A Low-Cost Electronic Interface for Electrochemical and Semiconductor Gas Sensors

A. Depari, A. Flammini, and E. Sisinni

1 Introduction

Chemical sensors for gas detection are used in several applications, such as air quality, home and work safety, and food quality control. When the detection of small concentrations of substances is required, electrochemical sensors are usually employed. Conversely, when the primary concern is the low cost, semiconductor gas sensors are generally used. In the former case, the quantity to measure is the current I_s of the working electrode (*WE*) of the sensor, and in the latter, the sensor is modeled with a gas-dependent electrical resistor R_s; thus a resistance estimation is necessary. Due to the vast choice of sensors, the range of current I_s or resistance R_s to estimate is rather wide (usually 1 nA ÷ 1 mA for I_s and 10 kΩ ÷ 10 GΩ for R_s). Low-cost sensor interface circuits for such a wide input range are usually based on multiple-range architectures [1], with the disadvantage of having complex calibration procedures. Alternative solutions are based on current-/resistance-to-time conversion [2], the main drawback of which is the long measurement time occurring with large resistance values, making such circuits not suitable when fast sensor transients need to be acquired and analyzed. In this paper, an innovative and fast-readout electronic interface circuit, able to be used with wide-range electrochemical as well as semiconductor gas sensors, is proposed. The simple architecture together with 3.3 V single-supply and digital signal output characteristics make the presented front end particularly suitable to be replicated for the use in sensor array applications and integrated in a single-chip solution, together with the digital stages for data acquisition and processing.

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2 The Proposed Solution

The proposed front end, based on the architecture in [3], is shown in Fig. 1a, whereas the timing diagram is reported in Fig. 1b. Connections with the sensor are displayed in Fig. 2a, b, related to an electrochemical and a resistive sensor, respectively.

The integration of the current I_s produces a ramp V_s, the slope α_s of which depends on the I_s value. A ramp V_t, with a constant slope α_t, opposite to α_s, is used to capture the ramp V_s and to generate the output signal V_o, which is also used to reset the integrators and iterate the measurement.

The *PulseGen* block of Fig. 1a, shown in Fig. 2c, is a monostable circuit to generate, during the low-to-high commutation of V_c, a positive pulse of V_o long enough to assure a complete reset of the integrators Int_s and Int_t as in Fig. 1b.

The time T_{meas} is related to the unknown quantities I_s or R_s by means of the relation in (1). The use of a moving threshold V_t allows the measurement time T_{meas} to

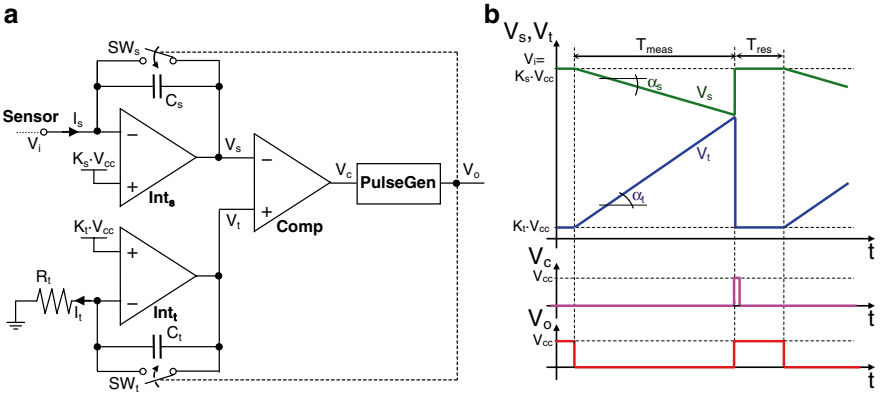

Fig. 1 (**a**) Scheme of the proposed interface circuit. (**b**) Time diagram of the circuit signals

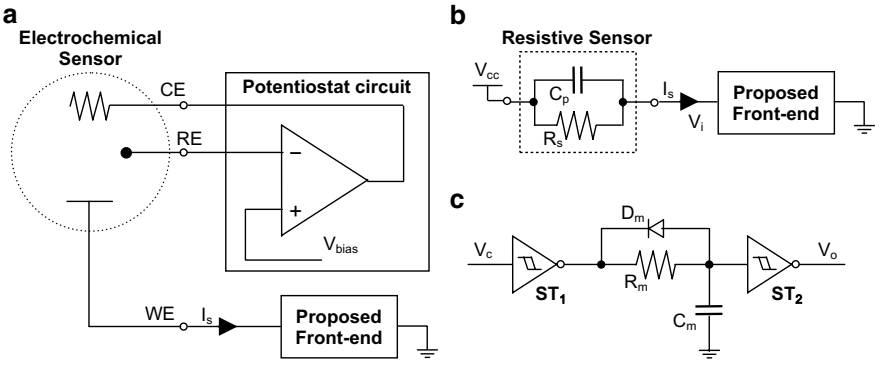

Fig. 2 The connection of the sensor to the front end in Fig. 1a in case of (**a**) electrochemical sensor and (**b**) resistive sensor. (**c**) The *PulseGen* block of Fig. 1a for the creation of the reset/output signal V_o

be limited, particularly when small current or large resistance values (almost flat V_s ramp) are under examination [4]. In this case, the maximum measurement time $T_{meas,MAX}$ is given by the relation in (2):

$$T_{meas} = V_{cc} \frac{K_s - K_t}{\frac{I_s}{C_s} + V_{cc} \frac{K_t}{R_t \cdot C_t}} = \frac{K_s - K_t}{\frac{(1-K_s)}{R_s \cdot C_s} + \frac{K_t}{R_t \cdot C_t}} \quad with \quad K_t < K_s < 1 \tag{1}$$

$$T_{meas,MAX} = R_t \cdot C_t \left(\frac{K_s}{K_t} - 1 \right) \quad with \quad K_t < K_s < 1 \tag{2}$$

