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Novel technique for the wireless reading of passive microfluidic sensors.

D. Henry, H. Aubert, P. Pons, J. Lorenzo, A. Lázaro and D. Girbau

Introduction: Nowadays the wireless reading of passive sensors is still a very challenging issue to overcome. In order to render such sensors competitive compared to the active sensors, two main technical improvements must be performed: (1) increasing the reading range to reach significantly more than few meters and, (2) achieving higher measurement resolution. As a matter of fact the typical interrogation reach significantly more than few meters and, (2) achieving higher competitive compared to the active sensors, two main technical very challenging issue to overcome. In order to render such sensors qualification for batteryless RFID tags is around 12 meters [1, 2].

Moreover passive sensors using an electromagnetic transduction (see, e.g., [3-5]) allow higher reading range (up to some decameters [6]) but suffer from poor measurement resolution of the physical or chemical quantity of interest compared to their active counterpart.

In this Letter we report for the first time a wireless reading technique for improving the measurement resolution of wireless, batteryless and chipless sensors. The technique is applied here for the remote interrogation of the passive microfluidic temperature sensors reported in [7]. This novel technique consists of performing the mechanical scanning of the monostatic FM-CW radar antenna main lobe in order to locate the sensor in the 3D illuminated scene and to compute an estimator for remotely deriving the temperature at the sensor location. Unlike previously reported approaches (see, e.g., [6]) this estimator is not only computed from the beat frequency spectrum obtained in the sensor direction but, from the appropriate combination of numerous spectra measured in many directions around the sensor direction.

After a very brief reminder of the microfluidic sensor design reported in [7] the Letter describes the proposed radar beam scanning technique for the sensor detection and wireless reading. The last section focuses on the remote estimation of the meniscus position of the fluid (water) inside the sensors microchannel by the original combination of multiple beat frequency spectra. The temperature resolution of the microfluidic sensor is finally estimated.

Principle of the Wireless Reading of Passive Sensors: Recently some of us have reported the design of a passive sensor using a fluidic microchannel within a gap of an impedance matched microstrip transmission line [7]. Due to the dilatation coefficient of the liquid (water), the meniscus position of the fluid inside the microchannel is modified as the temperature changes at the gap location. The temperature-dependent gap capacitance is designed on a 523µm B33 glass wafer metalized both sides with 0.5µm aluminium. A top view of the microchannel is shown on Fig. 1. The fluidic microchannel is located in the gap of the microstrip transmission line of length of 1.4cm which propagates only the fundamental mode at 24GHz. This line is impedance matched (50Ω) at one port and is connected to a horn antenna via a delay line (effective length of 1.8m) at its other port. A pressure monitoring system controls the meniscus position of the water inside the sensor microchannel.

Measurement results and discussion: Fig. 2 shows the obtained 3D radar image resulting from the FM-CW radar beam scanning technique when the microchannel is empty and when the water completely fills the gap. (Fig. 2 does not include the electromagnetic echo from the sensor antenna). This image, obtained from the pointing of the Tx-antenna main lobe in 441 directions, is composed of 33624 voxels of 11.4 cm³. It can be conveniently analysed by computing the so-called isosurfaces [8], that is, sets of superimposed 3D contours sharing the same echo level. When the microchannel is empty, the number of voxels for which the echo level is higher than a given threshold (here of -20dB) is found to be larger than the number of voxels obtained when the water completely fills the gap. This was expected because the fluidic microchannel in the gap behaves mainly as a series capacitance: when the gap is completely filled with water the measured series capacitance is of 150pF and is higher than the series capacitance (100F) of the empty microchannel. More microwave power is then transmitted through the gap and more power is dissipated in the 50Ω loading impedance. As a consequence less power is available for the sensor electromagnetic backscattering. This is the reason why the number of voxels when the gap is empty is larger than the number of voxels obtained when the water completely fills the gap. Note that the threshold value (-20dB) was chosen here to facilitate the analysis of 3D radar images obtained for various meniscus positions. The number of voxels for which the echo level is higher than the threshold is a function of the quantity of fluid inside the microchannel or, in other words, is dependent on the position of the fluid meniscus in the microchannel.
From this number of voxels a convenient parameter or estimator is now defined for deriving the fluid meniscus position from the radar measurement data.

\[
\Delta T = \frac{S_c}{V_{tank}} \Delta L
\]  

(1)

where \(\alpha\) designates the dilatation coefficient of the water, \(V_{tank} (= 3\text{mm})\) denotes a cylindrical tank volume and \(S_c (=0.015\mu\text{m})\) is the cross-section area of the microfluidic channel. The dilatation coefficient \(\alpha\) of water ranges from 247ppm/°C to 385ppm/°C between 24.0°C and 40.0°C but, for the sake of simplification, this variation is not considered here and the dilatation coefficient \(\alpha\) is taken at the initial ambient temperature of 24°C. Consequently, from (1) one derives \(\Delta T=0.8°C\). The microchannel is completely filled at a temperature of 37.6°C. The full-scale temperature range is then of 13.6°C and the temperature measurement resolution is of 6% of the full-scale measurement range. This is a significant improvement compared with our previous work [7] in which the temperature resolution was of 14% of full-scale range.

**Conclusion:** The radar beam scanning technique applied to the remote detection and reading of passive microfluidic sensor allows the estimation of the temperature at the sensors location with a temperature measurement resolution of 6% of the full-scale range. The sensor is remotely interrogated from a 24GHz Frequency-Modulated Continuous-Wave radar. By defining an appropriate estimator, a linear model for deriving the variation of the meniscus position of the fluid in the microchannel is reported, with a sensitivity of -6dB per mm. The smallest measurable variation of the meniscus position is found to be of 40µm. Preliminary measurement results (not yet published) indicate that the proposed radar beam scanning technique allows reading passive sensors up to 60 meters. Next step consists of exploring the practical and theoretical limitations of the proposed radar beam scanning approach in terms of measurement resolution, precision and reading range.

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