Flexible epidermal device for the RFID-based potentiometric sensing of skin parameters

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***Abstract*—Non-invasive monitoring of biological parameters can benefit from Radiofrequency Identification (RFID) devices attached over the skin. In this paper, a new lightweight, compact, and fully passive epidermal electronic device is proposed, capable of measuring surface pH. By integrating a self-tuning IC and a varactor diode as transducer, the mapping from the chemical agent to the output of the IC itself is achieved. To fully control the sensitivity, a closed-form formulation of the sensing mechanism is derived. The device is applicable over multiple body areas and readable up to 70 cm, with an average realized gain of -12 dB at 868 MHz.**

***Keywords*—RFID, flexible antennas, self-tuning ICs, chemical potentiometric sensing, pH.**

I. Introduction

Epidermal and wearable devices are revolutionizing body health monitoring in a fast, convenient and inexpensive way. Among the several biological parameters which are useful in diagnosing pathological conditions, such as chronic superficial wounds, the pH is well known to highlight infections and critical alteration in body exudates [1].

By means of Radio Frequency Identification (RFID) technology, epidermal devices can be low-cost and disposable. In particular, the recent family of self-tuning ICs, capable of automatically adjusting their internal RF admittance to make the IC-antenna matching rather insensitive to the change in the local boundary conditions [2], can be used to exploit chemical sensing by interfacing flexible electrodes. Self-tuning ICs have already been investigated for physical sensing [3], [4], or for limiting current systems in smart-home scenarios [5].

This paper proposes a flexible epidermal device capable of monitoring the body's surface pH through a potentiometric sensor [6] and the self-tuning transponder itself. By exploiting the IC's technology in combination with a varactor diode, a general framework for the controlled sensing of a chemical agent can be achieved. The varactor acts as a transducer converting the potentiometric output of a chemical sensor into a capacitance change that produces in turn a mismatch between the antenna and the IC. The antenna is shaped to maximize the device sensitivity.

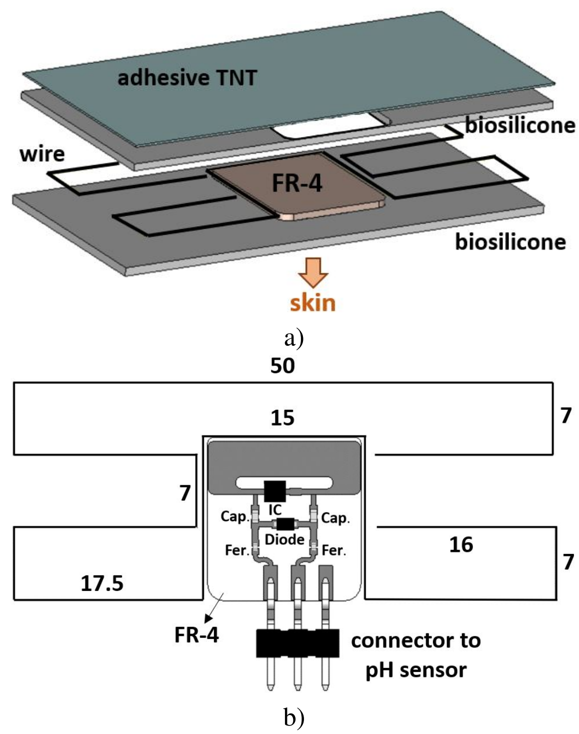

Fig. 1. a) Exploded view of the device and b) internal layout [size in mm] .

This paper is organized as follows: Section II introduces the epidermal device while the sensing method is explained in Section III. Finally, some preliminary experimental results are given and commented in Section IV.

