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Characterization of RF resonators made of biodegradable materials for biosensing applications

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Abstract

In this paper we present the characterization by galvanic coupling (direct contact) of radio-frequency (RF) driven RLC resonators made of different biodegradable materials, including biodegradable metals and new biodegradable conducting polymers. An equivalent electrical circuit is proposed based on the RLC resonator geometry and material properties. The Matlab modeling and the finite elements HFSS simulations are in good agreement with the measurements, and allow to extract the loaded and unloaded parameters of the RLC resonators for different materials.

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Keywords: RLC resonator; wireless communication; Radio-frequency RF; Biodegradable metals; biodegradable conductive polymers

1. Introduction

Many emerging medical applications require that the biosensor implanted in the body operates via a wireless link. The active transmitters used in wireless telemetry systems have the disadvantage that they need either an implanted battery, or a complex implanted active circuit that receives the power by inductive telemetry [1]. An alternative solution is to develop biosensors with a communication system based on a passive RLC resonant electrical circuit. The resonant frequency, which varies with the signal measured by the sensor, is read by inductive coupling with an external coil without the need for a complex powering system [2]. Moreover, it would be beneficial to have not only biocompatible, but also fully biodegradable implanted systems. The idea is to avoid a second surgical operation to remove the sensor after its period of use, thereby improving considerably the patient's comfort and safety. The ultimate goal of this research is to make a fully biodegradable sensor for *in-vivo* sensing (Fig. 1). The first step toward this objective consists of design, simulation, fabrication, and characterization of RF driven RLC resonators made of biodegradable metals and biodegradable conductive polymers. The objective of the

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research presented in this paper is to determine if these materials are suitable to fabricate biodegradable resonators for passive wireless communication between the biosensor and the transceiver outside the body.



Fig. 1. All-biodegradable biosensor based on an RLC resonator. Detection of the signal by inductive coupling with an external coil (adapted from [2]).

2. Materials and methods

2.1. Fabrication of the RLC resonators

The resonators characterized in the present study are made of 5 different materials as shown in Fig. 2: a) PLLA-PPy and PCL-PPy (conducting biodegradable polymers), b) copper (as a reference), and c) magnesium and iron (known as biodegradable metals) [3, 4]. *Resonators made of biodegradable conductive polymers:* Two newly developed polymer composites are produced by chemical polymerization [2]; they consist of conductive polymer nanoparticles (polypyrrole PPy, 40 % of the total weight) embedded in a biodegradable polymer matrix (either polylactide PLLA or polycaprolactone PCL). After polymerization, a compression molding step is performed using a laboratory hydraulic press, and 4 mm thick polymer plates are fabricated. The resonators are then laser-cut to obtain the desired shape. *Resonators made of biodegradable metals:* The metal resonators are fabricated by electric discharge machining (EDM) of 3 mm (Mg, Fe) and 4 mm (Cu) thick plates. The capacitor gap sizes are 0.7 mm (Cu), 0.6 mm (Fe, Mg) and approximately 0.5 mm (PLLA-PPy, PCL-PPy).

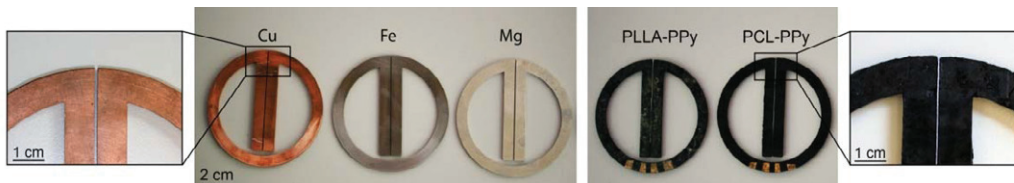


Fig. 2. RLC resonators characterized in the present study: Left, resonators made of biodegradable metal (iron, magnesium) and copper (reference). Right, resonators made of biodegradable conductive polymer composites, PLLA-PPy and PCL-PPy.

