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Telemetric model for passive resistive sensors in biomedical applications

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Abstract

The present work describes a telemetric resistive sensor to be exploited in biomedical applications, in order to monitor vital parameters in real time. The corresponding telemetry technique is based on an impedance measurement performed at its input terminal and on a theoretical study which identifies a complex mathematical relation between sensor's resistance and impedance phase value at a specific frequency point. A model for this system is proposed, analysed and discussed, while the telemetric technique based on it is described.

Keywords: impedance analysis; model; passive sensor; resistance; telemetric system.

1. Introduction

A sensor implanted inside the human body must respect very strict specifications, among which there are power supply and communication with external modules. Such requirements prevent the use of classical electronic technologies, batteries or cables. A possible and interesting solution regards the exploitation of a telemetric system, which is constituted by two components, i.e. a passive sensor, implanted inside the body and connected to an inductor, and an external readout unit, consisting of a second inductor placed outside the body. The readout module supplies the sensor, which has no active circuits for working autonomously, and reads the measured data, since they are magnetically coupled. The conceptual scheme of such a system is represented in Fig. 1.

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Literature reports some telemetric systems using capacitive sensors, positioned inside a harsh environment (the human body, but also an oven or an engine, where temperature is very high), to perform a measurement. Examples are provided in [1-4], for pressure monitoring, and in [5], regarding a strain sensor. The present paper describes a measuring method, based on a particular way of modeling the telemetric system, which exploits a resistance transduction sensing technique. The following sections will talk about such model and will explain the adopted measurement technique.

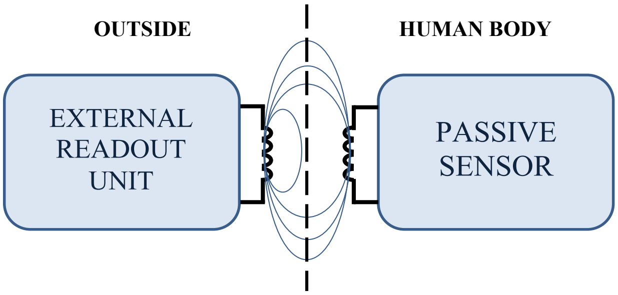

Fig. 1. Conceptual scheme of the presented telemetric system and rough indication of communication via inductive coupling.

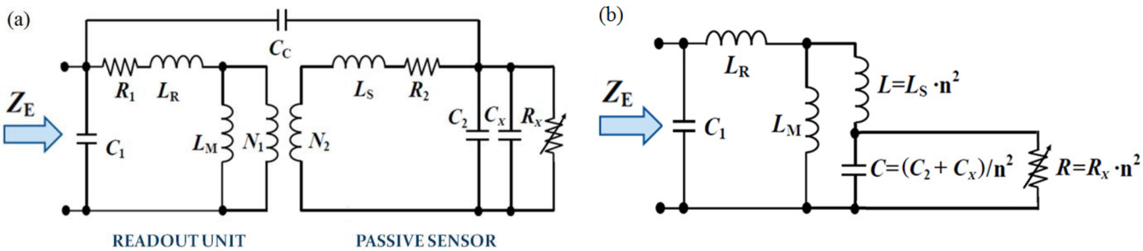

Fig. 2. (a) suitable circuit model for the considered telemetric system; (b) simplified circuit model (secondary components are brought to primary).

Nomenclature

C	C_p brought to primary circuit
C_1	parasitic capacitance of primary inductor
C_2	parasitic capacitance of secondary inductor
C_c	coupling capacitance
C_p	parallel capacitance between C_1 and C_x
C_x	tuning capacitance
f_a	frequency at module antiresonance peak (in Hz)
f_{min}	frequency at phase minimum (in Hz)
f_{ra}	frequency at module first resonance peak (in Hz)
f_{rb}	frequency at module second resonance peak (in Hz)
L	L_S brought to primary circuit
L_1	equivalent inductance of primary inductor
L_2	equivalent inductance of secondary inductor
L_M	coupled flux
L_R	leakage flux in primary inductor
L_S	leakage flux in secondary inductor
N_1	equivalent number of the windings of primary inductor
N_2	equivalent number of the windings of secondary inductor

n	windings ratio (between N_1 and N_2)
R	R_x brought to primary circuit
R_1	parasitic resistance of primary inductor
R_2	parasitic resistance of secondary inductor
R_x	sensor's variable resistance
Z_E	impedance at readout terminals
α	parameter to be estimated
φ	phase minimum
ω_{min}	frequency at phase minimum (in rad/s)

2. Modeling

The considered telemetric system can be properly represented through the circuit shown in Fig. 2a, taking into account inductors' parasitic components (i.e. resistances R_1 and R_2 and capacitances C_1, C_2 and C_c) and leakage and coupled fluxes. Sensor's resistance changes according to the variation of the magnitude which has to be measured, while tuning capacitance is a fixed capacitor, which affects system's performances and therefore has to be set with great accuracy. This model is simplified by neglecting parasitic resistances (since working frequencies are in the order of MHz, their impedance is much lower than the one corresponding to inductances L_R and L_S) and coupling capacitance (by designing the inductors in a proper way), leading to the circuit shown in Fig. 2b (where secondary components have been brought to primary).

