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Smart Interface Circuit to Ameliorate Loss of Measurement Range in Chemical Microsensor Arrays

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Abstract *– A programmable analog sensor interface integrated with an array of heterogeneous chemical FET/resistive sensors is presented. The sensory interface primarily addresses the problem of loss of measurement range due to large variations in baseline signals among sensors in the array. A circuit is proposed to cancel the baseline signals in the sensor array leading to improved measurement resolution. An integrated sensory array and interface electronics chip is fabricated and tested to perform odour analysis.*

Keywords *– chemical sensors, sensor interface, d.c cancellation, measurement range, odour analysis*

I. INTRODUCTION

Heterogeneous arrays of chemical sensors are widely used to improve selectivity in odour analysis [1]. Recently, an array of combined FET/resistive sensors in a single CMOS chip has been proposed for enhancing selectivity to perform various discrimination tasks [2]. However, such an integrated sensor array system puts several challenges to the design of a suitable analog interface circuit. The various undesirable features in a chemical sensor response include strong sensitivity to temperature and humidity, interference, cross sensitivities, drift and noise. In literature, many works addressing these issues exist.

With respect to an heterogeneous chemical sensor array, an important undesirable characteristic is the large variation in baseline (d.c) conditions among the sensors in the array [3]. Some of the causes for the baseline variations associated with a combined resistive/FET array are listed below,

1. Different d.c operating point requirement for the FET and resistive sensors
2. The poisoning effect on post-processing the sensors. For example, coating resistive sensors with different polymers show large variation in baseline resistance [3]
3. Different sensor types may require different current biases for optimal sensor operation

The large variations in initial d.c operating points among sensors may result in saturation of the outputs in the subsequent signal conditioning amplifier stages. This leads to loss of measurement range which cannot be recovered [4].

Several methods to improve measurement range are addressed in general sensor interface technology [4] and discrete programmable analog devices are commercially available [5]. In an integrated chemical sensory array interface, a common method is to fabricate and coat large number of sensors in a CMOS chip; the sensors with large variations are discarded. This approach will significantly reduce the yield and may result in loss of information at critical locations in the array. In [6] an adaptive median thresholding technique is used to ameliorate the effect of changes in baseline resistance of an array of three different resistive chemical sensors. Here, the sensory output is in digital format. However, analogue continuous time domain processing of sensor array signals offers potential solutions to complex tasks as evident in superior odour analysis performed by mammals.

A programmable continuous time domain sensor interface circuit with d.c cancellation is proposed for a heterogeneous chemical sensor array. The working of the interface circuitry is discussed in Section II. A chip is fabricated integrating the proposed interface circuitry with a large sensor array and is used for odour analysis. The results from the odour analysis experiment is discussed in Section III.

II. INTERFACE CIRCUIT FOR D.C SIGNAL CANCELLATION

The schematic of the sensor interface electronics for canceling the baseline (d.c) signals is shown in Fig. 1. In a combined sensor FET/resistive array, the resistive sensor component is formed by depositing carbon black polymer between two sensor electrodes. The FET sensor component uses the floating gate concept, where the sensing material is capacitive coupled to the floating gate of a FET. When subjected to a gas vapour, a potential is created at the sensing material due to the change of work function within the sensing material. This potential appears at the gate of the FET due to the capacitive coupling between the sensing material and the floating gate of the FET.

Prior to measurement, there is a set-up phase during which the baseline signals of all sensors in the array are digitally stored using a simple counting analog to digital converter. The output from the internal digital to analog converter (DAC) provides the initial analog offset signal which is then canceled using a difference amplifier.

The output of the baseline signal cancellation circuit is given by

$$V_{off} = V_{ref} \frac{D}{2^N}$$

where D is the equivalent N bit digital word of the baseline signal V_s of the sensor before measurement.

The residual signal after baseline compensation is given by

$$|V_s - V_{off}| = \frac{V_{ref}}{2^N}$$

If no baseline cancellation is performed, the largest gain G_1 at the programmable amplifier without loss of measurement range is

$$G_1 = \frac{V_{sat}}{V_s + \Delta V_s}$$

where V_{sat} is the saturation limit of the programmable amplifier. With the proposed d.c compensation circuit the largest gain G_2 is

$$G_2 = \frac{V_{sat}}{\Delta V_s + |V_s - V_{off}|}$$

$$\frac{G_1}{G_2} = \frac{\frac{V_{ref}}{2^N} + \Delta V_s}{V_s + \Delta V_s} \qquad (1)$$

From (1) it is seen that the cancellation of the baseline d.c signals of the sensors, allows the small signal responses to be amplified using larger gains thereby leading to improved resolution.