3 Experimental Results and Conclusions

The experimental validation of the proposed approach has been conducted by means of a discrete component prototype. Sample resistors from 1 kΩ to 10 GΩ in the configuration of Fig. 2a have been used to emulate resistive sensors; by assuring a resistor voltage drop of 1 V (referring to Figs. 1a and 2a, V_{cc} = 3.3 V and $V_i = K_s \cdot V_{cc}$ = 2.3 V), a current from 100 pA to 1 mA flows in the test resistor, thus emulating the electrochemical sensor output current. A digital counter (Agilent 53230A) has been employed for the measurement of T_{meas}, and estimation of I_s and R_s has been computed by inverting, respectively, the second and third terms of the relation in (1). Results obtained with the aforementioned experimental setup are shown in Table 1, in terms of relative standard deviation σ_{Rel} as well as of relative linearity error $\varepsilon_{L,Rel}$ (evaluated with the weighted least mean square line). The experimental results show a relative standard deviation less than 0.1 % and a relative linearity error below 5 % in the whole considered range (seven decades) for both I_s and R_s estimations [5].

The measuring time T_{meas} spans across five decades (from hundreds of nanoseconds to about 25 ms), thus showing a time compression behavior with large sensor

Table 1 Experimental results obtained with the discrete component prototype and sample resistors emulating the sensor

			R_s estimation		I_s estimation	
R_s (MΩ)	I_s (μA)	T_{meas} (μs)	σ_{Rel} (%)	$\varepsilon_{L,Rel}$ (%)	σ_{Rel} (%)	$\varepsilon_{L,Rel}$ (%)
1.00E−03	1.00E+03	2.91E−01	0.03	−4.14	0.03	4.32
1.00E−02	1.00E+02	2.22E+00	0.02	−0.58	0.02	0.58
1.00E−01	1.00E+01	2.15E+01	0.01	−0.16	0.01	0.16
1.00E+00	1.00E+00	2.14E+02	0.02	−0.52	0.02	0.52
1.00E+01	1.00E−01	2.00E+03	0.01	0.00	0.01	0.00
1.00E+02	1.00E−02	1.22E+04	0.03	1.30	0.03	−1.28
1.00E+03	1.00E−03	2.51E+04	0.04	4.16	0.04	−3.99
1.00E+04	1.00E−04	2.83E+04	0.12	−0.43	0.12	0.43

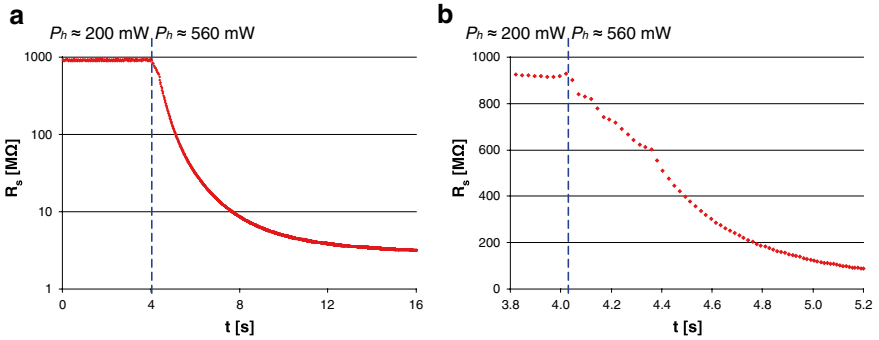

Fig. 3 (**a**) Fast thermal transient of a MOX sensor acquired of the proposed front end. (**b**) Detail of the sensor transient around the heater power variation

resistance (small sensor current) values which keeps the measurement time short. The power dissipation of the front end is less than 30 mW (at 3.3 V), and the cost of the realized prototype is less than 10 EUR, making it suitable for the use in low-cost and low-power gas detection systems.

A titanium dioxide MOX sensor has been used to test the capability of the proposed front end of acquiring fast sensor transients. To force such a sensor behavior, the heater voltage V_h has been quickly changed from $V_h = 2$ V (heater power $P_h \approx 200$ mW which corresponds to a sensor temperature of about 215 °C) to $V_h = 4$ V ($P_h \approx 560$ mW which corresponds to about 440 °C). As visible in Fig. 3a, the sensor resistance has a fast drop of almost three decades in about 15 s. The transient detail in Fig. 3b shows how the presented front end has been able to accurately track the resistance variation, even in the presence of a large resistance value (sensor baseline around 1 GΩ) and fast resistance variation, thus demonstrating the effectiveness of the proposed approach.

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