Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 47 (2012) 253 – 256

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXVI, September 9-12, 2012, Kraków, Poland

A Novel Uncalibrated Read-Out Circuit for Floating Capacitive and Grounded/Floating Resistive Sensors Measurement

Andrea De Marcellis*, Giuseppe Ferri, Paolo Mantenuto

University of L'Aquila, Department of Industrial and Information Engineering and Economics
Via G. Gronchi 18, 67100 – L'Aquila, Italy

Abstract

We here propose a new uncalibrated read-out circuit suitable for both capacitance and resistance measurements. This solution, employing only two Operational Amplifiers (*OAs*) as active blocks and some passive components, is based on a square-wave oscillator which, instead of a voltage integration typically performed by other solutions in the literature, operates a voltage differentiation. The circuit, performing an impedance-to-period (*Z-T*) conversion, results to be suitable as first analog front-end for both wide variation capacitive (e.g., for relative humidity) and resistive (e.g., for gas) sensors. Circuit sensitivity and dynamic range can be easily set through some passive components. A suitable prototype PCB has been fabricated so to perform electrical and humidity measurements, through the use of sample components and a commercial capacitive humidity sensor. Experimentals have shown a linear behaviour and a satisfactory accuracy in the evaluation of both floating capacitive (in the range [pF÷μF]) and grounded resistive (in the range [kΩ ÷MΩ]) variations.

Keywords: Uncalibrated circuit; Read-out electronic interface; Resistive sensor, Capacitive sensor; Wide dynamic range; Square-wave oscillator; Operational Amplifier; Impedance-to-Period Conversion; Voltage Differentiation; Relative Humidity Sensor; Gas sensor.

---

1. Introduction

Analog interfaces for wide range resistive/capacitive sensors are typically based on either sinusoidal or square wave generators, also named as oscillators, so performing an impedance-to-period (*Z-T*) conversion. These electronic circuits show an output period proportional to the sensor component, which is excited through this periodic AC waveform. Internally, they are typically implemented with a Voltage-

doi:10.1016/j.proeng.2012.09.131

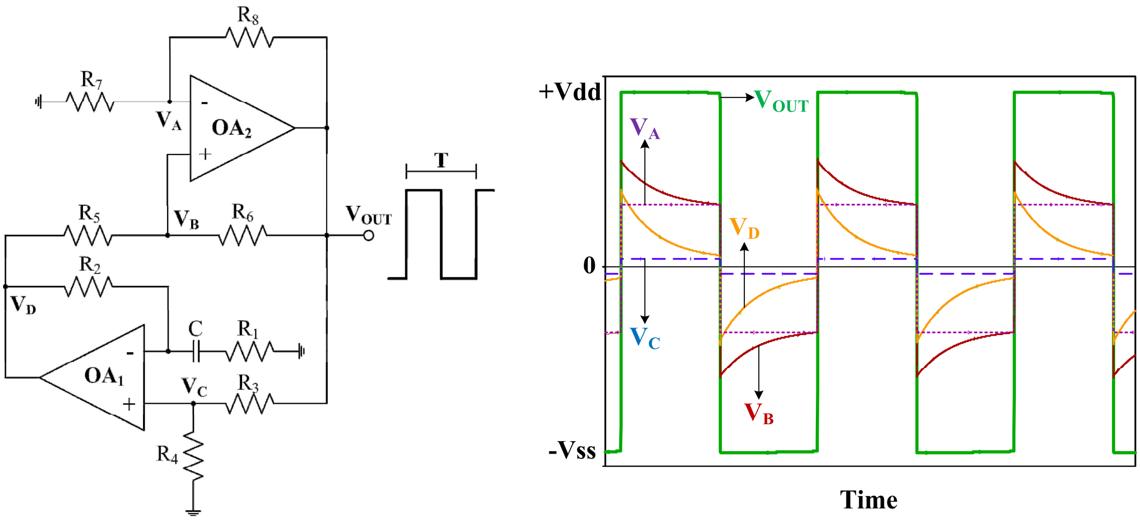
Mode (*VM*) approach by using Operational Amplifiers (*OAs*) and are based on an *R*–*C* integrating cell, followed by a voltage hysteresis comparator [1-9].

Here we present a new uncalibrated analog oscillating circuit suitable for both grounded/floating resistive and floating capacitive sensors interfacing, employing a reduced number of active and passive components. It is based on a voltage differential operation, instead of a voltage integration, so to achieve a better rejection of low-frequency disturbs. In this interface, through external passive components, it is possible both to easily select the working range and to fix the sensitivity to sensor parameters.