II. The epidermal device

The considered antenna layout and other interconnections are sketched in Fig.1. The device (size 50×21 mm) consists

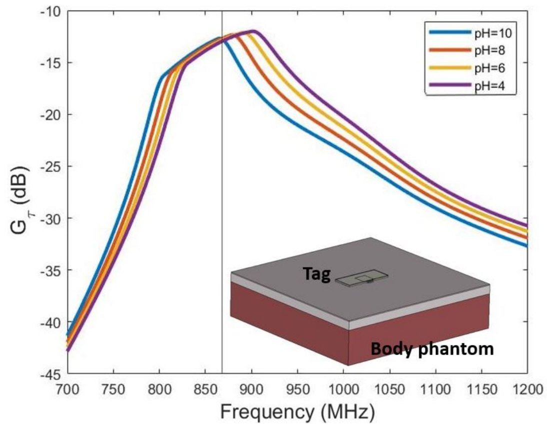

Fig. 2. Simulated realized gain of the epidermal sensor, placed onto a skin phantom, evaluated for four different values of pH.

of a meander-line copper dipole, deposited over a plaster-like adhesive substrate (thickness 0.22 mm) that is coupled to the IC through a loop transformer (over a 14.2×15.1 mm FR-4 substrate, thickness 0.8 mm), in turn connected to a varactor diode. To increase biocompatibility, the copper traces are incapsulated within a medical-grade silicone layer (overall thickness 2 mm). The resulting device is light, compact, and flexible, and can therefore be applied to multiple body areas for monitoring surface pH. Two couplets of capacitors ($C_D = 18\,pF$) and ferrite beads provide a proper RF/DC decoupling to avoid that the RF signal coming from the reader may be captured by the lines of the diode and that the DC voltage emitted by the sensor may enter into the RF port of the IC, thus producing artifacts.

The considered IC is the Axzon Magnus-S3 [7], with nominal power sensitivity $p_{IC} = -16.6\,dBm$. The varactor diode is the SMV1405 by Skyworks Solution Inc. [8].

III. Sensing mechanism

The sensing mechanism of the device considers a varactor diode as the transducer of the system with pH as input and the digital output of the microchip as output. The latter is called *sensor code* (s), and it's an integer number returned by the IC after an RFID query. It varies within the sub-range $S_{min} < s < S_{max}$, being S_{min} and S_{max} dependent on the implementation of the IC. By considering a parallel schematic with the sensor, diode, and antenna with the IC onboard, the potentiometric sensor generates a voltage in response to a given value ψ of the chemical agent to monitor, namely $V_S(\psi)$. Such a sensor is connected to the varactor so that its equivalent ideal susceptance $B_V(\psi)$ will be controlled by the sensor. The total susceptance B_T seen by the IC toward the remaining part of the network is:

$$B_T(\psi) = B_A + B_V(\psi) \tag{1}$$

where B_A is the tag antenna susceptance. The auto-tuning action of the IC is such that $B_T(\psi) \to 0$. Accordingly, the sensor code returned by the IC will be:

