NEW APPLICATIONS OF WIRELESSLY INTERROGABLE PASSIVE SAW SENSORS

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ABSTRACT

Applying passive wirelessly interrogable SAW sensors a lot of physical parameters can be measured. Up to now all SAW sensor applications are performed by taking a snapshot of the sensor's response periodically, evaluating the measurand assumed to be quasistationary. Therefore the upper limit for rate of sampling a mechanical affect to the sensor is the interrogation rate. Usually it is in the range of 100 kHz or less, measurands with a periodicity of up to a few tenths of kHz can be sampled satisfactory. Even audible vibrations of machine parts can be monitored.
Here, the behaviour of the sensors for dynamic measurands is discussed. Advanced applications for the measurement of vibration, acceleration, for dynamic pressure measurement in mechanical engineering, for example for monitoring the tires of cars are presented. Measurement results from an experimental setup are given.

INTRODUCTION

For a lot of applications, where a cable connection between the locations of sensor and measurement system cannot be established, wireless sensing is necessary. Therefore active transponder systems have been developed, containing semiconductors, capacitors and a power supply like batteries or inductive remote powering circuits. The employment of these circuits usually is subject of narrow limitations due to life time and environmental conditions like heat, radiation, electromagnetic interferences, etc. A few years ago, passive wirelessly interrogable surface acoustic wave devices were introduced for remote sensing [1,2]. On the plain polished surface of a piezoelectric substrate a number of metallic structures (interdigital transducers, IDT) are arranged. An RF signal received by the sensor's antenna is fed into the only connected IDT of the device.

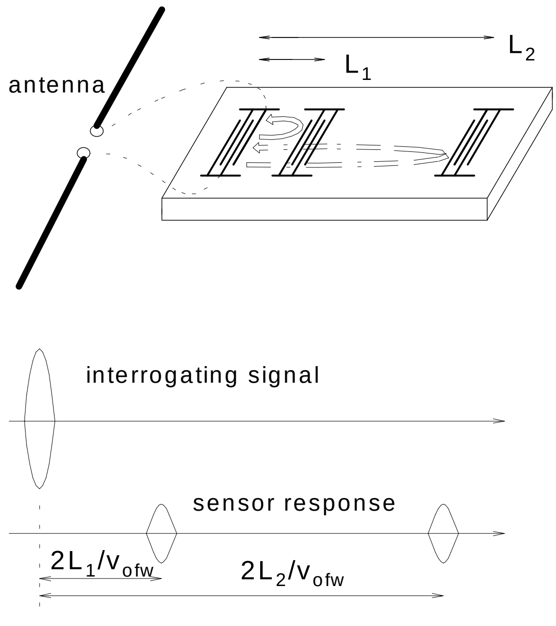

Fig. 1: Wirelessly interrogable passive SAW sensor and signals during interrogation cycle

The excited surface acoustic wave (SAW) propagates along the substrate's surface and is partly reflected by each of the acoustic reflectors. These SAW components arrive at the IDT with delays corresponding to the geometric length of the propagation path and the velocity of the surface acoustic wave, respectively. In the first IDT these components are converted back into RF signals and are retransmitted to the interrogator (fig. 1). The interrogator receives this signal train and converts it into an intermediate frequency band or to baseband range (fig. 2). Then, usually the signal is sampled, magnitude and phase of the sensor's response impulses versus time are evaluated (fig. 3).

