

Biodegradable Chipless Sensor Tags for Sustainable Smart Packaging in Logistics

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Compostable and biodegradable materials are the pillars of solutions for fighting against electronic waste, CSEM, EMPA and EPFL propose an ultra-low cost, simple, and eco-friendly chipless sensor and identification tags, able of direct biodegradation, disposal, or recycling — eliminating the need for return chain logistics or waste separation.

The combination of chipless RFID tags and a biodegradable substrate offers a cutting-edge solution for sustainable smart packaging. These tags eliminate the need for traditional IC-based technology, reducing costs and environmental impact. Designed for applications like logistics and environmental monitoring, the tags are eco-friendly, ultra-low-cost, and can be biodegraded, disposed of, or recycled without requiring complex waste management systems. This technology provides customers with the ability to monitor and identify items in real-time while supporting global efforts to reduce electronic waste.

Chipless RFID technology enables wireless data transfer without using integrated circuits (ICs), which are commonly found in conventional RFID tags. The tags operate by reflecting RF waves, allowing them to be read remotely. The chipless tag substrate is cellulose-based materials, which are fully biodegradable and free of harmful plastics, ensuring a minimal environmental footprint. Conductive materials such as zinc ink are used for the printed circuitry, which ensures conductivity while maintaining biodegradability.

The chipless tags are designed to function as both identification tools and sensors. For instance, temperature sensors are integrated into the tags by embedding a non-reversible temperature sensing element, such as a mixture of high melting point oils (e.g. coco oil), into the structure. When the temperature exceeds a predefined threshold, the sensor is activated, and the event is recorded^[1]. The prototyped fully biodegradable "GREEN" tag, which functions at short distances (direct contact and up to 3 mm), is shown in Figure 1 and Figure 3.

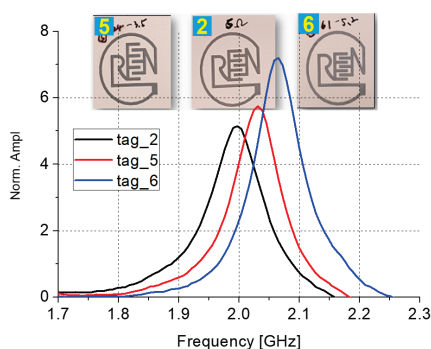


Figure 1: Short-range tags with Zn ink conductive lines: measured performance.

The short range, tag shown in Figure 1, operates over short distances (up to 3 mm). It is completely biodegradable and demonstrates excellent performance in transmitting data for identification and sensing purposes. The use of zinc ink for conductive lines ensures both functionality and environmental friendliness. A longer-range version of the tag, depicted in Figure 2, is capable of operating at distances up to 50 cm, with

current tests achieving a range of 30 cm. These tags can encode data with up to 10-bit resolution (with future potential for 16-bit).

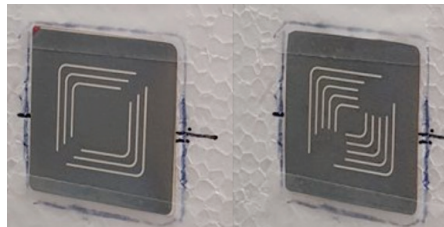


Figure 2: Long-range data tags with Zn ink conductive lines: 3-bit (left) and 10-bit (right).

While biodegradable tags present promising opportunities, they also face challenges. Due to the paper-based substrate and the use of non-toxic metallization like zinc ink, these tags have lower-quality resonators compared to traditional RF tags. Over time, the absorption of humidity by the substrate leads to reduced conductivity, resulting in increased losses and a decrease in operational distance.

The operational system developed at CSEM includes a custom-designed reader and software capable of detecting and classifying chipless RFID tags. It utilizes Principal Component Analysis (PCA) to categorize tags based on their frequency responses. Python-based software supports this process by managing numerical identifiers, such as frequency points and S11 values, which represent the tag's reflection coefficient.



Figure 3: Chipless TAGs (short and long-range) reader developed at CSEM: a portable device for the measured parameter visualization, reader with integrated antenna and short-range chipless tags.

Biodegradable sensors offer minimal environmental impact and a degradation behaviour that can be tuned for applications within zero-waste environmental sensing. Developed tag solutions can be used in smart packaging of perishable goods applications.

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- EPFL
- EMPA

[1] O. Vorobyov, C. Beyer, P. Nussbaum, Chipless Biodegradable Tags, theoretical performance estimation, IEEE UkrMW (2022)