The baseline compensation circuit is a part of the sensor signal pre-processor and hence it is desirable to use inexpensive circuits primarily in terms of power consumption and area. As the baseline sensor signal is d.c, a simple counting analog to digital converter is selected. The comparator is designed with hysteresis so as to account for noise in the baseline sensor signals.

A binary weighted current scaling architecture is chosen as DAC because it has a similar structure as the constant current bias driven sensors used in the proposed array. With respect to a chemical resistive array, this structure emulates the role of a reference sensor. In the proposed design, the power dissipation can be reduced by appropriate circuit parameter design compared to employing identical reference sensors. Noting that power dissipation is proportional to the square of the current, an equivalent baseline voltage can be generated by selecting smaller currents to drop across a higher reference resistor in the the binary weighted DAC. It is to be noted that use of a chemically coated resistive reference sensor to cancel baseline variation is not useful as the poisoning of the sensors is the primary cause for the baseline variations. The proposed structure facilitates to embed prior knowledge of sensor baseline variations for selecting the DAC resolution.

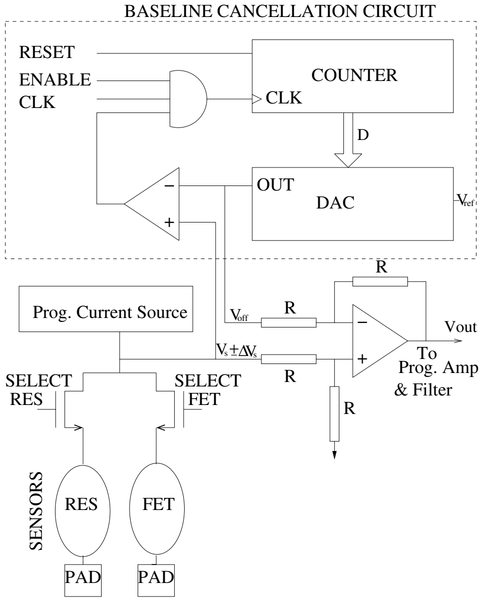

Fig. 1 Simplified schematic of sensor interface

The complete interface circuit implemented on chip includes programmable sensor selection and programmable current sources. The difference amplifier output is followed by programmable gain amplifier and a low pass filter. During set-up phase, the sensors and their appropriate current source drives are selected. This is performed by sending a control word to each sensor cell. The baseline signal cancellation is then carried out and the chip is ready for measurement. During measurement phase, the baseline compensation circuitry is disabled and the sensor measurement pathway operates in continuous time domain. Although baseline cancellation circuitry conditions the chemical sensor array signals for full measurement range and amplification, it is important to note that proper selection of gains at the programmable gain amplifier stage is critical. This is because an improper gain selection could result in saturation of amplifier outputs leading to loss of resolution.

III. EXPERIMENTAL RESULTS FROM CHIP

An integrated sensor array and interface electronics chip of size 10mmx5mm has been fabricated using AMS process 0.6µm CUP technology. There are 70 combined FET/resistive sensor cells arranged in a 14x5 array. Each sensor cell has a sensor interface circuitry integrated in the chip.

The chip photograph is shown in Fig. 2. The sensors are deposited with five different polymers. The polymers are mixed with 20% carbon black loading by weight in a suitable solvent. The mixture is sonicated for 10 minutes and the spray coated on the inter-electrode gap through a mechanical micro-mask using a micro spraying system.

