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*APPLIED PHYSICS*

# DETERMINATION OF TWO-LIQUID MIXTURE COMPOSITION BY ASSESSING DIELECTRIC PARAMETERS
## 1. PRECISE MEASURING SYSTEM

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Concentration measurements are important in bioethanol industries, in the R&D areas, for chemical, medical and microbiological analyses and processing as well as for diagnostics, manufacturing, etc. The overview shows development of the structural design of a system for measuring the concentration of solutions and mixtures consisting of two dielectric liquids. The basic principles of the system's design are given along with relevant equations. The concentration of dielectric liquids is measured using devices with capacitive sensors (1–300 pF). The operational frequency of the developed measuring system is 100.000 kHz. Configuration of the system excludes some errors usually arising at measurements, and broadens its applicability. For testing, the system was calibrated for measuring the concentration of anhydrous ethanol + de-ionized water mixture. Experimental results have shown a stable resolution of ±0.005 pF at measuring the sensor capacitance and a reproducible resolution better than ±0.01% at measuring the ethanol volume concentration.

**Key words:** *dielectric liquid, capacitive sensor, impedance measurement, dielectric constant*

## 1. INTRODUCTION

Like all other materials, dielectric liquid has a unique set of electrical characteristics depending on its dielectric or insulating properties. Accurate measurements of relevant liquid parameters can provide valuable information which makes it possible to ensure a certain manufacturing process, obtain proper biological or medical data, etc.

Concentration measurements are important for determination of the water, alcohol, oil, gasoline (or other fuels) composition as well as for analysis and control of processes in chemical, petrochemical, pharmaceutical, food and other industries [1]. Capacitive sensors are also used in biology, microbiology and medicine for detection of antigens, antibodies, proteins, DNA fragments, etc. [2].

A capacitive sensor is the sample probe for detection and quantification of the content composed of different components of dielectric liquid using their electrical characteristics. The sensor presents two metallic electrodes (plates) with a gap filled with dielectric liquid. The detection mechanism of capacitive sensor is based on the variations of liquid dielectric constant (permittivity), which in the simplest form are described by the equation:

$$C = (\varepsilon_r \varepsilon_0 A)/d, \qquad (1)$$

where: $C$ is the capacitance between electrodes (plates);
$\varepsilon_r$ is the relative dielectric constant of the medium between plates;
$\varepsilon_0$ is the dielectric constant of free space ($\varepsilon_0$ = 8. 85419 pF/m);
$A$ is the area of plates;
$d$ is the distance between plates.

Thus, the capacitance will change at variations in dielectric properties of the liquid between electrodes. If the space between electrodes is filled with liquid consisting of two substances with different dielectric constants, the dielectric constant of the composition will vary depending on the volume or mass ratio of the two substances.

As follows from Eq. (1), homogeneous dielectric materials can be described by the model (based on the electric field theory) in which capacitance is increasing proportionally to the dielectric constant of the material. However, many liquids are to be characterized by more complicated electrical properties than only dielectric constant and resistance. The electric field theory does not consider the charge transfer by ionic conduction across electrodes, with conversion of electrons into ions for which the activation energy is needed [3]. In practice, measurements depend on the surface properties of electrodes, their polarization, and other factors. To avoid problems caused by long-term polarization, the alternating current (AC) method is used for measuring the electrical impedance or its inverse (admittance). According to this method, a symmetrical bipolar periodic excitation signal (electrical current or voltage) is applied to the capacitive sensor with dielectric liquid.

The liquid filled in the space between electrodes of a capacitive sensor determines electrical properties of this sensor – the impedance or the admittance (depending on the interconnection of equivalent circuit elements), which, along with equivalent capacity $C_x$ and resistance $R_x$ provides the information about the properties of liquid. In a simplified model we consider an equivalent $C_x$, $R_x$ circuit connected in parallel. Therefore, if the liquid is composed of two or more miscible dielectric liquids, the measured capacitance will be proportional to the concentration of liquid [1].

In practice, parameters $C_x$ and $R_x$ of the sensor are measured using the sinusoidal excitation current with frequencies from one to several hundred kHz. As shown in [1, 4], the electrode effects are diminished and become negligible at a frequency of 100 kHz. In addition, it should be noted that using AC voltage above 500 mV rms leads to dissociation of the liquid molecules, which makes the measuring results unreliable. Most investigators use voltage from 5 mV up to 300 mV rms, which is considered acceptable. The results of dielectric liquid concentration measurements depend on the sample temperature; therefore, it is necessary to measure also the temperature. Using the measurement data and based on the equations obtained in the calibration process, it is possible to find the correct value of concentration at a chosen reference temperature (usually 20 °C).

