

All-Digital Interface ASIC for a QCM-Based Electronic Nose

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Summary: An all digital interface application specific integrated circuit (ASIC) has been developed for the control and data sampling of a quartz crystal microbalance (QCM)-based electronic nose. The ASIC is capable of measuring QCM resonant frequency between 0 – 11 MHz with a resolution of 1 Hz and +/- 1 Hz precision. The ASIC has been used to control polymer coated QCM sensors, in conjunction with polymer/carbon-black coated microresistor (μR) sensors, in the detection of primary alcohols.

Keywords: Electronic nose, All-digital interface ASIC, Quartz crystal microbalance

Subject Category: 9 (System architecture, electronic interfaces, wireless interfaces)

1 Introduction

Several different electronic noses have been successfully developed based on Quartz Crystal Microbalance (QCM) sensor technology [1]. A variety of different interface electronics designs, based on multiple discrete components such as FPGAs and frequency-voltage converters, have been successfully constructed and implemented [2,3]. A QCM-based electronic nose interface digital application specific integrated circuit (ASIC) has been developed at the University of Glasgow. This offers advantages of compactness and reduced power consumption in comparison to existing implementations, and is of particular value in battery-powered portable applications.

2 ASIC construction

The ASIC is capable of measuring QCM resonant frequency over a range of 0 to 11 MHz, with a resolution of 1 Hz and +/- 1 Hz precision, and generates 10 frequency measurements per second. The ASIC interface is fabricated using Austria Mikro Systeme's CUP 0.6 μm mixed-signal complimentary metal oxide semiconductor (CMOS) process, and consists of three main components (Fig. 1). Firstly, a CMOS oscillator (a standard library component) to which the QCM sensor is connected. This is linked to a frequency counter block, consisting of a counter incremented by the oscillator, which rolls over to zero every 10^{11}

counts. Finally, the counter's output is sampled every 100 ms and fed to an output block which converts the counter output to the measured frequency. This stores the 11 most recent counter values in a first in, first out (FIFO, S_n to S_{n-10}) and performs the following operation:

$$\text{If } S_n \geq S_{n-10} \text{ then Frequency} = S_n - S_{n-10} \text{ else} \\ \text{Frequency} = S_n - S_{n-10} + 11 \times 10^6$$

to obtain the frequency measured over 1 second. The output is generated as a 24-bit parallel output that is sent to an 8255 I/O card within a personal computer (PC) for data acquisition and logging.

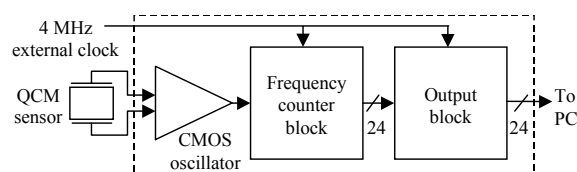


Fig. 1. ASIC block diagram.

3 Alcohol detection

The ASIC has been tested using a 10 MHz QCM sensor, in conjunction with a micro-resistance (μR) sensor, comprising interdigitated finger electrodes, within an electronic nose system (Fig. 2). Both sensors are polymer-coated with poly(ethylene-co-vinylacetate) (PE-co-VA), containing carbon black in the case of the micro-resistor sensor [5].

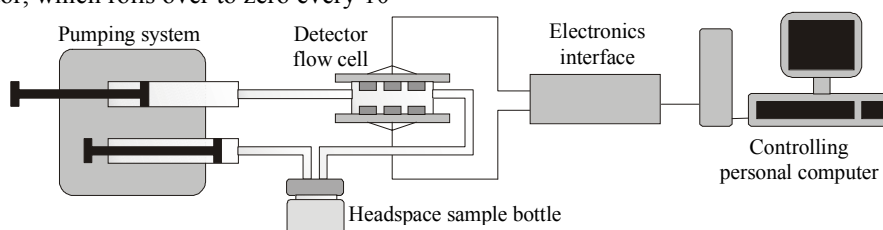


Fig. 2. Electronic nose apparatus consisting of an infusion/withdrawal pumping system, a detector flow cell, detector electronics interface and a controlling personal computer. Analyte gasses are introduced to the sensors from a headspace sample bottle.

The electronic nose system has been used to produce headspace analysis of alcohol vapors, $C_nH_{2n+1}OH$, where $n = 1$ to 8 and 10. Plots of the ratio of the response from the QCM and μR sensor pairs, S_{fr} , versus relative molecular mass (RMM) and alcohol liquid density (Fig. 3) show a linear relationship for alcohols where $n > 2$, despite the very non-linear response for Δf and ΔR produced by the respective sensors (inset).

