New developments for wireless temperature SAW sensors for immersed and biological applications

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Abstract : In this paper, the possibility to measure temperature using a passive wireless SAW device is regarded as a solution for immersed and biological applications. The RF set-up implemented in that matter is described and results are compare to those provided by classical temperature sensors. The problem of the size reduction of RF antenna is discussed for autonomous applications.

I. Introduction

The use of passive surface acoustic wave (SAW) devices for the development and implementation of wireless sensor systems has received an increasing interest during these last ten years [1,2]. Such devices have been designed to measure different physical parameters such as temperature, pressure or even torque for many applications mainly concerning the automotive industries. A lot of work has been devoted to improve the passive SAW devices used in that matter, with a particular attention devoted to coding capabilities and loss reduction. The efficiency of such an approach has been demonstrated for different working frequencies, most of the applications using the officially allowed frequency ranges corresponding to carrier close to 434 or 866 MHz.

In this work, the possibility to measure temperature (or more generally any physical greatness) using a wireless passive sensor based on a SAW resonator immersed in water or within an organic body is investigated. A first device was implemented, simply consisting in a single port resonator built on (YZ) LiNbO3 cut to take advantage of the large linear thermal dependence of the SAW frequency (≈ -100 ppm/K). It was then hermetically packaged to allow operations in current water (or assimilated bodies). The operating frequency is about 433 MHz. The sensor is immersed and then interrogated using a simple radiofrequency (RF) connection system. It is shown that the sensor provides an estimation of the bath temperature for interrogation distances corresponding to 10 cm of water plus a few cm in air with excitation power of 10 mW max. The very small dimensions of the SAW devices is compatible with many kind of immersed applications provided the length and shape of the RF antennas can be optimised. The availability of such antennas is reported and the problem related to their implementation is evoked. Also the possibility to enhance the interrogation distance has been investigated. This has been achieved by using (ST,X) quartz instead of lithium niobate to favour the quality factor of the resonator which is the most important parameter in the interrogation mode we have developed. As a conclusion, perspectives of implementing remote quartz sensors for biomedical applications are evoked.