As a rule, the values of capacitance variation are too small to detect them, therefore diversified detection circuits like a diode bridge, a switch capacitor and synchronized circuits have been developed [5, 6]. To determine capacitance $C_x$ with high precision and to obtain a cheap and compact measuring device we used the synchronous detection technique, with a phase-sensitive synchronous detector for separation of a signal's useful components from the complex one. Such detector (also known as a phase-sensitive detector or a lock-in amplifier) possesses a system for simultaneous processing of signal components and is devoid of the low-frequency 1/f noise at AC measurements; the detector is immune to the background noise since it detects only the sin-phase signal. The phase detection circuit is designed in a way that it can be easily integrated with a microcontroller.

## 2. BASIC PRINCIPLES UNDERLYING THE MEASURING SYSTEM AND RELEVANT EQUATIONS

Impedance and admittance are parameters that are commonly used to describe the electrical RC circuit. The equivalent capacitance $C_x$ and resistance $R_x$ of the sensor in Fig. 1 are connected in parallel to the sensor's excitation source (here and below the sinusoidal currents and voltages are represented by their respective maximum values). Voltage $V$ is considered as the reference for determination of the current through each circuit element. In our AC circuit analysis it is mathematically expedient to use the admittance $\boldsymbol{Y} = 1/\boldsymbol{Z}$, since the total admittance of parallel elements is simply a sum of individual admittances. The $R_x$ and $C_x$ values in this case are ideal resistance and ideal capacity.

As known, the current in the circuit with resistance $R_x$ is:

$$I_{Rx} = V(1/R_x) = VY_{Rx}, \tag{2}$$

with no phase shift between voltage and current. Thus, current $I_{Rx}$ is in zero-phase (zp) (or in-phase) against voltage $V$.

Current $I_{Cx}$ flowing through capacitor $C_x$ with reactive conductivity (susceptance) will lead the voltage $V$ by $90^{\circ}$ (quadrature phase (qp)). This phase shift in $C_x$ requires the use of complex numbers. The capacitive reactance is defined as $X_c = 1/(\omega C_x)$, where $\omega = 2\pi f$ is the angular frequency (rad/s), and, using the complex quantity expressed in rectangular coordinates, is $(-jX_c)$. Current in the circuit with capacitance $C_x$ is:

$$\boldsymbol{I}_{Cx} = V/(-jX_c). \tag{3}$$

The total current through $R_x\ C_x$ circuit of the sensor according to Eqs. (2) and (3) will be:

$$\boldsymbol{I} = V/R_x + V/(-jX_c), \quad \text{or} \quad \boldsymbol{I} = V/R_x + j(V/X_c). \tag{4}$$

Dividing each term in (4) by $V$ and taking into account that $X_c = 1/\omega C_x$, we obtain the total conduction of parallel $R_xC_x$ circuit representing the unknown admittance of capacitive sensor:

$$\boldsymbol{Y}_s = 1/R_x + j\omega C_x. \tag{5}$$

In Eq. (4) the real part is related to dissipative (resistive) component $I_{zp}$ (the phase ($zp$) coinciding with that of applied voltage $V$):

$$I_{zp} = V/R_x. \tag{6}$$

The imaginary (quadrature) part is related to capacitive (reactive) component $I_{qp}$ of current $\boldsymbol{I}$:

$$I_{qp} = V\omega\, C_{x.} \tag{7}$$

As follows from Eq. (7), the quadrature component of current $I_{qp}$ is a linear function of the sensor's effective capacitance $C_x$ and is independent of effective resistance $R_x$. Therefore, to assess the dielectric liquid parameters such as the dielectric constant and capacitance correlating with the concentration of liquid, only the imaginary component $I_{qp}$ of current $\boldsymbol{I}$ flowing through the sensor is required. Wherewith, it is no need to determine the value of sensor resistance $R_x$ and the phase angle between voltage $V$ and current $\boldsymbol{I}$, which simplifies the mathematical calculations. Therefore, we can obtain very simple measuring system and method for determination of the liquid properties.