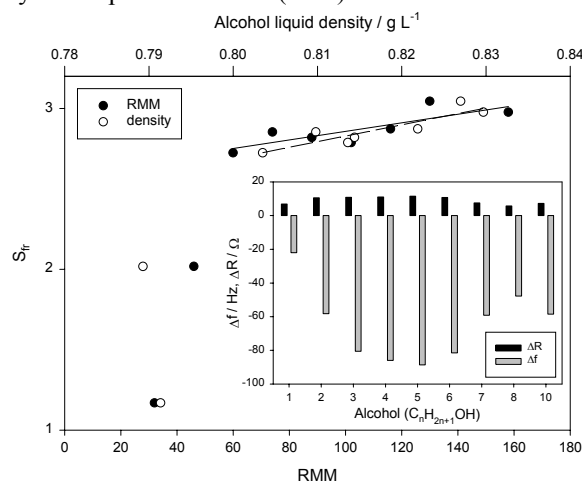


Fig. 3. S_{fr} versus RMM and alcohol liquid density calculated using, inset, ΔR and Δf upon the introduction of primary alcohols $C_nH_{2n+1}OH$ to QCM and μR PE-co-VA coated sensors ($n = 1$ to 8 and 10). A linear relationship is seen for both the RMM (solid line) and liquid density (dashed line) for alcohols where $n > 2$.

As the QCM response is proportional to a change in mass, and the μR response is proportional to a change in volume, S_{fr} can be defined as [4, 6],

$$S_{fr} = \frac{(\Delta f/f_c)}{(\Delta R/R_0)} \propto \frac{\Delta m}{\Delta V} \propto \rho_A \quad (1)$$

where Δf and ΔR are the change in frequency and resistance of the QCM and μR sensors respectively, f_c and R_0 are, respectively, the QCM resonant frequency and the baseline resistance value, m and V are the mass and volume change of the polymer deposited on the QCM and ρ_A is the density of the adsorbed analyte. Also,

$$\frac{1}{S_{fr}} = \frac{Sk''\rho_p}{RMM_A} \quad (2)$$

where, S is a gas/polymer sensitivity coefficient, k'' is a geometric constant related to the μR sensor electrodes, ρ_p is the polymer density and RMM_A is the relative molecular mass of the analyte.

Repeated measurement of methanol ($n = 1$) vapor at concentrations of approximately 800 ppm and 1600 ppm (Fig. 4) reveals that S_{fr} is independent of concentration change, in contrast to Δf and ΔR (inset). This concentration independence, allied to the linear properties of S_{fr} when detecting alcohols suggest that this system could be useful when designing electronic nose systems based on arrays of sensors for the detection of similar analyte gasses.

A full system on a chip (SoC) electronic nose is currently under development at the University of Glasgow, making use of IP from the nose ASIC, and featuring arrays of QCM and resistive sensors, along with on-chip processing and communications functionality.

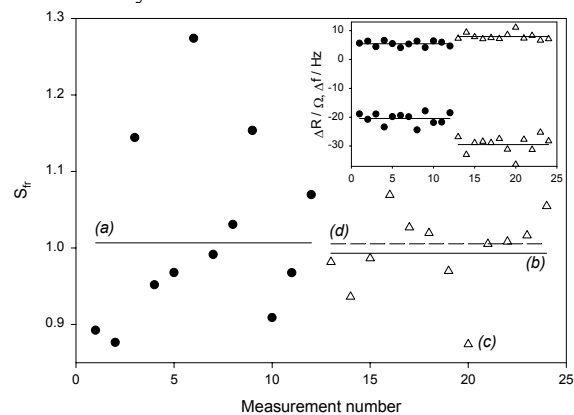


Fig. 4. S_{fr} for 12 repeat introductions of approximately 800 ppm (●) and 1600 ppm (Δ) of methanol to a pair of PE-co-VA sensors. The means (solid lines a and b) are plotted for each concentration. Upon removal of the outlier (c) using Dixon's Q-test, the mean of the 3.42×10^{-3} mol dm^{-3} measurements increases (dashed line d) to a value close to that of the 1.71×10^{-3} mol dm^{-3} measurements. Inset, ΔR and Δf for the 12 repeated introductions.

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