SAW Bioliquids Sensor with RF Interrogation

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Abstract: A system based on shear horizontal surface acoustic wave (SH-SAW) devices operating in the 433MHz and 869MHz industrial, scientific and medical (ISM) bands is proposed for wireless identification and characterisation of bioliquids. The theory of operation is briefly explained and details of the passive microsensors design and fabrication are presented. A small device antenna is analyzed and the interrogation unit implementation is discussed. A new low cost solution for measuring inter-pulse time delays with nanosecond resolution is also proposed.

1. INTRODUCTION

Primarily used in telecommunication industry, surface acoustic wave (SAW) devices have also been employed for sensing purposes. They can be used for measuring physical, chemical and biological parameters. Successful examples of sensors applications such as pressure, temperature, acceleration, humidity, vapour, gas, torque, mass and viscosity have been reported [1-3].

SAW sensors for medical and environmental applications have also been proposed for both gaseous and liquid media [4]. When used in liquid media these devices can have functionalized biochemical coatings [5] or they can be uncoated thus employing a generic fingerprint approach [6-8].

It has been shown in [9] that SAW sensing in liquids can make use of several sensing mechanisms: a mass loading mechanism is appropriate for measuring low level concentrations (ng/ml) and it is a useful tool for studying bio-interactions such protein binding; viscoelastic mechanism is employed in measuring viscosity, density, solidification and association/dissociation kinetics constants; electroacoustic mechanism can provide a way for measuring dielectric permittivity and electric conductivity; thermal mechanism is applicable to calorimetric measurements.

Although the majority of the SAW sensors work in a so-called wired configuration, successful remote operation of several types SAW sensors has been demonstrated [10-12]. Wireless sensors do not require battery operation, being completely passive devices and they benefit from the advantages of the RF communication.

This paper describes the concept of wireless characterisation of liquids with a SH-SAW device. Sensor design details are presented and solutions for implementing a wireless measuring system are proposed.

Envisaged applications for this proposed sensor are mainly in the biomedical area (as urine or blood sensor), but it can also be used in food and beverages industries (i.e. monitoring freshness of food) and environmental monitoring (i.e. water quality control).

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2. WIRELESS SYSTEM DESCRIPTION

The wireless system is composed of an interrogation unit (transceiver) and a passive SAW microsensor. A diagram of the wireless measuring system is given in Fig. 1. Using microfabrication techniques, thin-film interdigital transducers (IDTs) and reflectors are patterned on the $LiTaO_3$ substrate to form a dual reflective delay line configuration: one delay line is electrically shorted (metallised) while the other one is left free.

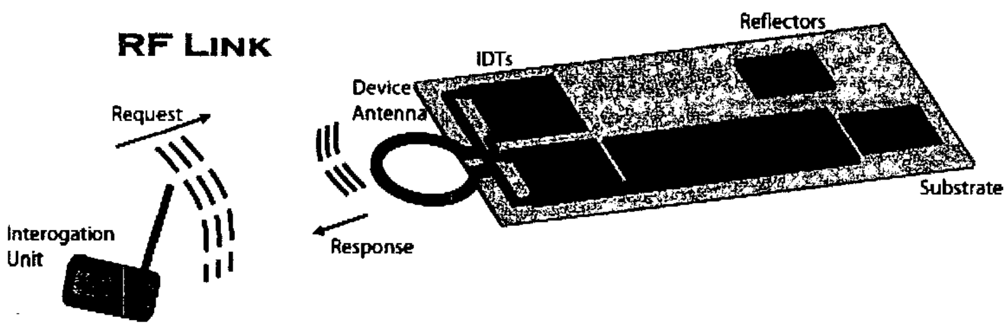


Figure 1: Wireless liquid sensing system

Electromagnetic waves sent by the interrogation unit are picked up by the small antenna connected to the IDTs of the SAW device and converted into acoustic waves that propagate along the piezoelectric surface. Two sets of reflectors bounce back the acoustic waves and the converse mechanical to electrical transduction takes place when the reflected acoustic waves reach back to the IDTs. Then the antenna radiates towards the interrogation unit a signal that incorporates the sensor's response. Further processing is done to extract the properties of liquid under test.

2.1 SAW Sensors

The liquid sensing principle employed in this work is based on a shear horizontal polarised wave mode. The perturbations of the SH-SAW propagating on an electrically shorted surface are mainly associated with the mechanical proprieties of the analyte, while the SH-SAW propagating on a free surface is affected by both mechanical and electrical proprieties of the adjacent liquid. The sensing mechanism of our devices is based on differential measurements taken between the two delay lines. Liquid information is extracted from the relative magnitude and phase data using a procedure described in [8]. Previous results obtained in our group [8], [13-16] proved successful identification and characterisation of various liquids and encouraged a wireless approach.