The synchronous detection method was employed here to extract either quadrature $I_{qp}$ or in-phase $I_{Izp}$ components of the complex current $\boldsymbol{I}$ flowing through the unknown sample. The synchronous detection is based on the orthogonality of sine and cosine functions and is illustrated by the block diagram in Fig. 1.

In the developed measuring circuit two single-chip micro-systems, DDS1 and DDS2, are used. These present direct digital synthesizers for generating the signals in a new configuration, which differs from the manufacturer's recommended.

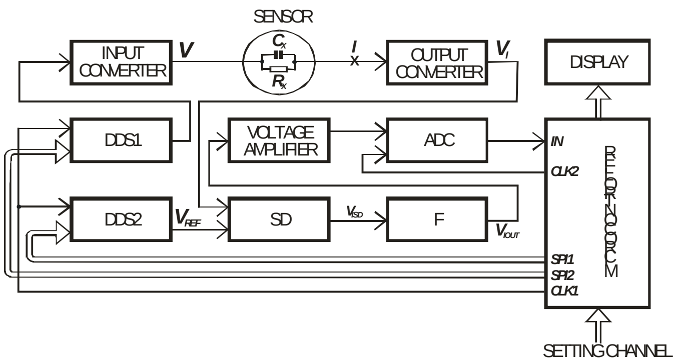


*Fig. 1.* Block diagram of the measuring system for determination of the liquid/liquid concentration.

The micro-system DDS1 is used to generate highly precise and stable sinusoidal voltage supplied to the input of INPUT CONVERTER, Fig. 1. The output of this converter serves as a power source with low output impedance for SENSOR and is connected directly to the sensor's input terminal. In turn, the SENSOR's output terminal is connected to the low-ohmic input of OUTPUT CONVERTER, which closes the path for excitation current through SENSOR. If the inverting converter is used as the OUTPUT CONVERTER of the measuring device (Fig. 1), the sinusoidal output voltage will be converted with respect to the

DDS1 output voltage. Thus, voltage ($-V$) causes current $\boldsymbol{I}$ to flow through the sensor. This current is supplied directly to the input of the OUTPUT CONVERTER, where usually the inverting operational amplifier is used as the current-voltage converter with feedback resistance $R_0$. This converter is reconverting voltage ($-V$) in accordance with well known equation $\boldsymbol{V_I} = -(-\boldsymbol{I}R_0)$. Taking into account the complex current $\boldsymbol{I}$ (4), we will write:

$$\boldsymbol{V_I} = VR_0\,[1/R_x + j(1/X_c)]. \tag{8}$$

The real and the imaginary components are:

$$V_{Izp} = VR_0\,/R_x, \tag{9}$$

$$V_{Iqp} = VR_0\,/X_c. \tag{10}$$

Extraction of each component of complex signal $\boldsymbol{V_I}$, is based on the synchronous detection technique described above. The phase-sensitive detector separates either the zero-phase component or the quadrature phase component from the complex current through the sensor's unknown admittance $\boldsymbol{Y_s}$. This is achieved by multiplying voltage $\boldsymbol{V_I}$ (signal channel) with reference voltage $V_{REF}$ (reference channel), and integrating with a low-pass filter in a specified period of operation. The resultant signal is essentially a DC one.

The second micro-system (DDS2) in our case is used as the source of reference signal generating the rectangular signal $V_{REF}$. Signals from generators DDS1 and DDS2 are synchronized with the microcontroller's clock signal (*CLK 1*), which makes it possible to generate the reference voltage $V_{REF}$ and the sensor's supply voltage $V$ in a definite sequence. Two separate serial peripheral interface SPI buses are arranged to control both generators. The operation mode of each DDS is set automatically before the start of measurements. After the control signal's command *reset*, each DDS installs the data to generate signals of definite shape and frequency. In addition, DDS2 receives instruction for output signal $V_{REFqp}$ relative to the phase shift settings. The installation procedures are automatically repeated every 3 min to prevent correlation errors of both DDS-synthesized signals which can accumulate over a longer measurement time. In the manner described, the microcontroller controls the phase shift between two DDS output signals. In our case this shift can be set in such a way that the DDS2 rectangular output reference voltage $V_{REFqp}$ will lead the sinusoidal excitation voltage $V$ by $90^o$ (quadrature phase), since for measuring the sensor's capacitance $C_x$ (8) (correlating with the detectable concentration of a liquid) the quadrature (imaginary) component of signal $\boldsymbol{V_I}$ is required. To achieve this, signal $\boldsymbol{V_I}$ (Fig. 1) should be multiplied by quadrature reference signal $V_{REFqp}$.

