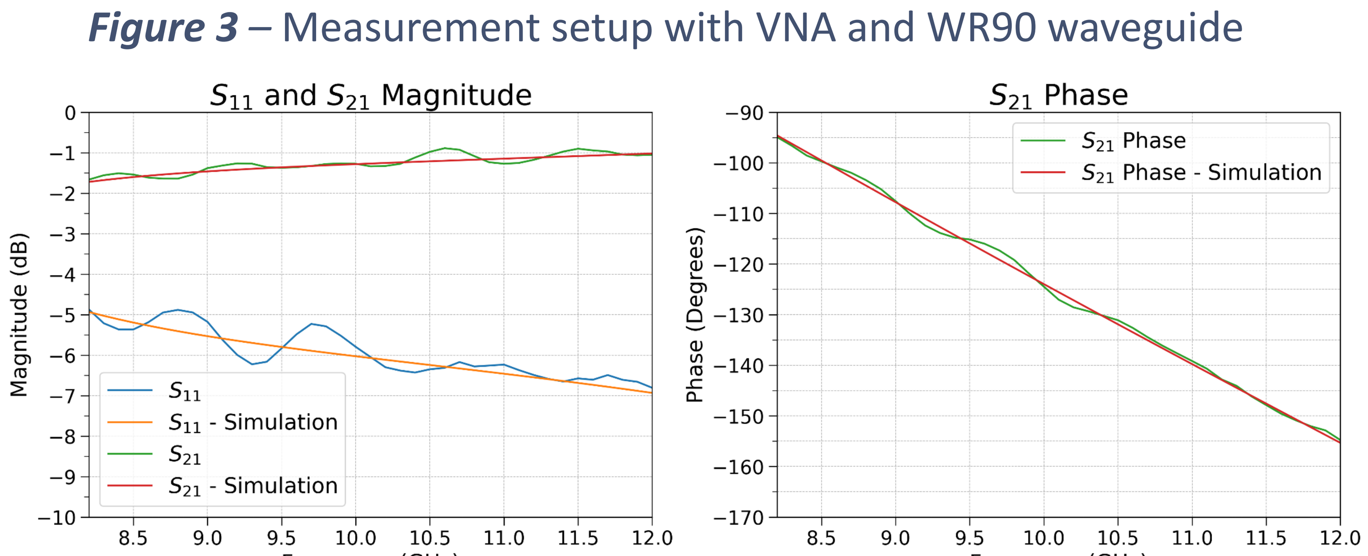

Figure 4 – Comparison of magnitude and phase between measured and simulated S parameters for 220 °C PLA

3. Results

Sample porosity at different extrusion temperatures

Ext. temp(°C)	200 °C	210 °C	220 °C	230 °C	240 °C	250 °C	260 °C
Porosity(χ_{air}) ± 5%	0.06	0.07	0.26	0.51	0.59	0.59	0.60