The SH-SAW microsensors have been designed for 433 MHz and 870 MHz ISM bands operation and were fabricated on top of a 36° Y cut X propagating lithium tantalate substrate (36° YX $LiTaO_3$). The acoustic velocity of $LiTaO_3$ is 4160 ms^{-1}, giving the wavelengths at the above frequencies of 9.6μm and 4.8μm respectively. These parameters were used in the design of the SH-SAW sensor shown in Fig. 2.

Reflective blocks have been designed with 50 fingers or 150 fingers each. Various devices accommodating for open circuit reflectors, short circuit reflectors (Fig 2 – upper right corner) and positive and negative reflectors have been designed and built. To avoid having the reflected pulses overlapping, the free delay line (top in Fig. 2) is 1 or 2 mm shorter than the metallised one (bottom path in Fig. 2).

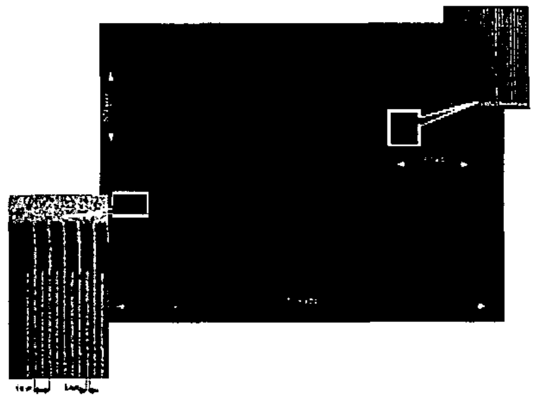
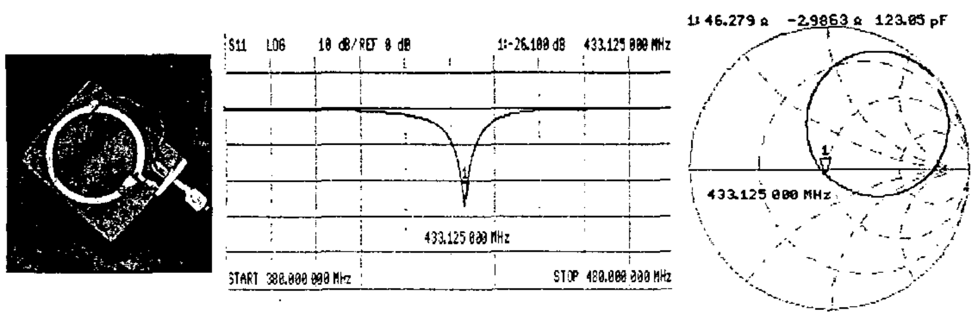


Figure 2: Picture of SH-SAW liquid sensor

The SH-SAW sensors have been fabricated using standard microfabrication techniques. A 130nm thick layer of aluminium was sputtered on top of a cleaned lithium tantalate wafer. A negative resist was spun on top of the Al layer and using a photolithography procedure followed by an aluminium reactive ion etch step, the desired patterns were transferred to the wafer.

2.2 Device Antenna

The SH-SAW sensor described above is a completely passive device. To supply the necessary electrical energy to the IDTs a 'device antenna' needs to be attached to the sensor. It will receive the RF interrogation from the IU and will retransmit the sensor response back to the IU (see Fig. 1).



3.a. Loop antenna picture

3.b. Antenna return loss vs. frequency

3.c. Smith chart: antenna input impedance vs. frequency

Figure 3: Small loop antenna for 433MHz ISM band

A simple small loop antenna was built and considered for our application. Fig 3.a shows a 24mm diameter loop printed on a PCB board and tuned with a surface mount trimmer. Fig 3.b and 3.c show S_{11} network analyser results in a logarithmic magnitude plot and a Smith chart respectively. Impedance matching can be realized by slightly moving the feeding point along the loop. The antenna has a very good return loss figure of 26dB and its input impedance at resonance frequency is closed to the 50Ω characteristic impedance (46.279-j2.986 Ω).

2.3 Interrogation Unit

The interrogation unit (IU) is designed to comply with current UK regulations as specified in the Radio Interface Requirements EN 300 220-1 for Short-Range Devices. The proposed IU (Fig. 4) operates in a similar way to pulsed radar systems.

Short bursts of radiated energy are produced by simply switching on and off a sinusoidal RF oscillator that is mixing the digital baseband modulating signal with an analogue carrier. Out of band radiated energy is controlled by pulse shaping the baseband on-off keyed (OOK) signal prior to modulation by means of a low pass filter. Both the modulation and the separation of the transmission and return paths within the IU are performed by a SPDT GaAs FET switch. The switch provides around 80 dB isolation whilst introducing a 1 dB insertion loss into the signal paths.

