Capacitive Sensor for Gaseous Substances, from Old to New

György Györök[1], Margit Makó[1], Borbála Györök[2], Olga Shvets[3]

[1] Óbuda University, Alba Regia Technical Faculty,
Budai Str. 45, 8000 Székesfehérvár, Hungary
{gyorok.gyorgy, margit.mako}@amk.uni-obuda.hu

[2] Óbuda University, Rejtő Sándor Faculty of
Light Industry and Environmental Engineering,
Doberdó st. 6, 1034 Budapest, Hungary
borbala.gyorok@cl.uni-obuda.hu

[3] D. Serikbayev East Kazakhstan Technical University
Protozanov Street 68, Ust-Kamenogorsk, Kazakhstan
oshvets@ektu.kz

***Abstract*—In a previous development, it became important to be able to detect changes in the concentration of certain gases in the air. To this end, we want to develop a capacitive sensor that can effectively detect very small changes in composition. To design such a sensor, we wanted to use an old capacitive component, the application of which is described in the following article.**
The capacitive sensor-processor circuit described in this paper, as a useful solution for operating a planar capacitor, can be advantageously used in the context of certain interactive suits, active wearable.
In this paper, the sensor itself, the analog-to-digital solution that interrogates the sensor, is presented.

I. Introduction

A few decades ago, rotary capacitors were widely used in electronic equipment, be it measuring instruments or even radio receivers. These were electronic components that consisted of a stator and a rotor disk package. By rotating a shaft, the position of the rotor could be changed, thus changing the effective surface area between the plates. Using this method, such air-insulated rotary capacitors could produce capacitance variations from a few pF to a few hundred pF [1][2].
The capacitance variation in a variable capacitor through an oscillator or filter in a circuit was an important means of determining frequency [3]. Nowadays, these components are much less important, but they can still be found in very large numbers and can be easily removed from older equipment [4][5].

The photo of the rotating capacitor shown in Fig.1 is a three-cell, $3x330pF$ capacitor. Other insulated rotary capacitors have been used, but are irrelevant for the present application.

II. Capacitor as Gas Sensor

We know from the theory of electricity that the capacitance of a planar capacitor depends on distant of plate (d), the surface of the plates facing each other (A) and the dielectric between the capacitor plates ($\varepsilon_0\varepsilon_r$), where ε_0 is permittivity of vacuum, ε_r relative value specific to the material; so $C = \varepsilon_0\varepsilon_r\frac{A}{d}$ [6][7][8].
When using such an air-insulated rotary condenser, changes in the air composition of this device are naturally associated with changes in capacitance. In this case, the relative change in the epsialon derived from the relationship will give a different value from the air or vacuum permittivity. Since such a capacitor is in contact with air or gas over a fairly large surface area, its capacitance can be greatly influenced for a

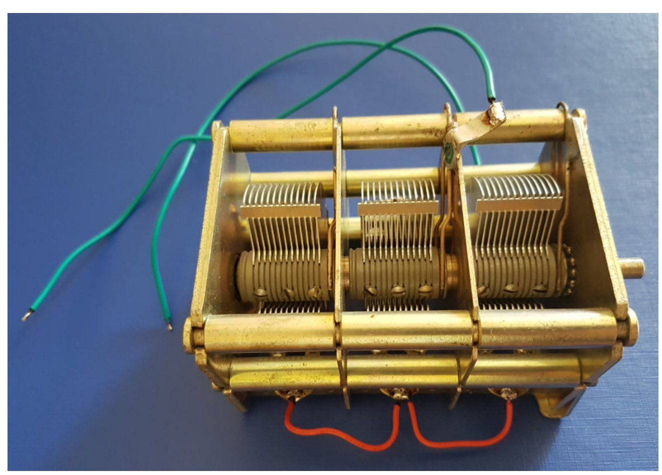

Fig. 1. Three-cell variable capacitor. The capacitance per cell is 330pF.

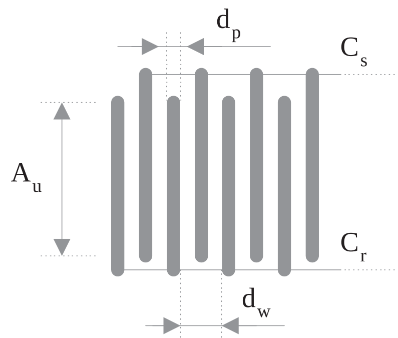

Fig. 2. Interpretation of rotary capacitor stator and rotor plates and derivation of useful surface area.

given rotor position (best when fully rotated).