In practice, this synchronous detection procedure can be realized by the synchronized analog electronic switch: it is turned *off* at the normal state and *on* at a positive half-period of reference voltage $V_{REFqxxx}$. If the switch is *off*, output signal $V_{ISD}$ of synchronous detector SD (Fig. 1) corresponds to the input voltage $\boldsymbol{V_I}$ multiplied by 1, and if the switch is *on* – to the $\boldsymbol{V_I}$ multiplied by 0. Therefore, it is possible to assume that this SD stage carries out the function of the phase-sensitive multiplier and performs synchronous detection of the half-period voltage $V_{ISD}$**.** Since some electronic elements and components of the measuring system cause parasitic phase shifts during measurements, especially important is the ability to adjust reference voltage $V_{REFqp}$ by a precise quadrature phase shift in relation to the sensor's excitation voltage $V$. Therefore, in our case the phase installation is performed using the same measuring system. For this purpose, the sensor is alternately replaced by resistors $R_1$ and $R_2$ with different resistances (e.g. $R_1$ =10 kΩ; $R_2$ = 50 kΩ), and the output voltage of measuring system is determined by notional units $n_1$, $n_2$. Alternately repeating these measurements at different phases of the reference signal, it is possible to fix the phase at which the absolute difference between $n_1$ and $n_2$ values is the lowest. Thus, it is possible to set and provide the precise fulfilment of above conditions for the quadrature phase, and automatically compensate the parasitic phase shift inside the measuring system. For this, the separate frequency and phase installing channels of MICROCONTROLLER (Fig. 1) are designed.

Using mathematical modelling it is possible to demonstrate the diagram of SD output signal voltage quadrature component defined above as $v_{ISD} = v_{IqpSD}$, where

$$v_{IqpSD} = \left[V_{\mathbf{I}} \cdot \sin\left(\omega - \theta\right)\right] \cdot \left[\frac{1}{2} - \frac{A}{\pi} \cdot \left[\sum_{n=1}^{500} \frac{\left(-1^n\right) - 1}{n}\right] \cdot \sin\left(\omega \cdot n - n \cdot \psi\right)\right]. \qquad (11)$$

The first part of Eq. (11) in square brackets characterizes sinusoidal voltage $V_I$ supplied to the synchronous detector signal input and corresponds to the sensor's excitation current. Initial phase $\theta$ of this voltage can vary from $0^o$ to $90^o$, depending on the active resistance and reactance relationship: $\theta = \mathrm{arctg}(R_x / X_c)$. The second residual part of Eq. (11) characterizes the reference channel's rectangular voltage $V_{REF} = V_{REFqp}$, which can be approximated by a rectangular Fourier's series and leads the sinusoidal excitation voltage $V$ by $\psi = 90^o$ (see Fig. 2*a*). As an example, the AC voltage amplitude $A = 1$ is taken. On the amplitude-phase diagram of Fig. 2*b* the shape of voltage $v_{IqpSD}$ is the result of a half-period synchronous detection by phases from $0.5\pi$ to $1.5\pi$, which corresponds to the separated part of the complex current at voltage $\boldsymbol{V_I}$ characterizing in this case the imaginary (quadratic) component. If the sensor presents a pure resistance $R_x$, the average value $V_{IqpSD}$ is zero ($\theta_1 = 0^o$, Fig. 2).

The average value is the greatest at $\theta_4 = 90^o$. In this case the average values of voltage quadratic component for a full period can be expressed as

$$V_{IqpOUT} = \frac{1}{2\pi} \cdot \int_{0.5\pi}^{1.5\pi} V_I \cdot \sin(\omega - \theta) d\omega \ . \qquad (12)$$

The variations in DC voltage $V_{IqpOUT}$ depending on phase angle $\theta$ and voltage amplitude $V_I$ are shown in Table 1.

