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Position-independent chemical quantitation with passive 13.56-MHz radio frequency identification (RFID) sensors

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Abstract

Recently, we have demonstrated an attractive approach to adapt conventional radio frequency identification (RFID) tags for multianalyte chemical sensing. These RFID sensors could be very attractive as ubiquitous distributed remote sensor networks. However, critical to the wide acceptance of the demonstrated RFID sensors is the analyte-quantitation ability of these sensors in presence of possible repositioning errors between the RFID sensor and its pickup coil. In this study, we evaluate the capability for such position-independent analyte quantification using multivariate analysis tools. By measuring simultaneously several parameters of the complex impedance from such an RFID sensor and applying multivariate statistical analysis methods, we were able to compensate for the repositioning effects such as baseline signal offset and magnitude of sensor response to an analyte.

Keywords: Radio frequency identification (RFID) tag; RFID sensor; Ubiquitous distributed sensor network; Chemical sensing; Complex impedance; Multivariate statistical analysis

1. Introduction

Proximity sensors operating on the principles of inductive coupling have been under development since the 1950s when “endo-radiosonde” sensors of 2–6 mm in diameter were reported [1] that consisted of a passive LC resonant circuit, the resonant frequency of which was predictably affected by an ambient environment and was measured with an external pickup coil. More recently, a variety of other similar passive LC resonant circuit-based sensors have been demonstrated [2–5].

Radio frequency identification (RFID) tags are widely employed for automatic identification of animals, tagging of garments, labels, and combinatorial chemistry reaction products, and detection of unauthorized opening of containers [6–8]. For these and many other applications, the attractiveness of conventional passive RFID tags come from their low cost of being less than $1 [9,10]. For sensing applications such as temperature, pressure, and some others, RFID tags required a specific redesign of portions of their electronic circuitry [11,12]. Furthermore, those RFID sensors also required a battery [6], that eliminated their attractiveness as passive sensors.

Recently, we have demonstrated an approach for multianalyte chemical identification and quantitation using a single conventional passive RFID tag [13–15]. These RFID sensors are very attractive as ubiquitous distributed remote sensor networks. Unlike other approaches of using RFID sensors, where a special tag should be designed at a much higher cost, we utilized a conventional RFID tag and coated it with chemically sensitive films to form a chemical sensor (see Fig. 1). Upon a careful selection of the sensing film and measurement conditions, we were able to achieve part-per-billion vapor detection limits in air. In such RFID chemical sensor, both the digital tag ID and the complex impedance of the resonant circuit of the RFID antenna are measured. The measured digital ID provides information about the sensor and the object onto which the sensor is attached, while measured complex impedance provides multivariate response for chemical determinations.

However, critical to the wide acceptance of the demonstrated RFID sensors is the analyte-quantitation ability of these sensors in presence of possible repositioning errors between the RFID sensor and its pickup coil. In this study, we evaluate the capability for such position-independent analyte quantification using

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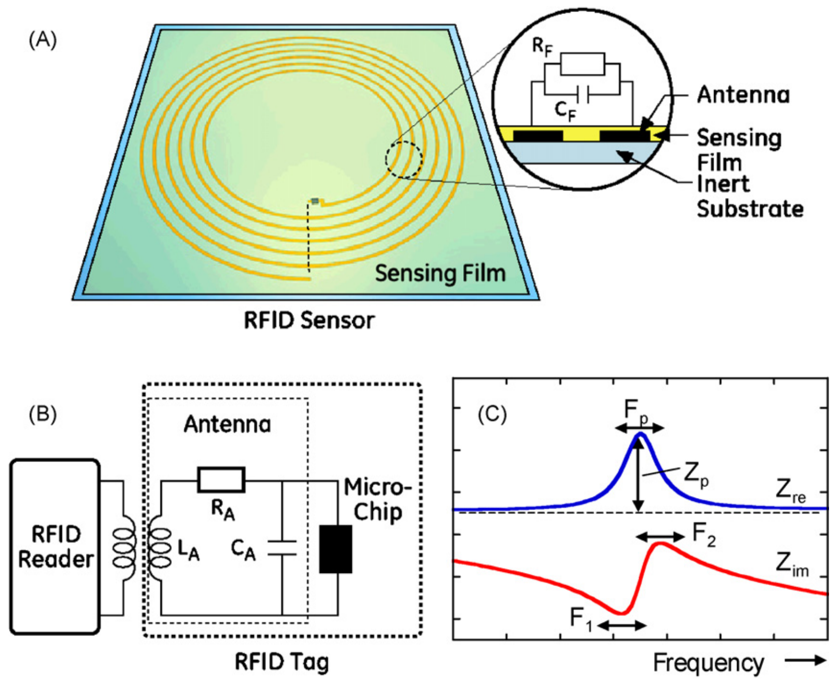