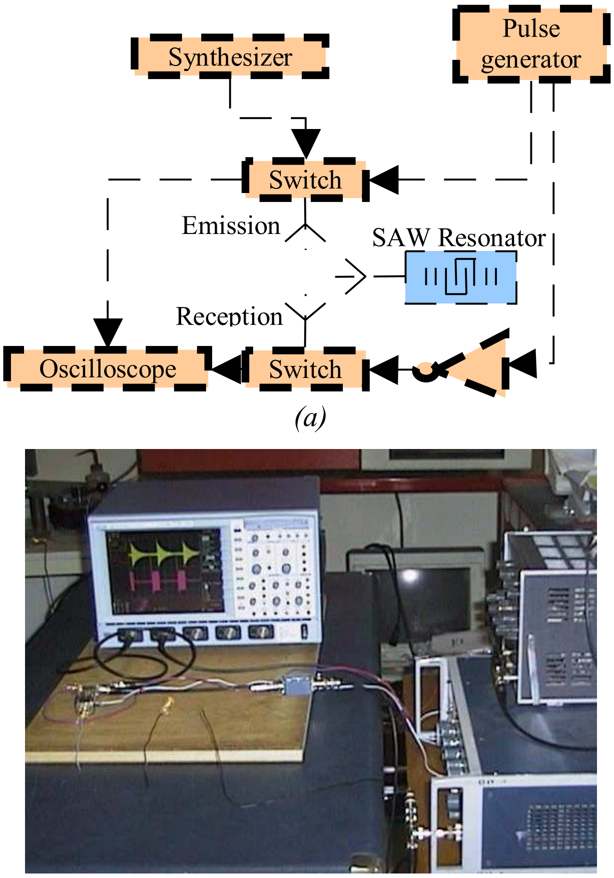
II. RF experimental set-up and device

II.1 SAW resonator

In this work, the SAW device used for temperature sensing consists in a single port synchronous resonator composed of 150 finger pairs for the transducer and 200 electrodes for each Bragg mirror. This yields a $3.5\times1.5\times.35$ mm^3 device well-suited for the considered applications. The devices have been tested using a Suss Microtec PM-5 RF pointing out QF products in the vicinity of 2×10^{12}. This poor value can be explained by the influence of the serial resistance when probing the device, found equal to 1Ω by comparison with theoretical analysis. This serial resistance significantly degrade the operation of our device, reducing the coupling efficiency but also the quality coefficient Q. This is of primarily importance for resonant device and this aspect is almost never evoked in the literature. Also the spectral purity of the resonator was not as expected and predicted. Nevertheless, such devices have been initially used in our system to benefit from the very high sensitivity of Rayleigh waves on LN YZ to temperature (-95 ppm/K experimentally verified). The SAW package has been specifically developed to optimise the RF working of the system. A circular metallic case has been manufacture in brass to ensure a good RF isolation. Two copper wires have been used as antennas with adjusted length to provide the largest response in air. The reference antenna is welded to the brass case, the active one being isolated form it. The device is glued to the package using an epoxy resist.

II.2 RF interrogation set-up

Different approaches have been investigated to implement the interrogation system able to detect the SAW sensor response according to the official requirements and specifications [3]. The adopted principle consists in emitting a sinusoidal signal during a duration allowing the resonator to store enough electromechanical energy to provide the largest response. The interrogation signal is then turned off to collect the SAW sensor response. This was tested using a frequency synthesiser as RF source and a Lecroy Waverunner® oscilloscope to acquire the signal re-emitted by the SAW resonator. Figure 1 shows the experiment and the typical signal provided by the SAW resonator. This first experimental tests have helped to define the best operating conditions of the interrogation process. A more compact set-up has been then developed based on the same principle, but using a frequency scan and a detection network to automatically detect the frequency of the SAW device. The greatness to be measured (here the temperature) is directly deduced from the SAW resonance frequency change.



(a)

(b)

Fig.1 First RF interrogation set-up:
(a) principle
(b) implementation : Interrogation and SAW response signals on the oscilloscope screen

The synoptic scheme of the implemented electronics is reported in fig.2. The set-up is controlled by a low frequency pulse generator which is used to synchronise the operation of the circuit. The pulse generator also controls a counter which is used to operate a VCO enabling one to provide a frequency sweep signal used to interrogate the SAW sensor. The received signal is then amplified and enters a detector providing a maximum voltage when the interrogation frequency corresponds to the SAW resonance. This signal is then trigged, enabling to operate a digital/analogic conversion once the SAW frequency is detected. A voltage proportional to the temperature change is then delivered,.

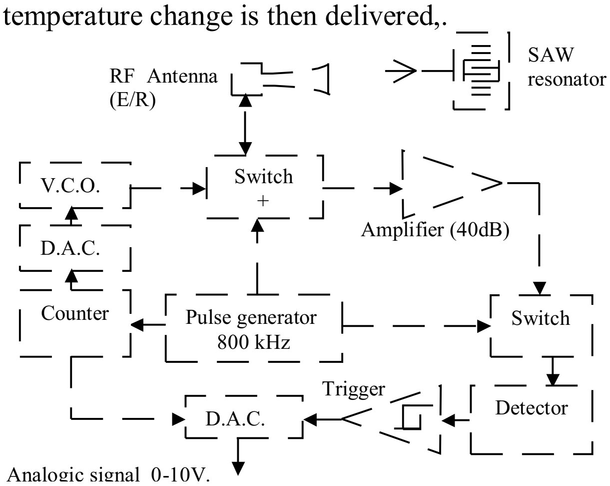


Fig. 2 Synopsis of the RF interrogation electronics

Figure 3 shows the shape of the slope applied to the VCO and the signal at the output of the detector. The width of the peak corresponding to the SAW resonance detection is directly controlled by the Q of the resonator (this curve corresponds to the power density spectrum). In the present case, a rather wide response is obtained due to the sensitivity of the resonator to the serial resistance previously pointed out. The 0.45 ms scan corresponds to a operating bandwidth of 3 MHz in the vicinity of 434 MHz.

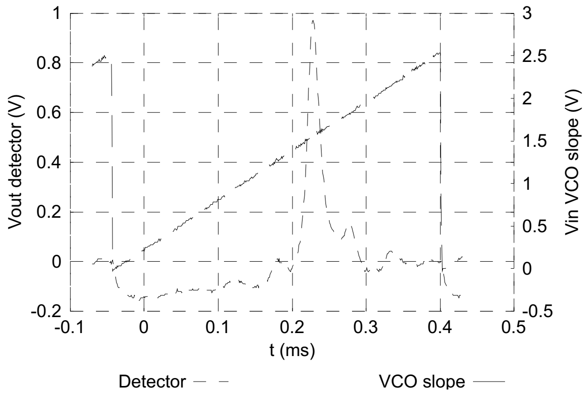


Fig.3 Shape of the signal at the output of the detector and slope applied to the V.C.O.