After transmission, the IU switches to the receive mode and the IU antenna now captures the reflected energy from the SAW device. The receiver's RF front end is built around a simple homodyne architecture (Fig. 4). Its primary function is to perform signal detection, followed by amplification and mixing of the received echoes with the carrier. This section provides the measurement unit with a pairs of digital pulses.

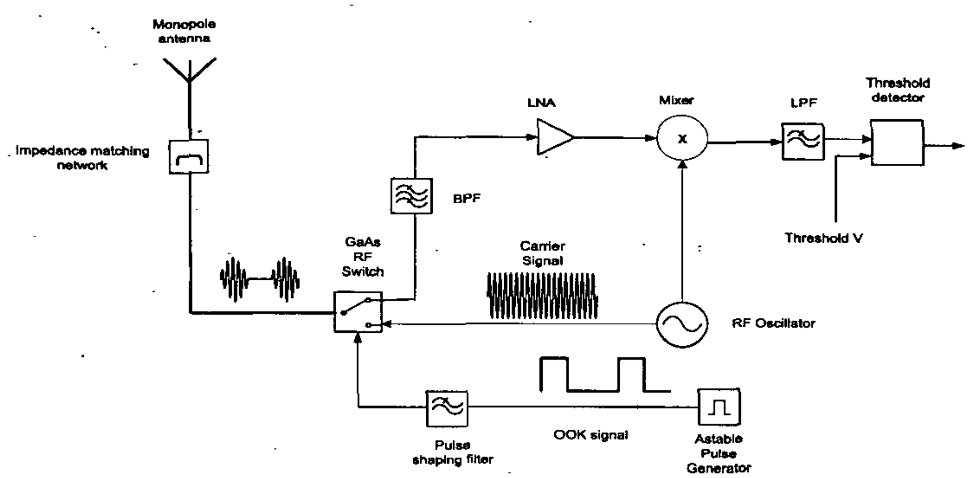


Figure 4: Block diagram of the interrogation unit

Useful information about the liquid under test can be extracted from the variation in the arrival times of the two reflected pulses. The demodulated received signal is fed into the time delay measurement system which will determine the pulse separation time (Fig. 5). The core elements of this section are a counter, a programmable delay line and a two input AND gate. The first pulse of the SAW echoes increments the counter, which then increments the programmable delay line by a fixed amount. This first pulse of the two reflected echoes is then fed via the programmable delay line to one input of the AND gate. Meanwhile the second reflected pulse arrives and is also fed to the AND gate. If the time by which the first pulse is delayed is equal to the inter-pulse separation time, both inputs of the AND gate are simultaneous be high and that determines the counter value to be latched and both the counter and the programmable delay are reset. Otherwise the process is repeated.

The latched value, which determines the number of increments made by the programmable delay line, is then used to determine the pulse separation time and hence information about the measurand. This value can be processed numerically or can be converted to an analogue value to be displayed.

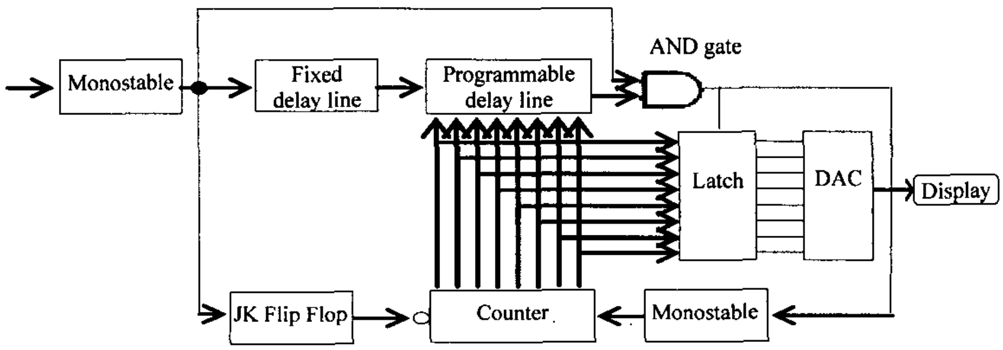


Figure 5: Time delay measurement system

4. CONCLUSIONS

The paper presents a new remote system for SAW sensing and characterisation of bioliquids. Wireless sensors design details are presented and interrogation unit implementation is discussed. A low cost method for detecting inter-pulse delay time is also proposed. The measuring system combines the sensitivity of the high frequency acoustic devices with the advantages of wireless communication. Potential applications of this class of sensors are in food and beverage industry and in the biomedical and environmental area.

ACKNOWLEDGEMENTS

We would like to acknowledge help of Prof. P. Hesketh and Mr. H. Noh from Georgia Institute of Technology, USA in fabrication of our devices. We would also like to thanks Dr. C. Mias from the Applied Electromagnetics Group, University of Warwick, UK for his guidance in the antenna experiments.

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