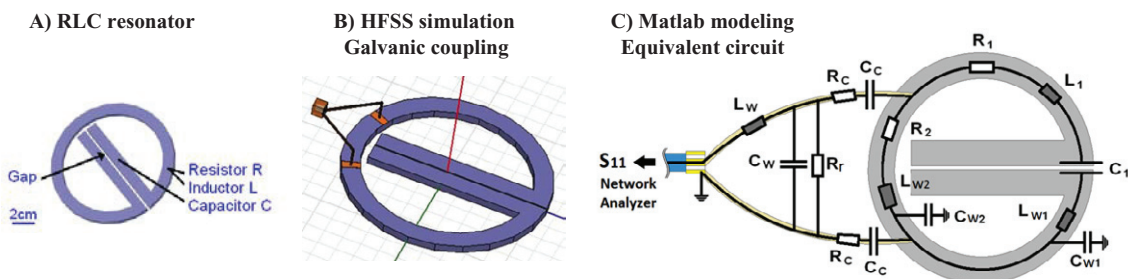


Fig. 3. A) Schematic of RLC resonator. B) HFSS finite elements simulation of the galvanic coupling measurement (direct contact). Gold electrodes are sputtered on the polymer resonators in order to ensure a low resistance ohmic contact between the connecting wires and the resonator [5]. C) Equivalent electrical circuit modeled with Matlab.

2.2. Galvanic coupling measurements, and the corresponding equivalent electrical circuit model and HFSS simulations

The RLC resonators made of different materials are characterized by galvanic coupling as presented in Fig. 3. Two copper wires are welded on a coaxial connector (feed line and ground) which is plugged onto coaxial cable. The S_{11} scattering parameter is measured with a network analyzer after an appropriate calibration procedure including a standard RF calibration followed by a phase-nulling step which compensate for the phase shift introduced by the connecting wires. Fig. 3B shows the HFSS simulation and Fig. 3C gives the equivalent electrical circuit modeled in Matlab. L_w and C_w are the equivalent inductor and capacitor of the connecting wire. R_r is the overall loss due to radiation. R_c and C_c are the coupling resistor and capacitor between the connecting wire and the resonator. L_{w1} , L_{w2} , C_{w1} , C_{w2} are the equivalent transmission line series inductors and shunt capacitors of the two branches of the resonator. L_1 , C_1 , R_1 , R_2 are the inductor, capacitor and resistor of the two branches of the resonator, calculated from the resonators dimensions and the materials conductivity.