Fig. 2 shows a simplified model of the capacitor. The stator (C_s) and rotor (C_r) plates are shown separately. The effective surface area of the plates is marked with A_u [9]. The distance between the stator plates is denoted by d_p, while the thickness of the rotor plates is denoted by d_w. Thus, the capacitance of the plate capacitor can be calculated using Equation 1.

$$C_v = n_c \varepsilon_0 \varepsilon_r \frac{2A_u}{d_w - d_d}, \tag{1}$$

where; n_c the number of cells, $\varepsilon_0 = 8.854187817 \cdot 10^{-12} \frac{As}{Vm}$.
With the approximate most accurate measurements, the capacitance is close to 1nF [10].
From the geometry ($A_u \simeq 5,6cm^2$, $d_p = 0,8mm, d_w = 0,6mm$) it is easy to calculate that the volume (V_d) of the dielectric (air, gas) in the capacitor is about $\simeq 40cm^3$. The volume of the dielectric between the arms of a capacitor is synonymous with the sensitivity and speed of the sensor [11][12].

III. Analogue Sensor circuit for capacitance change

We need a solution where the output signal of the sensor changes the most with the change in capacitance, the change in permittivity.
Frequency mixing, or heterodyne, is usually a good answer. In the commonly used solution shown in Fig.3, the signal

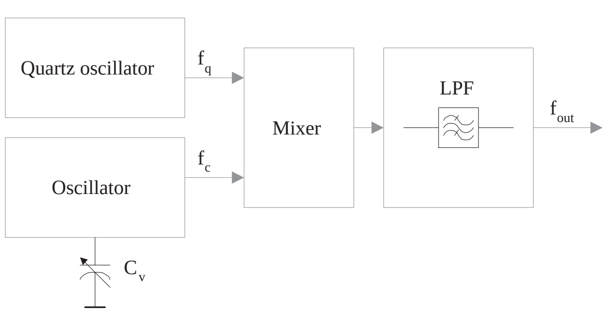

Fig. 3. Detecting the change in capacitance by changing the difference frequency between an oscillator and a reference oscillator.

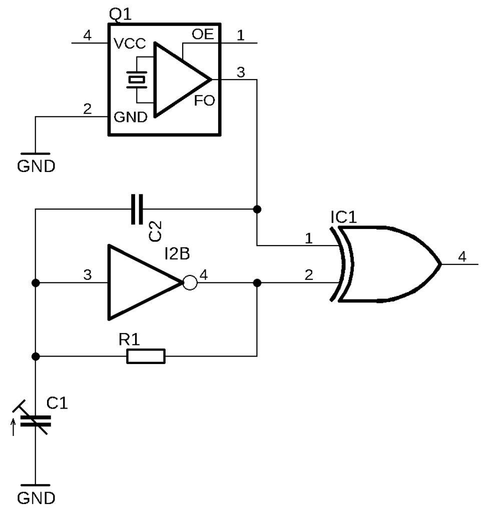

Fig. 4. Digital circuit for frequency or phase difference based capacitance difference detection.

from a fixed-frequency oscillator (f_q) is mixed with the signal from the capacitance-dependent (C_v) oscillator (f_c) and the difference frequency is selected using a low-pass filter (f_{out}). So we can formally write; $f_{out} = f_q - f_c$ [13].
As described in the equation 1, the equation follows 2;.

$$\Delta f_c = \mathbb{F}(\Delta C_v), \tag{2}$$

that is, Δf_c is some function of ΔC_v), where formally write (3);

$$\Delta C_v = \mathbb{G}(\Delta \varepsilon_r). \tag{3}$$

To achieve a high sensitivity, even with small changes in capacitance, a significant frequency difference must be achieved using relatively high frequency values. The experimental example operated at 10MHz. Also important is the stability of the reference oscillator, which in practice is quartz-precision [14][15].
In this case, it is the change in output frequency and its magnitude that provides information about the change in capacity [16] [17].
Our "gas detection" device was tested for CO_2 and O_3 gases. The change in capacitance was detectable even for not very exact measurements, the value was not greater than 0,3% (a few pF) [18].

IV. Digital Sensor circuit for capacitance change

On Fig. 4 is a circuit solution to detect the change in capacitance.
Capacitor (C_1) at the input of inverter (I_2B) is charged with resistor (R_1). When the comparator level is reached, the output of the inverter goes low and C_1 discharges. The frequency can be determined approximately; $f = \frac{1}{2\pi R_1 C_1}$. The $Q1$ is a quartz oscillator. Its output ($Q1_3$) and the output of the oscillator ($I2B_4$) are connected to the inputs of an exclusion gate (IC_1). An important part of the circuit is C_2, which synchronizes the