Fig. 1. Strategy for the application of conventional passive RFID tags for chemical sensing. (A) Adaptation of a conventional RFID tag for chemical sensing by deposition of a sensing film onto the resonant circuit of the RFID antenna. Inset, analyte-induced changes in the film material affect film resistance (R_F) and capacitance (C_F) between the antenna turns, (B) schematic of digital ID reading from the RFID tag and the equivalent circuit of the antenna of the RFID tag, and (C) measured parameters from a single RFID sensor for multiparameter chemical detection and quantitation. Arrows indicate changes of respective measured parameters.

multivariate analysis tools. By measuring simultaneously several parameters of the complex impedance from such an RFID sensor and applying multivariate statistical analysis methods, we were able to compensate for the repositioning effects.

2. Experimental

2.1. RFID sensor

To perform analyte-quantitation measurements, an RFID sensor was made by applying a chemically sensing polymeric film onto a 13.56-MHz RFID tag (Texas Instruments, model RI-I03-112A-03, antenna size 22.5 mm × 38 mm). The sensing film was a composite poly(vinyl acetate)/carbon black polymer film responsive to relative humidity in air. To form an RFID sensor, the film was applied onto the RFID tag by a draw-coating process [16]. For each position of the sensor, two replicate exposures to humid air were performed. Humid air was generated by bubbling dry air through water at room temperature. Thus, during each step, the sensor environment was switched twice from dry air to 45% relative humidity (RH) air as measured with a reference humidity meter.

2.2. Test setup

For evaluations of repositioning effects, we assembled a test system as shown in Fig. 2. It contained an RFID sensor positioned in a low dead volume gas flow cell. A pickup coil was made from several turns of a copper wire with a form factor matching the RFID sensor and was positioned outside the flow cell on a *X*–*Z* translation stage. The relative position of the RFID sensor and the pickup coil was changed in a controlled fashion. Fig. 3 illustrates the different tested positions of the RFID sensor in the *X*- and *Z*-direction with respect to the pickup antenna coil. The studied repositioning conditions-included 5-mm step changes in *Z*-direction (0, 5, 10, 15, 20 mm and back to 0 mm) and 5-mm step changes in *X*-direction (0, 5, 10, 15, 20, 15, 10, 5, 0 mm).

Digital ID readings from the memory micro-chip of the RFID tag were performed with an RFID reader (Model M-1, SkyeTek, Westminster, CO) operated under a computer control using LabVIEW. RFID sensor measurements were performed with a network analyzer (Model 8751A, Hewlett Packard, Palo Alto, CA) under a computer control using LabVIEW. The network analyzer was used to scan the frequencies over the range of interest and to collect the complex impedance response from

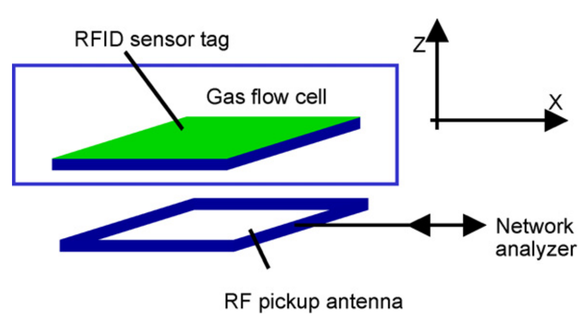

Fig. 2. Schematic of a test system for the evaluation of the analyte-quantitation ability of RFID sensors in presence of repositioning errors between the RFID sensor and a pickup coil.