Experimental measurements have been performed implementing the proposed solution through the fabrication of a prototype PCB that utilizes the commercial component OPA602 as *OA* and employing both passive sample resistors and capacitors (to emulate sensor behaviours) and the commercial capacitive sensor HCH-1000 Series by Honeywell (to detect the relative humidity). Measurement results have validated the correct operations of the proposed interface providing a reduced estimation error with a linear behaviour and a good accuracy.

2. The novel sensor interface: circuit analysis and theory

The proposed interface is shown in Figure 1a. It is composed of two main active blocks: the first, OA_1, is utilized in a non-inverting voltage differentiator, while the second, OA_2, is employed in a non-inverting hysteresis voltage comparator. The feedback loop allows to avoid the initial calibration. Figure 1b shows the main voltage signal behaviour at each circuit nodes from which the differentiating effect on V_D can be seen.



(a) (b)

Fig. 1. (a) Block scheme of the capacitive-resistive sensor interface: capacitor *C* (floating) and resistor R_1 (grounded) or R_2 (floating) can be replaced by suitable sensors; (b) Typical time responses evaluated at main interface nodes.

Through a straightforward circuit analysis, considering ideal *OAs*, it is possible to achieve the following most general expression for the period *T*, revealed at V_{OUT} node:

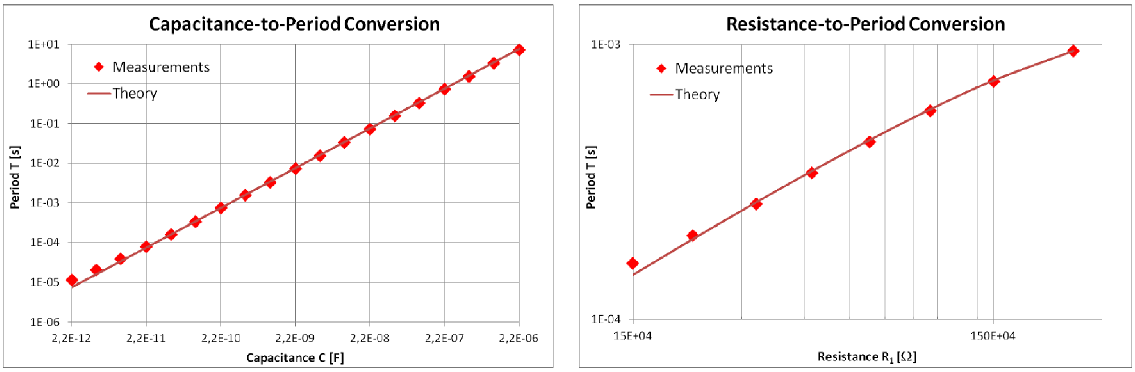
$$T = 2CR_1 \ln\left(\frac{\left(\frac{R_7(R_5+R_6)-R_5(R_7+R_8)}{R_6(R_7+R_8)}\right) - \frac{R_4}{R_3+R_4}\left(1+\frac{2R_2}{R_1}\right)}{\frac{R_4}{R_3+R_4} - \left(\frac{R_7(R_5+R_6)-R_5(R_7+R_8)}{R_6(R_7+R_8)}\right)} \right) . \qquad (1)$$

From eq.1 it is evident the direct proportionality between the output period, which is also independent from both *Vdd* and *Vss*, and capacitance *C*; in this manner, the interface is particularly suitable for capacitive sensor applications, but can also be employed, under particular conditions on the resistance values, considering R_1 (or R_2) as a resistive sensor.

3. Electrical measurements through the prototype PCB

Waiting for the integrated solution development, some experimental measurements, conducted on a PCB with high accuracy sample resistances and capacitances (emulating sensors), have shown the system capability to work in a large interval of sensor variations (e.g., kΩ÷MΩ or pF÷μF, settable ranges), with a reduced error, with respect to the ideal values (taken from eq.1). The employed *OA* in the PCB is OPA602 by Texas Instruments, supplied at ±15V.

More in particular, this interface estimates, with a good linearity, wide-range capacitance values (i.e., *C* from 2.2pF to 2.2μF, covering different kinds of capacitive sensors), as shown in Figure 2a. In the range 22pF÷2.2μF (5 decades), the relative error is lower than ±4%. Moreover, the circuit evaluates resistive variations (i.e., R_1 from 150kΩ to 2.5MΩ), as reported in Figure 2b. In the range 250kΩ÷2.5MΩ (1 decade), the relative error is lower than ±1%. In these operating conditions, the system sensitivity has been set to 3.5μs/pF and 350÷950μs/MΩ, respectively.



