# LOW TB RADIO SAW SENSORS INCORPORATING CHIRPED TRANSDUCERS AND REFLECTORS FOR WIRELESS PRESSURE SENSING APPLICATIONS

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## ABSTRACT

We report on the design and performance of two basic SAW delay line structures developed for a wireless pressure sensing system operating at 434 MHz. The pressure sensor has been fabricated in all-quartz-package (AQP) technology with the SAW structures being placed on a diaphragm inside the hermetically sealed cavity. Both SAW structures show a linear phase although they both incorporate chirped SAW components for enhancing the sensor sensitivity. They have low time-bandwidth (TB) products of 2 and 11, respectively. We attained an improvement of the sensor sensitivity by factors of up to 20 compared to sensors employing non-dispersive SAW components.

## INTRODUCTION

In recent years, a great and important progress in wireless SAW sensor specifications was made and a variety of innovative applications was acquired [1]. SAW sensors are small, rugged and show a low aging rate. When designed as a one-port device with its port connected to a dipole, patch or loop antenna they can easily be accessed wirelessly even in extremely noisy and hazardous industrial radio environments. As a passive device, a SAW transponder requires neither wiring nor batteries. An RF burst impulse transmitted by a local radar transceiver is received by the Rx/Tx-antenna of the SAW transponder the RF response of which is re-transmitted to the local transceiver [2]. The RF response carries a modulation which often can be directly attributed to the sensor effect for a certain physical measurand. SAW transponders can easily be designed to have delay times in the order of a few $\mu$s, long enough to separate the data signals from the echoes due to multipath radio propagation effects in the VHF/UHF range. They allow for access rates of more than 100 kHz so that even fast moving or rotating objects can be tracked.

## AQP PRESSURE SENSOR

Fig. 1 illustrates the pressure sensor concept which is described in detail in Ref. [3]. The AQP sensor geometry is carefully designed to allow for the absolute measurement of pressure. The diaphragm bends under hydrostatic pressure resulting in stress as well as compressed and stretched sections which influence the SAW propagation, an effect which can be detected as a change of the SAW sensor delay time. From an accurate FEM-analysis by which we calculated the bending of the diaphragm and the cover plate as well as the stress distribution at various pressures, AQP dimensions and SAW propagation directions, we found the optimum locations of the SAW components on the diaphragm. Fig. 2 shows the velocity distribution at an AQP size of 11x11 $mm^2$ and a maximum pressure of 8.5 bar which we derived from the computed stress distribution over the diaphragm.

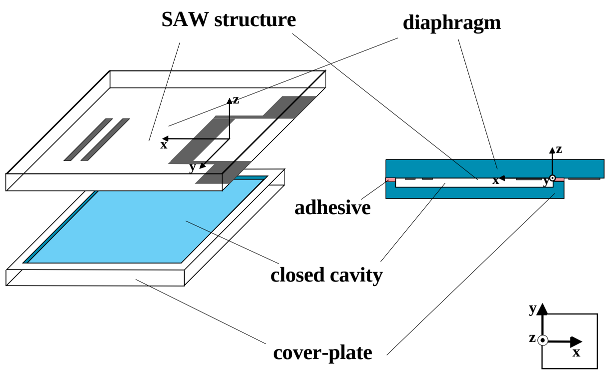


Figure 1: SAW pressure sensor schematic.

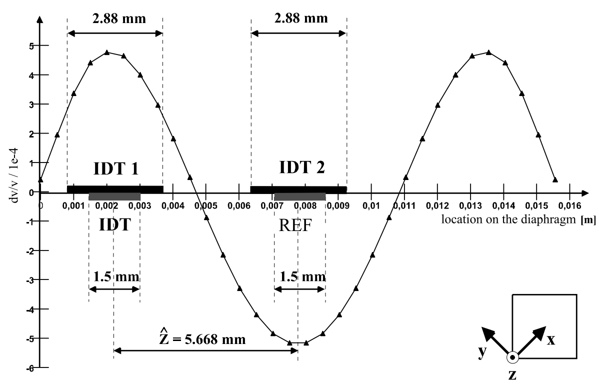


Figure 2: Velocity distribution on the diaphragm and positions of SAW components.

As is seen in Fig. 2, sections with nearly symmetric velocity change occur on the diaphragm, and the maximum difference between the positive and the negative peak is 988 ppm/8.5 bar. The locations of the SAW components were chosen so that they experience both stretch and compression. In Europe, the ISM band at 433.92 MHz has a bandwidth of 1.74 MHz. The change of velocity of about 500 ppm at 8.5 bar with a positive and a negative sign corresponds to a shift of center frequency of about ±0.22 MHz. Therefore, we need a bandwidth of about 2.2 MHz to utilize the full ISM-bandwidth over the measuring range. The SAW components were placed on the diaphragm as is indicated in Fig. 2. The delay time at center frequency is 1.8 $\mu$s corresponding to a length of 5.668 mm.