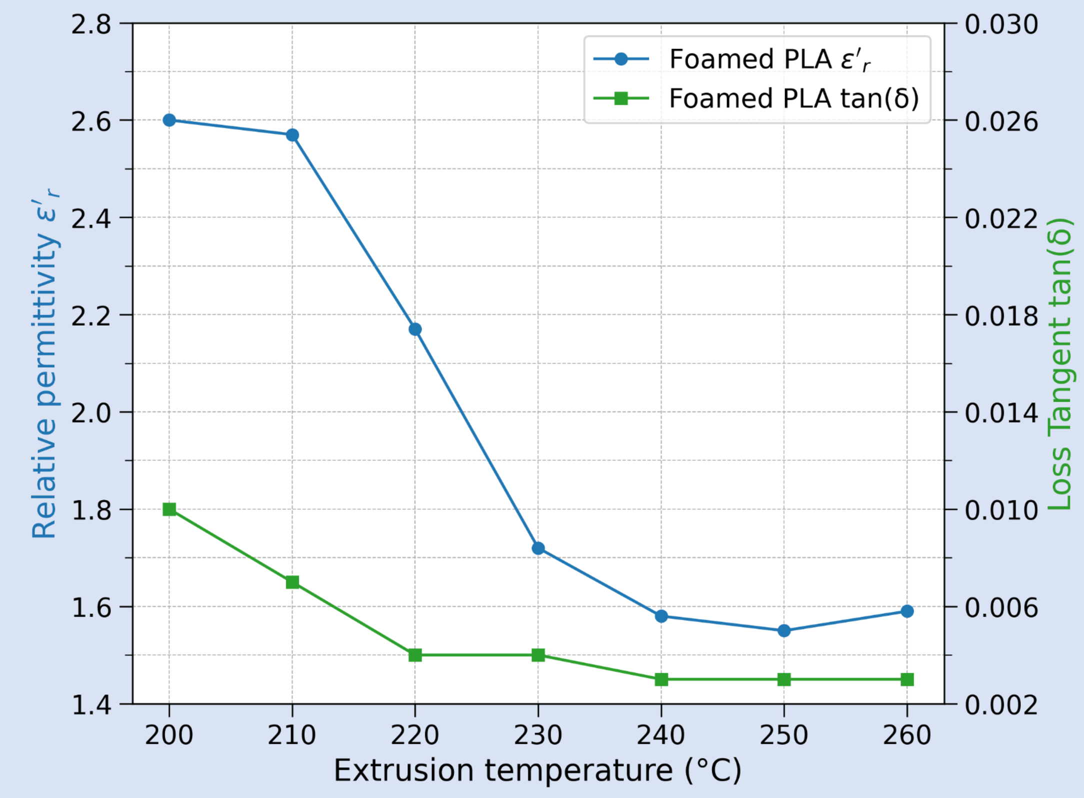

Figure 5 – Relative permittivity and loss tangent for different extrusion temperatures of LW PLA.

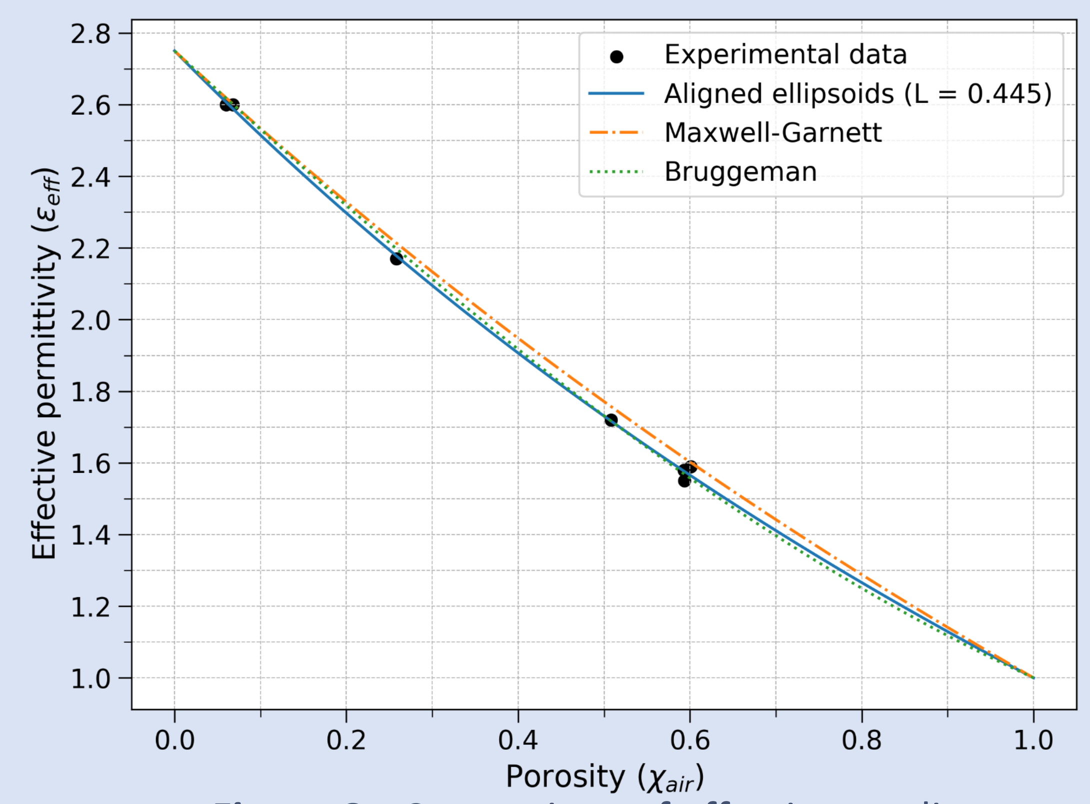

Figure 6 – Comparison of effective medium approximations [5] for LW PLA. L = depolarization factor.

- The loss tangent (tan δ) was found to be between 0.01 and 0.003, making it an excellent material to use as a substrate for RF applications in this frequency range.
- The data is consistent with Maxwell-Garnett's effective medium approximation which assumes diluted spheres. A refined approximation that considers aligned ellipsoids shows an even better agreement with experimental data. Reference data is $\varepsilon_{r,PLA}$=2.75, tan(δ)=0.15 [3] and $\varepsilon_{r,air}$=1.