(a) (b)

Fig. 2. Theoretical responses (from eq.1) and measurement results related to the period *T* of the output square waveform: (a) vs. *C*; (b) vs. R_1.

4. Humidity measurements employing a commercial capacitive sensor

A commercial capacitive humidity sensor (i.e., HCH-1000 Series by Honeywell) has been also employed to reveal and quantify the Relative Humidity (*RH*) time-variations, as reported in Figure 3, where the time response of the period variations for different RH% values, ranging in 0–80%, by mixing dry and wet airs in a controlled chamber (capacitance-to-time, *C-T*, conversion), is reported. The *RH* reference values have been achieved through the HTD-625 High Accuracy Thermo-Hygrometer, having a resolution of 0.1%RH and an accuracy of ±2%RH. These preliminary experimental results confirm the theoretical expectations and show a good agreement with the capacitive humidity sensor datasheet parameters.

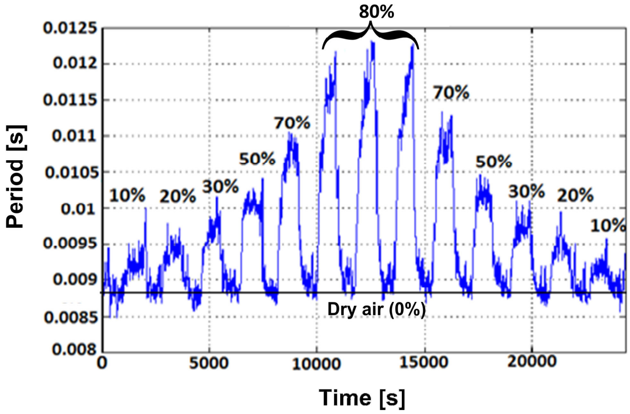


Fig 3. Experimental results of *RH* detection with the capacitive humidity sensor HCH-1000 Series by Honeywell: time response of the output period variations for different *RH%* values.

References

[1] De Marcellis A, Ferri G. *Analog Circuits And Systems For Voltage-Mode And Current-Mode Sensor Interfacing Applications*. Springer; ISBN 978-90-481-9827-6; 2011.

[2] De Marcellis A, Depari A, Ferri G, Flammini A, Marioli D, Stornelli V, Taroni A. A CMOS Integrable Oscillator-Based Front End for High-Dynamic-Range Resistive Sensors. *IEEE Trans. on Instr. and Meas*. 2008; **57**: 1596-1604.

[3] Depari A, Flammini A, Marioli D, Sisinni E, De Marcellis A, Ferri G, Stornelli V. A New And Fast-Readout Interface For Resistive Chemical Sensors. *IEEE Trans. on Instr. and Meas.* 2010; **59**: 1276-1283.

[4] Ferri G, De Marcellis A, Di Carlo C, Stornelli V, Flammini A, Depari A, Marioli D, Sisinni E. A CCII-based low-voltage low-power read-out circuit for DC-excited resistive gas sensors. *IEEE Sensors Journal* 2009; **9**: 2035-2041.

[5] Depari A, De Marcellis A, Ferri G, Flammini A. A complementary metal oxide semiconductor—integrable conditioning circuit for resistive chemical sensor management. *IOP Meas. Sci. and Tech.* 2011; **22**: 1-7.

[6] Lu JHL, Inerowicz M, Sanghoon J, Jong-Kee K, Byunghoo J. A Low-Power, Wide-Dynamic-Range Semi-Digital Universal Sensor Readout Circuit Using Pulsewidth Modulation. *IEEE Sensors Journal* 2011; **11**: 1134-1144.

[7] Malfatti M, Perenzoni M, Stoppa D, Simoni A, Adami A. A high dynamic range CMOS interface for resistive gas sensor array with gradient temperature control. *Proc. of IMTC* 2006; 2013-2016.

[8] Ferri G, Di Carlo C, Stornelli V, De Marcellis A, Flammini A, Depari A, Jand N. A single-chip integrated interfacing circuit for wide-range resistive gas sensor arrays. *Sensors & Actuators B* 2009; **143**: 218-225.

[9] De Marcellis A, Ferri G, Mantenuto P. A Novel OA–Based Oscillating Circuit for Uncalibrated Capacitive and Resistive Sensor Interfacing Applications. *Proc. of IMCS* 2012; 1707-1709.