## SAW STRUCTURES

In Ref. [3] we have presented a pressure sensor using a SAW reflective delay line the length of which (corresponding to the required delay time) determined the size of the diaphragm and the sensor sensitivity. To solve the length-delay time trade-off in general and to increase the sensitivity at a smaller AQP size (and thus at lower cost) in particular, in this work we now use SAW chirped components. We investigated several IDT-IDT and IDT-reflector structures (IDT: interdigital transducer) two of which are discussed in the following. Structure S1 consists of two IDT's and structure S2 of one IDT and one reflector. Fig. 3 gives the schematics of the SAW structures which all were fabricated from 37.5°rotYX-quartz substrates.

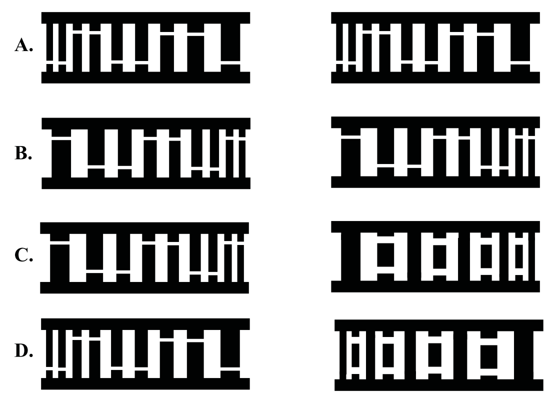


Figure 3: Schematic of implemented SAW pulse compression configurations. A,B: IDT-IDT (electrically connected in parallel; C,D: IDT-reflector.

The IDT-IDT and IDT-reflector configurations both operate as pulse compression systems. Due to the different change of velocity within the SAW components a change of the system group delay $\Delta\tau$ occurs which is proportional to the the measurand. This group delay change is given by

$$\Delta\tau = \tau_0 \left[ 1 \pm \frac{f_0}{\mu\tau_0} \right] S_y \Delta y \qquad (1)$$



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with $\Delta y$, $S_y$, $\mu$, $f_0$, and $\tau_0$ being respectively the change of the measurand, the un-chirped material-dependent sensitivity, the chirp rate, the center frequency, and the group delay time corresponding to $f_0$. The $\pm$ signs correspond to the up-chirp and the down-chirp law, respectively. The sensitivity increase compared to the non-dispersive configuration is given by the term in the brackets.

Structure S1 incorporates two dispersive apodized split-finger IDT's which are connected in parallel. We set the length of each IDT to about 2.88 mm corresponding to a delay time of 1 $\mu$s resulting in 1580 electrodes. S1 allows for an optimization of the sidelobe suppression in the time-domain and for a suppression of Fresnel ripples in the frequency-domain [4]. The TB-product is about 10 dB.

Structure S2 has the decisive advantage that its SAW delay time is double the delay time of the structure S1 since it employs a reflective configuration. Both the IDT and the reflector have a length of about 1.5 mm with 840 electrodes or strips corresponding to a delay time of 0.4 $\mu s$. The IDT is again a split-finger IDT. Here, the TB-product is about 3 dB, and therefore all reflection centers operate synchronously yielding a high reflection coefficient. Hence, $\lambda/4$-width strips ($\lambda$: acoustic wavelength) are not feasible. Instead, we chose a dispersive $\lambda/8$-open/short-reflector configuration [5]. The sensitivity of S2 is about 25 per cent less than that of S1.

The SAW design was carried out using signal-theory modeling, network-theory algorithms and diffraction analysis. In what follows, we show only the experimental results for SAW configurations B and D since A and C show nearly the same fidelity. In all cases, we found a very good agreement between the simulated and the experimental curves. The SAW devices were characterized after they were mounted into a standard metal package. Figs. 4 and 5 show respectively the experimental frequency response for B (38 dB close-in selectivity) and D (42 dB close-in selectivity).

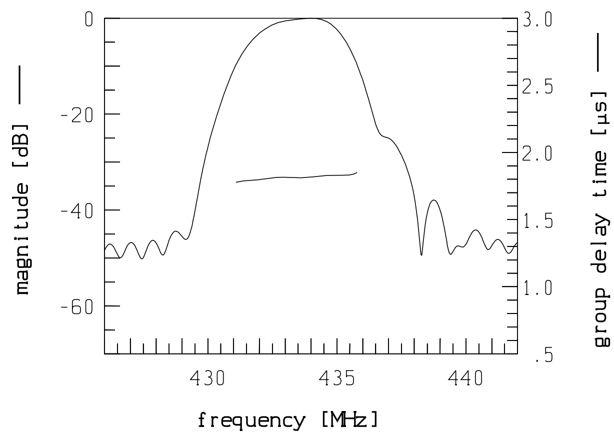


Figure 4: Experimental frequency response of structure B.