With data regarding the material's permittivity it is possible to simulate tags:

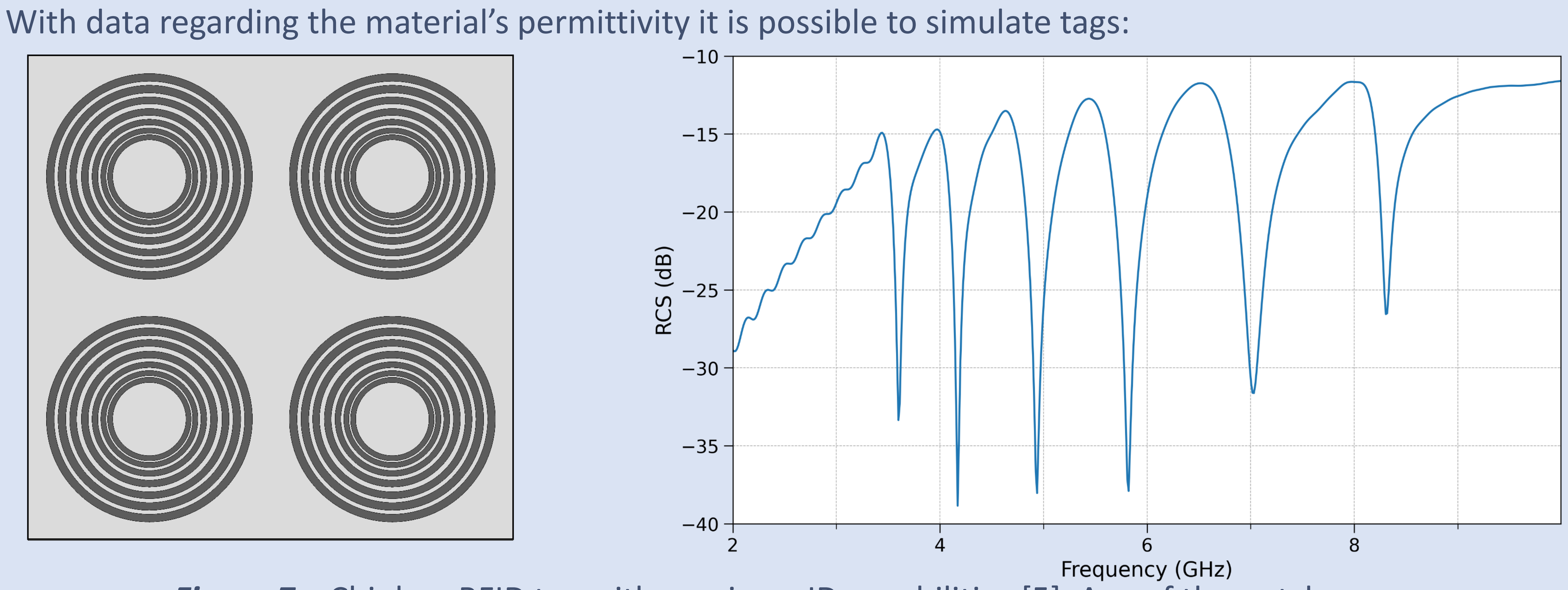

Figure 7 – Chipless RFID tag with sensing + ID capabilities [5]. Any of the notch resonances can be used for sensing.

By creating a tag with an array of identical resonators, it is possible to increase the effective area, therefore the RCS and the reading range according to the radar equation.

Combining the permittivity of LW PLA at 220 °C, simulations, and literature data on standard PLA's permittivity as a function of temperature [6] we estimate the sensitivity of this sensor as 0.5 MHz/°C using the ~8.3 GHz resonance. This sensor can be used at temperatures below 60 °C. Above this temperature, PLA undergoes a glass transition and could be used as a one-time temperature threshold sensor.

4. Conclusions and next steps

- The sensor's sensitivity is consistent with other chipless RFID sensors in literature and can be manufactured with 3D printing and electroplating (after printing with conductive PLA). This approach allows for the development of an eco-friendly sensor that has a minimal environmental footprint.
- Characterization for humidity changes will be done next. It can be implemented on the tag by using resonators of different lengths, resulting in a different thermal expansion, or by combining multiple materials.
- Other eco-friendly materials will be studied similarly, for example, PolyHydroxyAlkanoates (PHA), a completely biodegradable 3D printable material.

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