*Table 1*

**DC voltage $V_{IqpOUT}$ at different phase angles $\theta$ and voltage amplitudes $V_I$**

| $\theta$ | $\theta_1 = 0^o$ | $\theta_2 = 30^o$ | $\theta_3 = 60^o$ | $\theta_4 = 90^o$ |
|---|---|---|---|---|
| $V_{IqpOUT}$ | 0 | $V_I \cdot 0.159$ | $V_I \cdot 0.276$ | $V_I \cdot 0.318$ |

Using the measuring system depicted in Fig. 1, voltage $v_{IqpSD}$ is supplied to the first or a higher order low-pass FILTER, whose output voltage $V_{IOUT}$ can be measured directly, without measuring angle $\theta$ and amplitude $V_I$. This considerably simplifies the measurement procedure and the measuring device.

At $X_c = 1/(\omega C_x)$ and $\omega = 2\pi f$, taking into account Eq. (10), we have:

$$V_{IqpOUT} = 2\pi f\, V R_0\, C_x \;, \tag{13}$$

and

$$C_x = V_{IqpOUT} \,/\, (2\pi f\, V R_0). \tag{14}$$

The output voltage $V_{IqpOUT}$ varies depending on the sensor's effective capacitance $C_x$, and practically is not affected by effective resistance $R_x$ of the sensor.

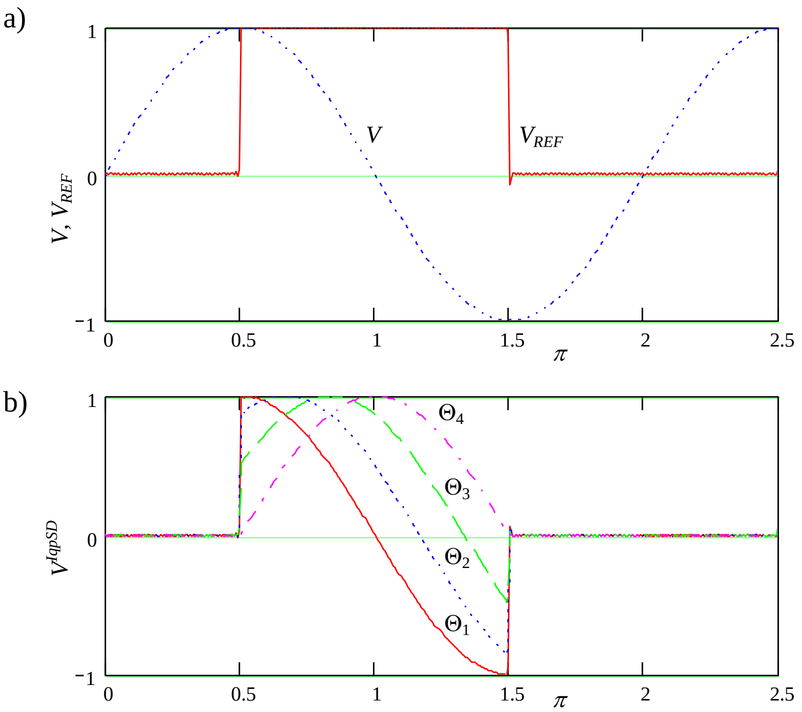


*Fig. 2.* The calculated amplitude-phase diagrams: *a*) sensor excitation voltage $V$ and reference voltage $V_{REF}$ of synchronous detector (SD); *b*) output voltage $v_{IqpSD}$.

In Fig. 2*a*, the rectangular output reference voltage $V_{REF}$ is by $\pi/2$ ($90^{o}$) leading the sinusoidal excitation voltage $V$. The output voltage of synchronous detector (SD) $v_i = v_{IqpSD}$ (Fig. 2*b*) is depending on the relation of sensor's active resistance to reactive reactance $R_x/X_c$, which is characterized by phase angle $\Theta = \text{arctg}\,(R_x/X_c)$.

Thereby, the effective sensor capacitance $C_x$ can be determined if we know voltage $V_{IqpOUT}$, voltage $V$, frequency $f$, and the resistance of feedback resistor $R_0$, which all together characterize the concentration of a dielectric liquid.