Impedance at readout terminals has been studied. It can be expressed in an analytical way by the following transfer function (its parameters refer to Fig. 2b):

$$Z_E(s)=\frac{C(L_M L_R+L(L_M+L_R))Rs^3+(L_M L_R+L(L_M+L_R))s^2+(L_M+L_R)Rs}{C_1C(L_M L_R+L(L_M+L_R))Rs^4+C_1(L_M L_R+L(L_M+L_R))s^3+(C(L_M+L)+C_1(L_M+L_R))Rs^2+(L_M+L)s+R} \quad (1)$$

whereas its module and phase can be represented in graphs as functions of frequency. An example of these curves is shown in Fig. 3, where the frequencies corresponding to module resonance peaks and phase minimum have been highlighted. If tuning capacitance C_x is chosen to be much greater than C_1, the last one can be neglected, leading to a further simplification of the circuit model and the transfer function. Such assumption has been confirmed by simulations executed using Matlab software.

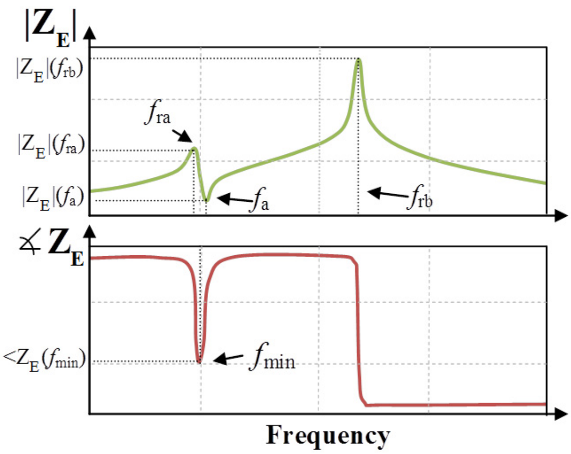

Fig. 3. Impedance module and phase at readout terminals (peak frequencies are indicated with an arrow).

3. Measurement technique

The previous hypothesis permits to obtain the analytical expression of sensor's variable resistance, starting from equation (1). It depends on impedance phase at f_{min} and on the value of the same frequency, and has been reported below:

$$R = \frac{(L_1 L_2 n^2 - \alpha)tg(\varphi)\omega_{\min} - \sqrt{\Delta}}{2\left(L_1 - C_p\left(\frac{\alpha}{n^2} + L_1 L_2\right)\omega_{\min}^2 + \frac{\alpha}{n^2} C_p^2 L_2 \omega_{\min}^4\right)} \tag{2}$$

where:

$$\Delta = (\alpha^2 - 2L_1 L_2 \alpha n^2 + L_1^2 L_2^2 n^4)tg^2(\varphi)\omega_{\min}^2 - 4L_1 L_2 \alpha n^2 \omega_{\min}^2 + 4C_p L_2(\alpha^2 + L_1 L_2 \alpha n^2)\omega_{\min}^4 - 4C_p^2 L_2^2 \alpha^2 \omega_{\min}^6 \tag{3}$$

$$L_1 = L_M + L_R \qquad L_2 = L_S + L_M / n^2 \qquad C_p = C \cdot n^2 = C_2 + C_x \qquad \alpha = L_M L_R + L(L_M + L_R) \tag{4, 5, 6, 7}$$

Referring to equations (4), (5) and (6), respectively, inductances L_1, L_2 and capacitance C_p can be measured, for example using an impedance analyzer, and n can be obtained through simulation. Also parameter α depends on leakage and coupling fluxes and remains constant if distance is fixed. In this way, variable resistance R can be estimated by measuring impedance phase at f_{min} and the value of such frequency.

An experimental system was developed in order to implement the proposed solution. Two planar inductors, one for sensing circuit and one for readout, have been fabricated through PCB technology (Fig. 4). Impedance at readout terminals for different discrete resistances was measured through HP4194A analyzer, obtaining curves similar to the ones in Fig. 3. In particular, phase minimum and relative frequency, whose trends are represented in Fig. 5 as functions of resistance, have been detected. Further experimental tests for optimizing parameter α and for validating resistance expression are currently being performed.

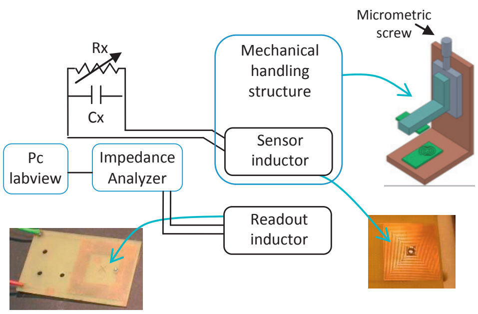

Fig. 4. Block diagram of the utilized experimental setup.

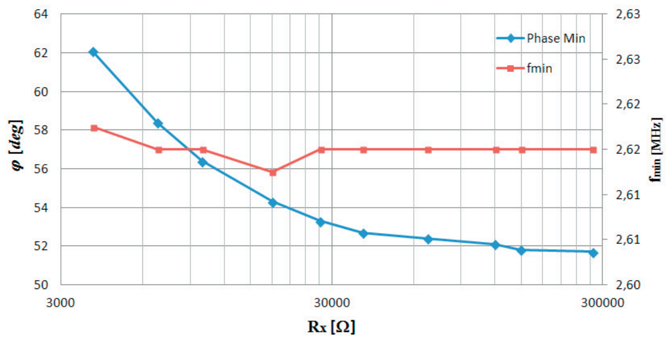

Fig. 5. Phase minimum and corresponding frequency as functions of resistance.

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