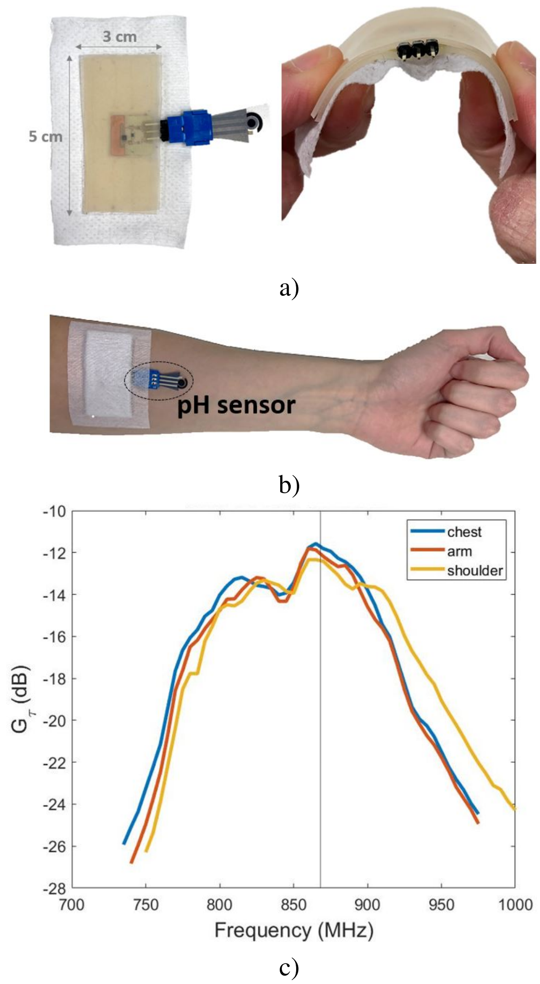

Fig. 3. a) The assembled prototype; b) placement on a forearm with the connection of the pH sensor; b) realized gain for each body site.

$$s(\psi) = nint(-\frac{1}{C_0}(C_{IC}(S_{min}) + \frac{B_A}{\omega} + \frac{C_{j0}}{\left(1+\frac{V(\psi)}{V_J}\right)^M})) \tag{2}$$

where the operator "*nint*" approximates its argument to the nearest integer number, $\{C_0, C_{min}\}$ are specific parameters of the IC and $\{C_{j0},\ M,\ V_J\}$ are the capacitance of the un-polarized diode, a constant dependent on the material, and the barrier potential [9], respectively. The relation that governs the entire transduction process is thus obtained and will be useful to master the $\psi - s$ mapping.

The performance of the device is estimated with the help of numerical simulations, by considering a human body phantom in Dassault's CST Microwave Studio (Fig.2). The realized gain is just slightly affected by the variation of the pH and in any case, it's always higher than -15 dB in the UHF band which is a typical value of epidermal antennas [10], [11], [12].

IV. Experimentations

A prototype of the device is shown in Fig.3 a), and an experimental evaluation is carried out by means of a lin-

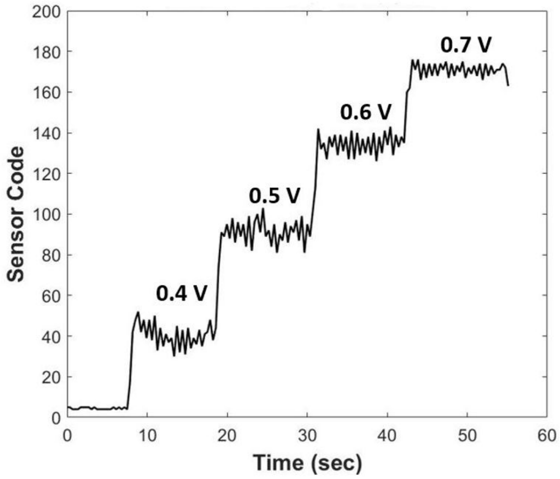

Fig. 4. Sensor code versus voltage applied across the varactor diode of the epidermal device .

early polarized interrogating antenna, and an electromagnetic characterization is performed using the Voyantic Tagformance station in the 700-1000 MHz frequency band.

The device is readable up to a distance of 70 cm. To quantify the robustness with respect to the monitoring site, the tag was characterized on three different body areas of a single user, i.e. chest, arm, and just below the shoulder, and the results are shown in Fig.3 b). In particular, the average realized gain of -12 dB at the working frequency is in good agreement with numerical simulations.

Finally, the sensing response of the device was evaluated by using a voltage power supply to emulate the output of the pH sensor. Fig.4 shows that the epidermal device can distinguish different voltages and promisingly different pH values on the human skin.

V. Conclusions

In this paper, a fully passive, flexible, and compact epidermal device for surface pH measurement has been proposed and preliminarily tested. The biochemical parameter is transmitted to the remote reader in terms of sensor code, through a well-controlled transduction process described by closed-form equations.

Up to this point, the pH sensor has only been emulated, so further experiments could corroborate the preliminary results. Even so, the electromagnetic performance is in good agreement with numerical simulations as a confirmation of the proposed sensing mechanism.

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