III. Temperature measurements

The above described system has been used to measure the temperature of a ionic water bath in order to consider the most general and realistic conditions for temperature measurements. The temperature of water is controlled by a heating resistance dived in the bath. The temperature is homogeneous thanks to a circulator. The sensor and its antenna (dipole type) is first placed in a waterproof tube together with a classical platinum temperature probe (PT1000) allowing precise temperature measurements in order to check the accuracy of the SAW temperature sensing. Figure 4 shows a photo of the device outside the tube, with the associated thermo-probe. Figure 5 presents a general view of the experimental bench and fig.6 reports the evolution of the sensor resonance frequency versus temperature. The linearity of the frequency-temperature dependence is clearly demonstrated, yielding a temperature measurement with a resolution of 1K with the presented set-up.

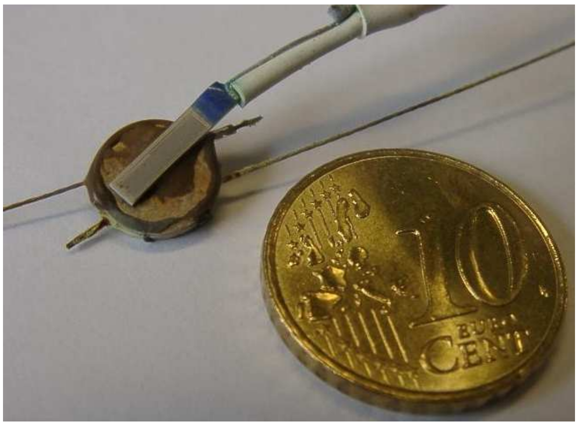


Fig.4 Photo of the SAW device and the thermo-probe

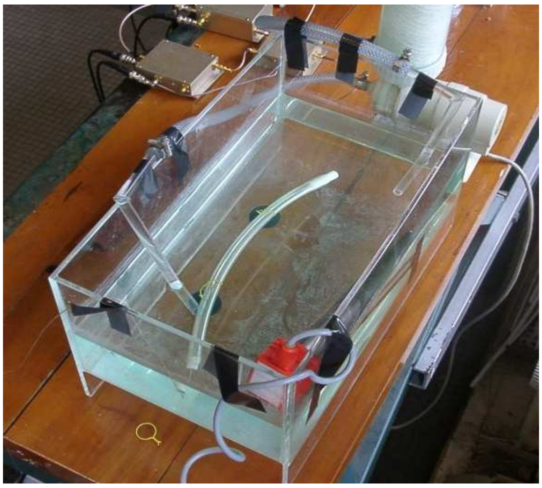


Fig.5 Global view of the experimental set-up

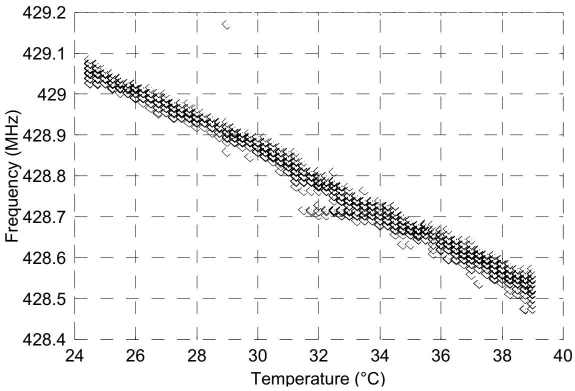


Fig.6 Comparison between temperature measured with the thermocouple and the SAW device

IV. Discussion

The superimposition of both temperature measurements shows that the temperature can be measured using a wireless interrogation system. However, one points out a digitalizing noise on the SAW device temperature measurement. This noise can be suppressed using a more accurate DAC (12 bits instead of 8 bits), a reduce frequency excursion or an averaging process (for instance, summation of 1000 temperature measurements for each sec.). Another way to improve the accuracy of the system consists in using SAW devices with sharper resonance (higher Q factors). Due to the electrical damping of water, the resonance of the $LiNbO_3$ resonator is poorly defined. Concerning the interrogation distance, it was found that the SAW device should not be further than 10 cm (within the bath) from the interrogation system to enable sufficient signal/noise ratio for a reliable temperature measurement. An air gap between the water tank and the antenna does not dramatically degrade the interrogation process provided it does not exceed a few centimetres.