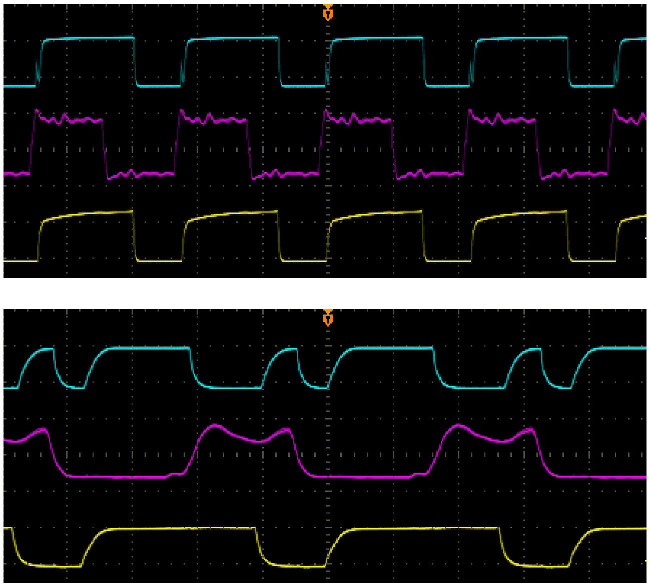

Fig. 5. Output signals of the phase change detection circuit (yellow for the output of the reference oscillator, purple for the output of the RC oscillator, blue for the output of the EXOR). C_1 $1nF$ and $f_{Q1} = 1MHz$ in the upper figure, C_1 $700pF$ and $f_{Q1} = 6MHz$ in the lower figure.

I2B oscillator to the quartz oscillator signal [19].
A signal appears at the output of IC1 when a signal change occurs if there is a phase difference or change in phase between the output signal of Q_1 and the output signal of *I2B*. Since the frequency of $I2B_4$ is a function of C_1, the output of IC_1 will also be a function of C_1 [20].
Fig. 5 shows the typical circuit in Fig. 4 at two capacitance values. For the experiment, two reference oscillators with different frequencies and the RC oscillator synchronized to them were also tested.

V. Specific application, specific field

The fashion industry (Fig. 6) can also use the capacitive principle sensor and its special application as a threshold switch. The digital circuit shown in the figure can be used for this purpose. In this case, the output of the sensor is not the magnitude of the change in capacitance, but its state relative to a threshold value. In this case, this could mean a change in the position of a bodily surface (palm movement) [21]. In this case, a certain response can be given within the limits of the designer's imagination. Different lighting effects are shown in the figure [22].
The "closing in" of the environment in active clothing can be perspective. In this case, the wearer can expect reactions that depend on the social environment. The correlation between carbon dioxide-rich air and room occupancy warrants further investigation [23].
This application - by nature - requires a different capacitor design [24]. A sandwich structure capacitor (Fig.2) strapped with a porous material (special polymer) could be a perspective [25].
Also in perspective is the capacitance retrieval technique,

Fig. 6. Interactive fashion products on the actuator side. Color LEDs as indicators of the wearer's "emotion".

where the digital input circuit of a microcontroller is measured with an internal TIMER peripheral to measure the time-delay variation [26][27].

VI. Conclusions

With this article, we wanted to present a re-use of an existing device that can be used with some ingenuity and care. To this end, we have proposed two processing circuit techniques, with the proviso that a conventional technique using cap-sense can also be used if sufficiently sensitive.
The capacitance-change detection circuit as a method predicts a new field of application in the context of interactive clothing.
All the areas highlighted in this paper are the beginning of a specific field that will require further research, often under laboratory conditions.

References

[1] Gy. Györök. Pwm tesztgenerátor. In *Alkotás/MTMT*, 2018.
[2] L. O. Chua. *Computer aided nalyss of electronic circuit*. Prentice-Hall INC., New Jersey, USA., 1975.
[3] J. F. Wakerly. *Digital design*. Prentice-Hall, Newjersey, USA., 2001.
[4] B. Beszédes. Reliable presence and intrusion detection with collaborative sensor modules in electronic property protection systems. In *SAMI 2019, IEEE 17th World Symposium on Applied Machine Intelligence and Informatics*, pages 354–360, Feb 2019.
[5] Tolner N.; Beszédes B. Cseh D. Györök, Gy.; Dávid. *Supervision of the operation of digital circuits by Embedded Microcontroller*. 13th International Symposium on Applied Informatics and Related Areas: AIS 2018, Óbuda University: Budapest, Hungary,, 2018.
[6] Gy. Györök. *Continuous Operation Monitoring of Electronic Circuits with Embedded Microcontroller*. IEEE 18th International Symposium on Computational Intelligence and Informatics (CINTI 2018), Budapest, Hungary, 2018.
[7] A. Y. Baklanov; A.E.Baidildina; S. Grigoryeva; Gy. Györök. *Optimization of the work of LED lighting systems*. The Public fund editorial publishing center.
[8] Gy. Györök. *Interactive Monitoring of Serial Electronic Circuit with Embedded Microcontroller*. IEEE 23nd International Conference on Intelligent Engineering Systems: proceedings (INES 2019), Budapest, Hungary, 2019.
[9] C. K. Sedra, A. S.; Smith. *Microelectronic circuit*. Oxford University Press, New Yor, Oxford, 1998.