3. Results

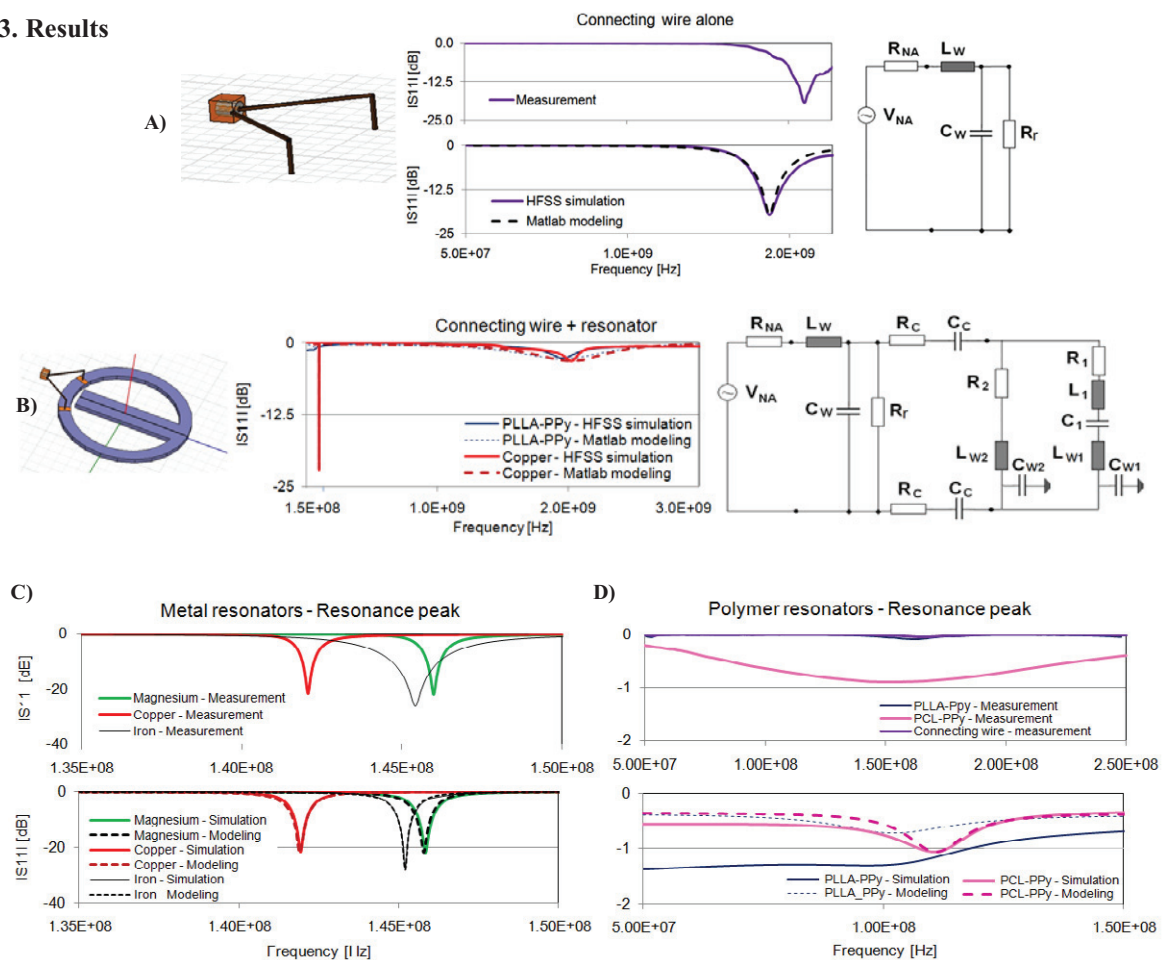


Fig. 4. Comparison between measurements, Matlab modeling and HFSS finite elements simulations: A) Connecting wire alone. B) Connecting wire galvanically coupled to the RLC resonator for different materials. C) Zoom on the signal at the resonance frequency for the metal resonators and D) for the polymer resonators.

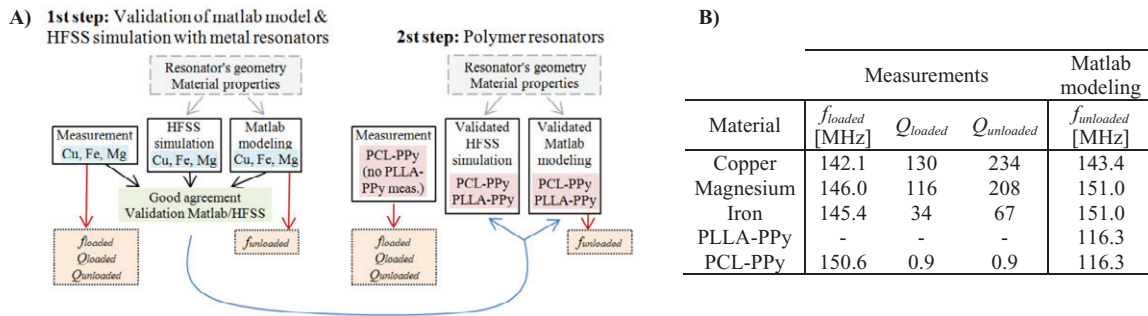


Fig. 5. A) Procedure followed to characterize the RLC resonators by galvanic coupling and extract f_{loaded} , Q_{loaded} , $Q_{unloaded}$ and $f_{unloaded}$. In a first step, the good agreement between the measurements of the metal resonators and the corresponding Matlab model and HFSS simulations allows to validate the Matlab/HFSS results. In a second step, the polymer resonators are characterized using the validated Matlab model and HFSS simulations. B) Loaded and unloaded resonant frequency and Q factor.

As shown in Fig. 4C, a good agreement is observed between the Matlab modeling, the finite element HFSS simulations and the measurements for the metal resonators. It is verified (Fig. 4A and 4B) that the wires resonant frequency located around 2 GHz has no influence on the resonator signal located at 100–150 MHz. Fig. 4C and 4D show the resonance frequency peaks of the metals and polymers resonators. For the metal resonators, very similar results are obtained for the measurements, simulations and modeling. For the polymer resonators, measurements by galvanic coupling are only possible for PCL-PPy. Matlab modeling and HFSS simulation are performed for both PLLA-PPy and PCL-PPy based on the resonators geometry and materials conductivities, but the results for PCL-PPy do not perfectly mimic the measurements (Fig. 4D). A possible explanation is that the contact resistance between the connecting wire and the PCL-PPy resonator is higher than expected or is not ohmic, having a strong impact on the Q factor measured. This particular point will be later investigated with inductive coupling measurements.

4. Conclusion

An equivalent electrical circuit for the characterization by galvanic coupling of RLC resonators made of biodegradable materials is proposed. The matlab modeling and the finite elements HFSS simulations are in good agreement with the measurements, and allow to successfully extract the resonators unloaded Q factor and resonant frequency for different materials. The metals Mg and Fe are the best candidates to fabricate a wireless passive circuit for *in-vivo* application since they combine high conductivity (high Q) and biodegradable features.

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