Student Paper

A Finite State Machine Read-out Chip for Integrated Surface Acoustic Wave Sensors

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Summary

A new frequency to voltage closed loop integrated sensor circuit suitable for the read-out module of a monolithically integrated SAW sensor on Si is reported. This closed loop system consists of a voltage controlled oscillator (VCO), a peak detecting comparator, a finite state machine (FSM), and a monolithically integrated SAW sensor device. The novelty of the read-out circuit is in the design of the control loop, particularly the control of the VCO using the FSM. The output of the system oscillates within a narrow voltage range that correlates with the SAW pass-band response. The period of oscillation is of the order of the SAW phase delay. We also use timing information from the FSM to convert SAW phase delay to an on-chip 10 bit digital output operating on the principle of time to digital conversion (TDC). The output voltage range varies with changes in SAW center frequency, thus tracking mass sensing events in real time. Based on measured VCO gain of 16MHz/V our system will convert a 20 kHz SAW frequency shift to a corresponding mean voltage shift of 1.3mV. The system can handle alternate SAW center frequencies and group delays simply by adjusting the VCO control and TDC delay control inputs. Because of frequency to voltage and phase to digital conversion, this topology does not require external frequency counter setups and is uniquely suitable for full monolithic integration of autonomous sensor systems and tags.

Motivation

Typically, readout modules for vapor and liquid phase SAW sensors fabricated on piezoelectric films are configured as single or dual delay line oscillator loops. Mass loading of the sorbent film realized on the SAW device is detected as a frequency shift which is read externally via a frequency counter. However, this approach is not directly applicable in the development of a monolithically integrated autonomous sensor system suitable for wearable sensor tags and other field applications. The motivation of this work is to present an alternate read-out topology for an integrated CMOS SAW sensor which achieves closed loop conversion of the SAW frequency response to a well defined output voltage accurately tracking sensor behavior in real time. Our readout topology is best targeted for low loss interdigitated (IDT) SAW sensors, such those reported in [1] and [2], that have high electromechanical coupling coefficient (k^2). Additionally, this low frequency loop architecture (Fig. 1) precludes mode jumping issues found in designs incorporating the SAW delay line or the resonator in the feedback loop of an amplifier.

Results

Transient simulation and experimental results for a closed loop sensor system with the fabricated test chip and a commercially available SAW device operating at 140MHz are shown in Figs. 2 and 3. The SAW output frequency variation in steady state was between 143.4 MHz and 146.4 MHz while the corresponding output ranged from 1.9664V to 2.1476V. White noise injection on the supply shows increased jitter but no change in the statistical mean of the output. Experimental results show good agreement with simulation results with respect to the VCO fine input sensitivity which is determined to be 16.8MHz/V for experiment and 15.8MHz/V for simulated at the typical process corner. For a frequency shift of 20 kHz due to mass loading, the output voltage mean shift is calculated to be 1.25mV. To prove scalability, we also simulated the loop with a SAW device model centered at 374MHz. The SAW output frequency variation in steady state was between 376.2 MHz and 388.9MHz. For a frequency shift of 10 kHz due to mass loading [1], the mean voltage shift is calculated from to be 0.2mV.This would correspond to a detected mass in the fg (10^{-15}g) range for a SAW device similar to that reported in [2].

Figures

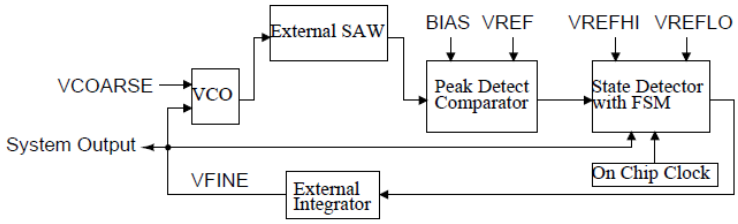

Figure 1: Top level block diagram

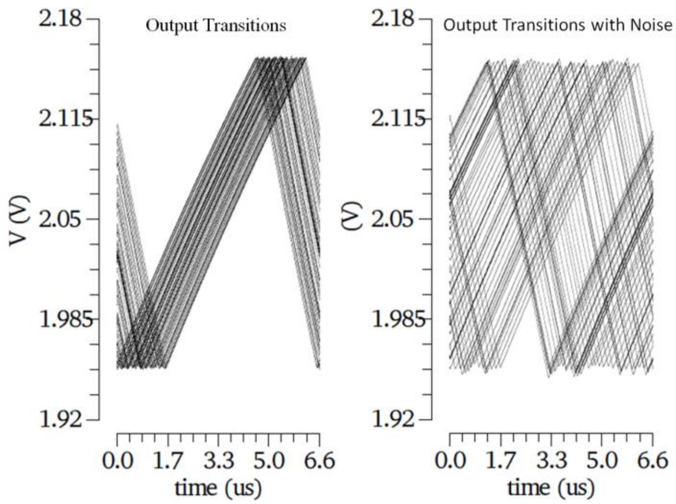

Figure 2: Output transitions with and without noise interference

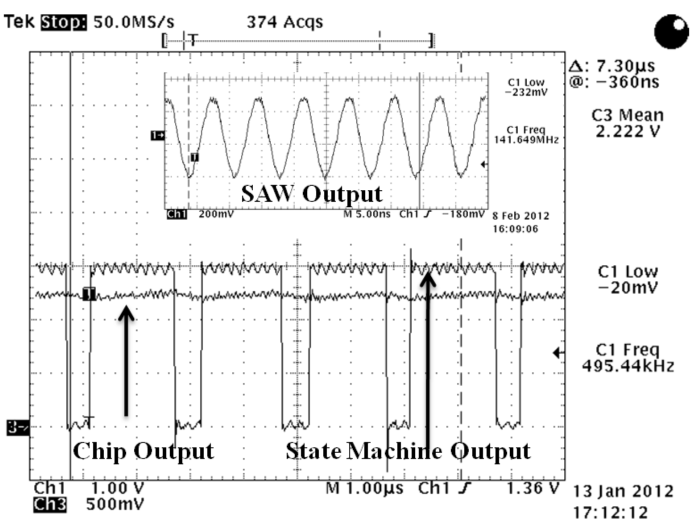

Figure 3: Experimental waveforms of sensor and state machine outputs

References

[1] S. Krishnamoorthy, and A. A. Iliadis, “Properties of High Sensitivity Surface Acoustic Wave Mass Sensors on ZnO/SiO_2/Si”, Solid State Electronics, 52, pp 1710-1716, 2008.

[2] S. Krishnamoorthy, A.A. Iliadis, T. Bei, G.P. Chrousos, “An interleukin-6 ZnO/SiO2/Si surface acoustic wave biosensor”, Biosensors and Bioelectronics, 24, pp. 313-318, 2008.