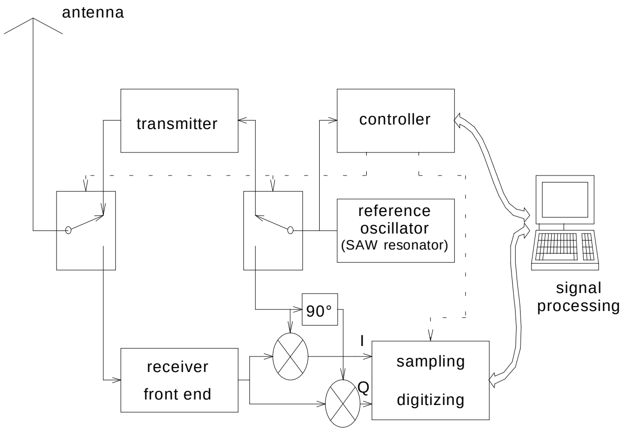

Fig. 2: System for interrogation

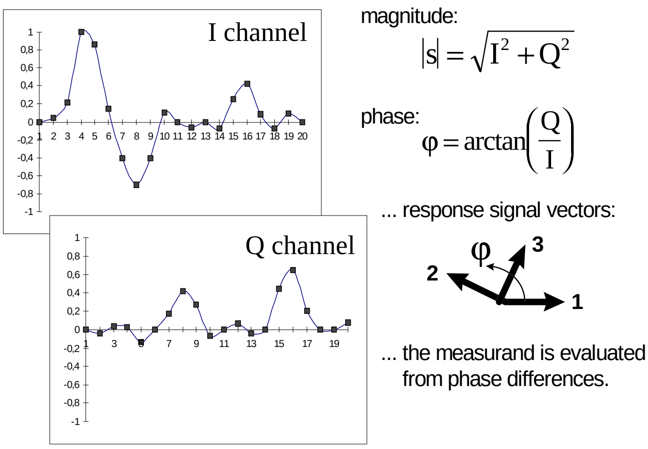

Fig. 3: Signal processing for interrogation

The measurand affects the propagation of the SAW in the sensor in attenuation and delay, respectively. If the sensor is heated, stretched or compressed or if it is loaded to be bent the substrate's length and its elasticity constants are changed. The sensor's response is scaled by a factor 1+ε. Like shown in figure 3, the measurand can be calculated from the information gained from the sensor's response.

In a number of publications applications for identification purposes, temperature, bending, torque measurement have been published [3,4]. All of these are characterized by a quasistationary behaviour of the measurand, usually the results are averaged. This helps to get more signal's energy into the total sensor's response used for evaluation of the measurand and to match to the governmental regulations for wireless telemetry systems easier. In our paper we present the measurement of dynamic processes. In the next chapter, the limits and possible errors for these purposes are discussed. Then two experimental measurement results are shown. A brief conclusion summarizes the contents of the paper.

DYNAMIC MEASUREMENTS

In the discussion we will relate to the SAW delay line sensors shown above. Therefore limits have to be considered when operating the devices to measure with high resolution in time. The affect of the measurand, the scaling of the sensor's response due to the mechanical or the thermal extension and due to the change of crystal's constant is denoted by ε(t). Here f_ε denotes the frequency of the periodical e.g. mechanical affect to the sensor. The time ΔT denotes the measured delay between two reflectors on the surface of a SAW delay line.

For many applications, the measurand is said to be stationary during the reflective propagation of the acoustic wave in the SAW device. The actually delay ΔT is calculated to be a sample of the measurand. Therefore, with a delay ΔT of a few µs, the frequency of changing the

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

measurand should be at least for a factor 10 smaller than 1/ΔT. For usual sensors and common signal processing methods, dynamic measurands with a frequency of up to 25 kHz can be recorded. Like shown in [4] this approximation fails, if this condition of stationarity is broken. Then, the scaling changes during one interrogation cycle for terms not neglectible any more. If we assume, that the measurand changes periodically with a sinus function, the actually scaling ε(t) is

$$\varepsilon(t) = \varepsilon_{max} \cdot \sin\left(2\pi \cdot f_{\varepsilon} + \varphi_{sample}\right) \qquad (1a)$$

with the phase angle φ_{sample} of the measurand's periodicity where the interrogation is started.

In general, the scaling will be an unknown function of time and sampling time t_s:

$$\varepsilon(t) = f\left(t + t_s\right) \qquad (1b)$$

The effective scaling ε_{eff}, the scaling measured by the interrogation system, is

$$\varepsilon_{eff} = \frac{1}{\Delta T} \cdot \int_{\Delta T} \varepsilon(t)\, dt \qquad (2)$$

If for the periodic ε(t) the sensor's delay ΔT is the same as the period length of the exciting measurand, the affect will be masked. From the equations above it can be seen, that with sensors with a number of reflectors the information about ε(t) can be gained by parameter estimation even for high measurand's frequencies and delay intervals ΔT if the course of the measurand is known. Otherwise the course of measurand has to be sampled according to the Shannon's theorem. At least two sample points must be recorded every period of the highest spectral component of the measurand and the scaling ε(t), respectively. This sampling can be achieved by short sensors with small ΔT and using high interrogation rate. It also can be achieved by periodical arrangement of n reflectors with a spacing ΔT. The sensor's response time is increased to n·ΔT, the interrogation rate is decreased approx. by a factor n.