Since the choice of lithium niobate was not optimal for wireless measurements using resonators, we have implemented such resonators on (ST,X) quartz. In that case, loaded Q factor in excess of 11000 can be easily fabricated, yielding a much higher resolution of the measurement system. Even if weakly coupled, the sensor can be interrogated at a distance larger than 30 cm in water plus a few centimetres of air-gap. The returned signal was so strong that a 3 dB attenuator was required to avoid saturation of the measurement system, as shown in fig.7, yielding a reduction of 6 dB for the whole RF interrogation system. One can also note that spurious resonance are obtained which might trouble the electronic detection. However, this signals are small enough to avoid any dramatic failure of the system.

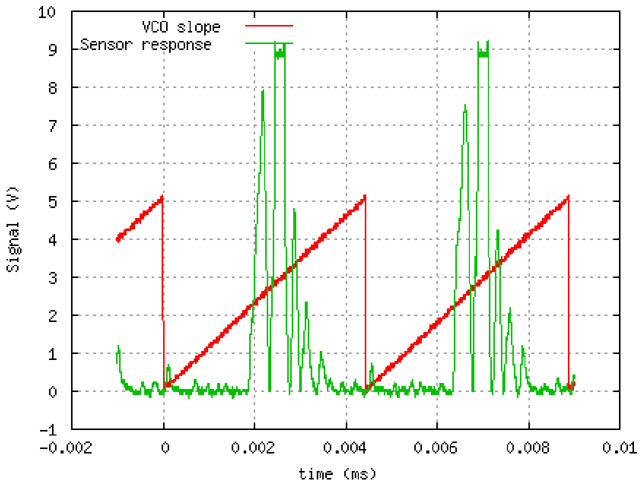


Fig.7 Response of a quartz sensor immersed in water : saturation of the detection system

For in-vivo experiments, the problem of the size of the sensor must be addressed. For the above result, the size of the sensor antenna was fixed to about a quarter of electromagnetic wavelength in water, i.e. 20 cm. Since this dipole antenna was found so efficient that one had to attenuate the interrogation and response signals, it was expected that the size of the antenna could be reduced by a factor of 2 (λ/8). Figure 8 shows a comparison between the attenuated λ/4 antenna configuration (with the 3 dB attenuator placed before the interrogation antenna) and the λ/8 one without attenuator. It appears that without any dramatic reduction of the interrogation distance, the system actually operates with sufficient signal/noise ratio, allowing for sensitive measurement. The system then requires less room for equivalent working characteristics.

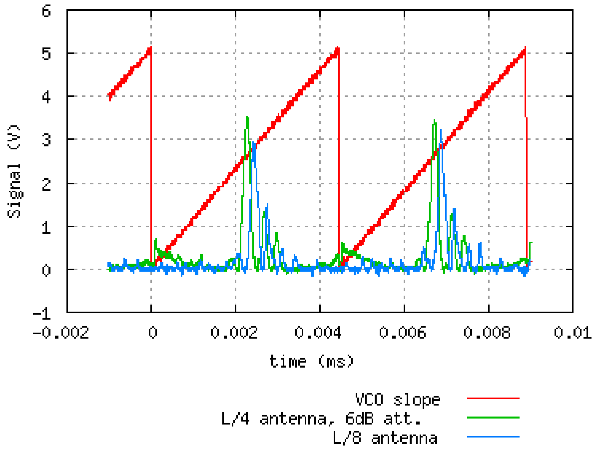


Fig.8 Comparison between (attenuated) λ/4 and λ/8 sensor's antenna configuration

V. Conclusion

A temperature SAW sensor that can be wirelessly interrogated has been developed and used to measure temperature within a ionic water tank. The RF link circuit has been reported and described, and validation measurements have been reported, demonstrating the possibility to measure physical parameters even in moderately conductive media. Significant improvement of the RF interrogation has been achieved by replacing $LiNbO_3$ resonators by (ST,X) quartz ones. Since the later exhibit very small linear temperature dependence, it is not the better solution for temperature measurement but this point can be easily improve by a proper choice of crystal cut. The possibility to operate with reduced antenna size has been also successfully tested. This opens very attractive opportunities for the use of wireless SAW sensors in various domains, such as medical or biochemical applications. Next developments of the presented work will mainly consists in adapting the proposed device for human health purposes.

References :

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