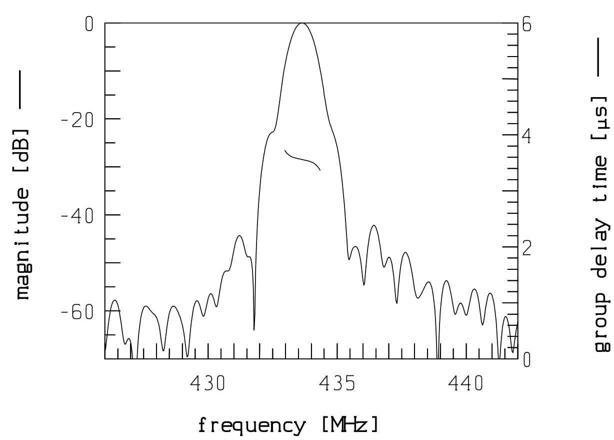


Figure 5: Experimental frequency response of structure D.

## PRESSURE SENSOR DEMONSTRATOR

Before implementing the SAW structures into the AQP pressure sensor, we carried out several fundamental experiments by attaching the SAW chips to a double-bending beam in order to verify the increase of sensitivity. These experiments clearly demonstrated the feasibility of our new robust wireless sensing technique. With all SAW structures A to D we found an enhancement of the sensitivity by factors of up to 20.

In a second step, we built up several versions of the AQP sensor. Fig. 6 gives a photograph of a sensor incorporating SAW structure A, i.e.

the IDT-IDT configuration employing two down-chirp IDT's. In this case, the SAW propagates diagonally across the diaphragm with a velocity of 3150 m/s. The sensitivity $S_y$ and the change of delay time $\Delta\tau$ were $0.32 \times 10^{-3}$ s/m and -25.7 ns, respectively. Fig. 7 shows the AQP pressure sensor characteristic. As is seen, the agreement between theory and measurement was excellent. In general, this was also the case with the AQP sensor demonstrators incorporating the other SAW structures. We found some optimization potentials for a further improvement of the sensitivity: (i) IDT-IDT configuration: steepening the skirts of the frequency response; (ii) IDT-reflector configuration: increasing the time lengths of IDT and reflector and using apodization-weighting for a further sidelobe suppression.

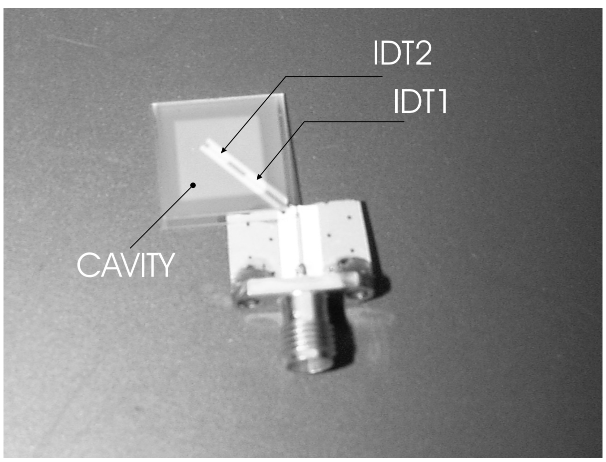


Figure 6: Photgraph of an AQP pressure sensor incorporating SAW structure A with a diagonal SAW propagation path on the diaphragm.

## CONCLUSION

We demonstrated the feasibility of increasing the sensitivity of wireless AQP pressure sensors by using SAW structures incorporating chirped SAW components. Compared to non-dispersive SAW techniques we found an improvement by factors of up to 20. Currently we are designing the wireless versions of the sensors. As a radar

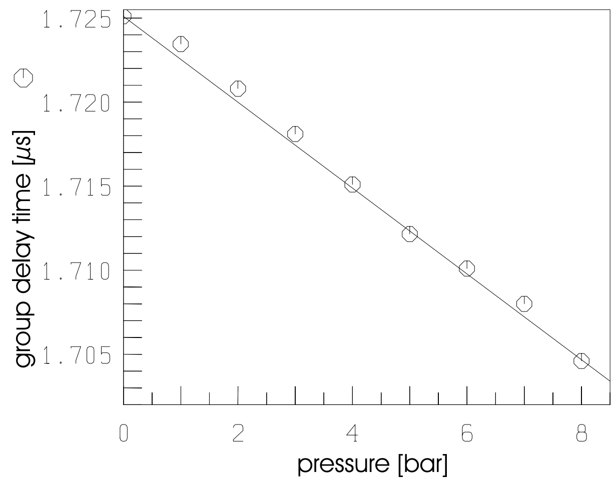


Figure 7: Experimental (circles) and simulated (solid line) characteristic of the present AQP pressure sensor.

principle, we apply the pulse radar technique. We built up a coherent system which enables to improve to the signal-to-noise ratio (SNR) by summing up several RF responses of the SAW transponder. At 25 mW EIRP and 10 dB SNR, the local transceiver-SAW transponder interdistance in the 434 MHz ISM-band is about 10 m.

## References

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