For both, to distinguish the impulses of the sensor's response, short interrogation pulses requiring a high bandwidth are necessary. If every delay is evaluated, the sample rate for the measurand is 1/ΔT, the interrogation bandwidth. Since the sample interval should be short compared to the period $1/f_{\varepsilon}$ of the frequency of the signal to measure, the spacing ΔT is chosen e.g. 1/10 of $1/f_{\varepsilon}$. This yields a maximum bandwidth of the dynamic measurand up to e.g. a tenth of the interrogation bandwidth, Here, with constant reflector spacing, the measurand is oversampled. Depending on the admissible error, dynamic processes up to a frequency of some MHz can be measured with passive wirelessly interrogable SAW sensors.

For dynamic measurements, where the measurand changes rapidly, some further practical aspects have to be considered. In general, for dynamic measurements the system have to be able to perform fast signal processing. For on-line monitoring high amount of calculation power has to be spent. If the process should be monitored off-line only, the data can be stored in an extensive memory. The access to the memory cells have to be fast. Solutions with banks of RAMs with access time intervals of less than 10 ns switched by turns have been built for measurements.

To avoid such extensive signal processing effort, strategies for data reduction must be implemented. Therefore, with a kind of asynchronous sampling, only the information necessary for calculation of the measurand can be recorded for calculation.

EXPERIMENTAL MEASUREMENTS

First, the measurement of tire pressure in car tires in motion is discussed. Here a dynamic pressure measurement is possible, implementing passive SAW sensors.

In figure 4 the air pressure in a front wheel of a car is drawn while the vehicle passes a railway crossing with two tracks and an adjacent water channel.

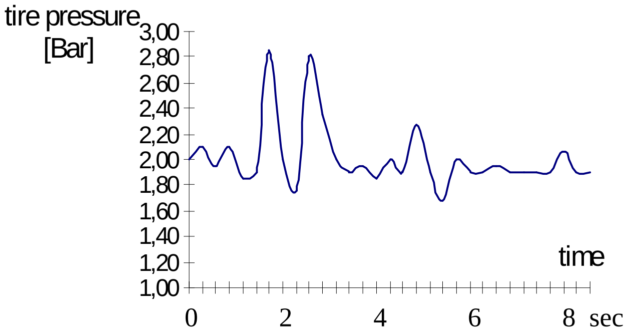

Fig. 4: Pressure in car tires overriding a two track railway crossing

As an other example of dynamic measurement the implementation for vibration and acceleration measurements is proposed.
To proof the capability of the principle we performed measurements with a SAW sensor fixed to a Dart arrow. The passive sensor was fixed right angled to the handle of the arrow. For acceleration and retardation the sensor is bent. For small affects the scaling of the response is proportional to the force F at the seismic mass m. The acceleration a = F·m can be calculated.
Measurements of the retardation in the phase of invading into the target are shown in figure 5.

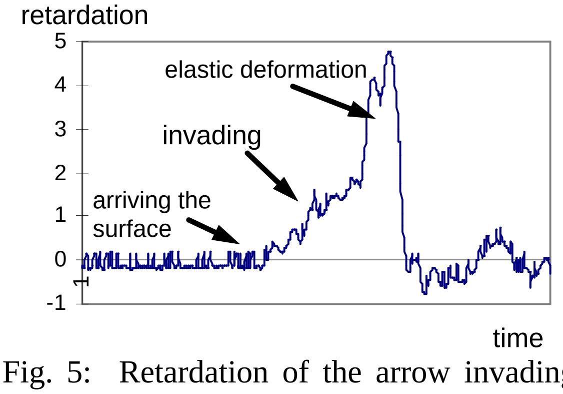

Fig. 5: Retardation of the arrow invading the target made of foamed polyethylene

Arriving the target's surface the arrow is retarded almost linearly. Then the handle causes elastic deformations of the target's material connected with a peak of the retardation and a decaying oscillation.

CONCLUSION

It is obvious, that passive SAW sensors are capable to measure a lot of physical parameters. They are useful even for a high measurement rates. Usually the sensor is assumed to take snapshots and the measurand is stationary for the time interval of the sensor's response length. If the change of the measurand is faster, errors occur.
In the paper it was shown, that the upper limit of the capability of SAW sensors to measure dynamic processes is given by the interrogation bandwidth. Therefore, with the Shannon's sample theorem the maximum resolvable Frequency of the measurand is up to some MHz. A lot of advanced applications become feasible where fast dynamic processes have to be observed using reliable passive sensors.

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