[10] B. Beszédes; K. Széll; Gy. Györök. *A Highly Reliable, Modular, Redundant and Self-Monitoring PSU Architecture*. ACTA POLYTECHNICA HUNGARICA 17: 7, Budapest, Hungary, 2020.

[11] Gy. Györök; B. Beszédes. *Concept of a Reliable Redundant Off-grid Power Supply Chain*. IEEE 13th International Symposium on Applied Computational Intelligence and Informatics: SACI 2018, Timisoara, Romania, 2019.

[12] Grigoryeva Y.; Koshubaev Z. Baklanov, A. Y.; Györök. *Embedded LED lamp control system based on the ESP8266 microcontroller*. 14th International Symposium on Applied Informatics and Related Areas: AIS 2019, Óbuda University: Budapest, Hungary, 2019.

[13] A. Zhaparova; D. Titov; A. Y. Baklanov; Gy. Györök. *Study of the Effectiveness of Switching-on LED Illumination Devices and the Use of Low Voltage System in Lighting*. The ACTA POLYTECHNICA HUNGARICA 12: 3, Budapest, Hungary, 2015.

[14] Gy. Györök; B. Beszédes. *Duplicated Control Unit Based Embedded Fault-masking Systems*. IEEE 15th International Symposium on Intelligent Systems and Informatics: SISY 2017, New York, United States of America, 2017.

[15] Gy. Györök; B. Beszédes. *Fault-tolerant Software Solutions in Microcontroller Based Systems*. 12th International Symposium on Applied Informatics and Related Areas: AIS 2017, Óbuda University, Budapest, Hungary, 2017.

[16] Kaliyev Daniyar, Shvets Olga, and Gyrgy Gyrk. Uav based navigation system for forest fires monitoring. In *AIS 2021-16th International Symposium on Applied Informatics and Related Areas - Proceedings*, pages 47–50, 2021.

[17] SHVETS OLGA, SMAKANOV BAUYRZHAN, Levente Kovcs, and Gyrgy Gyrk. Intelligent system for driver support using two classifiers for simulation. *JOURNAL OF THEORETICAL AND APPLIED INFORMATION TECHNOLOGY*, 100:4767–4782, 2022.

[18] Gyrgy Gyrk and Shvets Olga. Adaptive ozone generator with embedded microcontroller. In *2022 IEEE 26th International Conference on Intelligent Engineering Systems (INES 2022)*, pages 155–158, 2022.

[19] Bertalan Beszdes and Gyrgy Gyrk. Nagy megbzhatsg, egy tengely mentn forgathat fotovoltaikus feszltsgforrs. *BIZTONSGTUDOMNYI SZEMLE*, 3:73–83, 2021.

[20] Dr. Gy. Györök. Mikrokontrollerek és programozható analóg áramkörök egyedi alkalmazásai. In *'Obudai Egyetem, Disszertáció benyújtásának éve: 2015, Védés éve: 2015 Megjelenés/Fokozatszerzés éve: 2015*, pages 1–40, 2015.

[21] Bertalan Beszdes, Kroly Szll, and Gyrgy Gyrk. Redundant photo-voltaic power cell in a highly reliable system. *ELECTRONICS*, 10:1253–1273, 2021.

[22] Gy. Györök. *The Veterinary Horse Circuit for a Microcontroller Supervised System*. IEEE 16th International Symposium on Intelligent Systems and Informatics (SISY 2018), Budapest, Hungary, 2019.

[23] Gyrgy Gyrk. Interactive monitoring of electronic circuits with embedded microcontroller. In *2021 IEEE 19th World Symposium on Applied Machine Intelligence and Informatics (SAMI)*, pages 000223–000228, 2021.

[24] Dr. Gy. Györök. Számítógép perifériák ii. (háttértárak). In *Budapest, Magyarország: Óbudai Egyetem, Alba Regia Müszaki Kar (2015)*, pages 1–60, 2015.

[25] Gy. Györök; B. BeszédesFHighly. *Adaptive optocoupler degradation compensation in isolated feedback loops*. IEEE 12th International Symposium on Applied Computational Intelligence and Informatics: SACI 2018, Timisoara, Romania, 2018.

[26] Gy. Györök; A. Y. Baklanov; B. Beszédes. *Extension of Nodal Voltage Method with the Thermosensing*. 12th International Symposium on Applied Informatics and Related Areas: AIS 2017, Óbuda University: Budapest, Hungary,, 2017.

[27] Gy. Györök; B. Beszédes. *Highly reliable data logging in embedded systems*. IEEE 16th World Symposium on Applied Machine Intelligence and Informatics: SAMI 2018, Seattle (WA), United States of America, 2018.