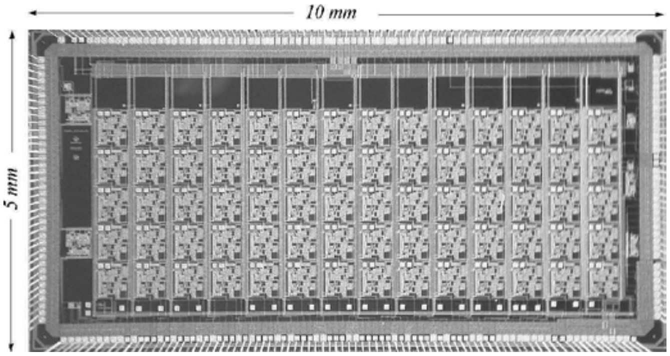

Fig. 2. Photograph of integrated sensor array and interface chip

The sensor array chip is used for odour analysis. The experimental setup is shown in Fig. 3. The chip is powered to 0~5V. The responses of two sensors (S2 and S16) located in the array to a 25sec toluene and ethanol vapour pulse at a flow rate of 30sccm are shown in Fig. 4. The sensor S2 is coated with Poly Stylene-co-butadiene (PSB) material and S16 with Poly Ethyl-co-vinyl acetate (PEVA). The sensitivity, for example, of the PSB sensor material to ethanol vapour is about 0.00012%ppm and 0.00644%ppm to toluene vapour.

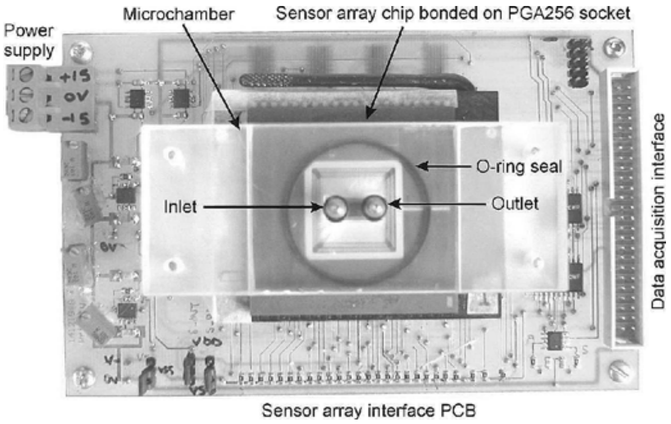

Fig. 3. Experimental setup for odour analysis

The baseline variation between S2 and S16 sensors responses is about 800mV as shown in Fig. 4(a) and 4(c). The sensor responses after baseline compensation and a fixed (inverting) amplification of 10 are shown in Fig. 4(b) and 4(d). It is seen that the interface circuit is able to compensate the baseline variations thereby facilitating full measurement range amplification to be carried out by a programmable gain amplifier. The ±1 bit error of the baseline compensation circuit is found to be ±5mV. The typical set-up time for baseline cancellation on all the sensor cells is 512μs (based on a 2Mhz clock).

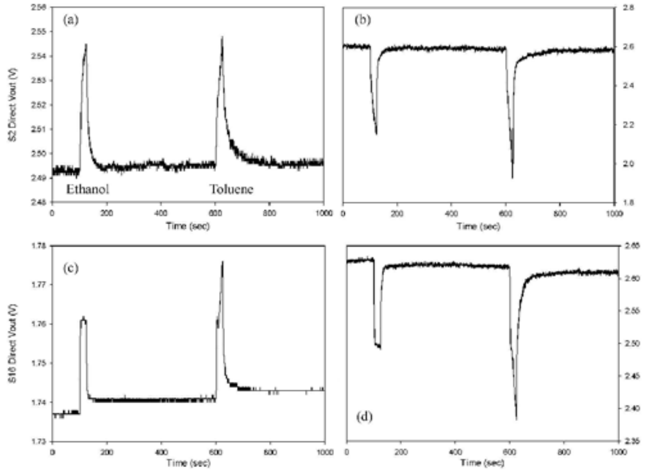

Fig. 4. Sensor responses to ethanol and toluene vapour. (a) Sensor 2 (S2) response with direct measurement (b) S2 response with interface circuit c) Sensor 16 (S16) response with direct measurement (d) S16 response with the interface circuit

CONCLUSIONS

An interface circuit to improve measurement range in a heterogeneous array of combined FET/resistive chemical sensors has been developed. On power-up, the interface circuit automatically tracks and cancels the large variation in the initial baseline signals of the sensors in the array. An integrated sensor and interface electronics array chip of size 10mmx5mm with 70 combined FET/resistive sensors has been fabricated using AMS process 0.6μm CUP technology. The efficient working of the sensor interface circuit has been demonstrated by using the fabricated chip for odour analysis.

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