Using signal $V_{REFzp}$ in the reference channel with the same phase as that of sensor feeding voltage $V$ it is possible to separate the in-phase component (9) of the complex current (characterized by voltage $\boldsymbol{V_I}$ ) and to determine the sensor's effective resistance:

$$R_x = (VR_0)/V_{IzpOUT} . \tag{15}$$

Voltage $V_{IOUT}$ is connected to the input voltage amplifier, whose output is connected to the analog-to-digital converter ADC (Fig. 1). The ADC output is connected directly to the MICROCONTROLLER's input *IN.*

Besides, the half-wave synchronous signal detection (if the half of input signal $\boldsymbol{V_I}$ period is taken) it is possible to use the full-wave synchronous detection [7], which allows increasing the detected signal. However, for this it is necessary to supplement the measuring channel with on-off devices, which not only complicates the measuring device but also introduces errors into the detection results. As practice shows, the half-wave detection gives good results.

## 3. RESULTS OF TESTING THE MEASURING SYSTEM AND ITS IMPLEMENTATION

The output signal, which is proportional to sensor's capacitance of the described system for measuring the dielectric liquid concentration, should be converted to the corresponding concentration value. For this purpose it is necessary to perform the system's calibration. The conversion proportionality factor is different for various dielectric liquids, and may vary nonlinearly in the range of concentration values. Besides, to determine the sample concentration at different temperatures, the temperatures and corresponding concentrations must be measured, mathematically estimated and then corrected with reference to the standard temperature. The percent volume concentration also should be calculated.

Taking into account these considerations and basing on Eq. (14), testing the developed measuring system for the quality parameter was carried out by replacing the capacitance sensor with an equivalent circuit (a resistor and a capacitor in parallel), whose electrical parameters suit the sensor with liquid equivalent parameters $R_x$, $C_x$ thus simulating a real sensor. The exact $R_x$, $C_x$ values were determined using a highly precise meter (LCR-821) at the frequency 100.000 kHz. The meter is installed in the measuring system.

The proposed measuring system in its operation provides high precision and stability of the direct digital synthesizer AD9833 (DDS1, DDS2, see Fig. 1).

The chosen DDS has a 12-bit phase resolution, and the selected phase value can be set with the resolution $\Delta\varphi = 360^o/2^{12} = 360^o/4096 = 0.088^o$.

The input and output converters are developed using 24 MHz rail-to-rail dual amplifiers (AD8646) as inverting ones.

The half-period synchronous detection was carried out using 74HC4066 type high-speed analog switches and a first-order low-pass filter. The filter's output is connected to the non-inverting 10-fold voltage amplifier LMC6081 whose output is connected directly to the analog-to-digital converter's (ADC) input. In the measuring system a 19-bit AD7789 converter was used.

The use of an individual non-integrated ADC made it possible to achieve a greater resolution and to exclude microcontroller's noises.

The microcontroller (ATXMEGA 128A3) was used not only to perform control over the measuring system but also for processing and registration of mathematical data; it is easily compatible with the LCD module (PH240320T) displaying the relevant output signals.

During the tests, the sensor system was replaced with an equivalent variable capacitor *C*, which simulates the sensor's equivalent capacitance $C_x$ in the range 10 pF – 170 pF. This range fits the measuring system, which was calibrated to measure the concentration of ethanol.

The 10 kΩ resistor simulating the sensor's equivalent resistance $R_x$ was connected in parallel to capacitor *C* to approximate measurements to the real conditions of measuring the dielectric liquid concentration.

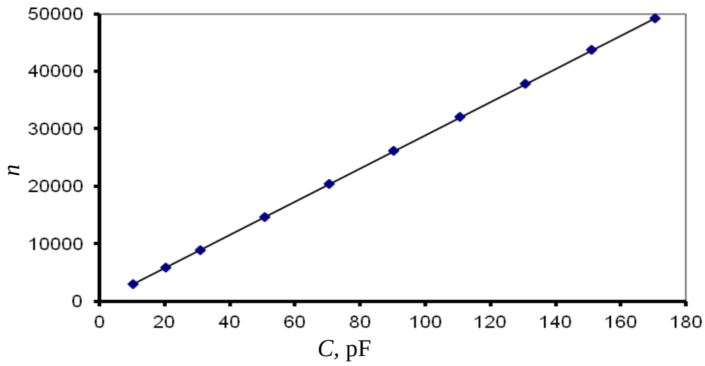


*Fig. 3.* Output voltage of the measuring system in notional units (*n*) depending on equivalent capacitance *C*.

The measurement results in Fig. 3 show that the measuring system's output voltage (expressed in notional units *n*) is increasing linearly (with squared correlation coefficient $R^2$ = 0.99983), depending on each measured capacitance *C* value. The resolution of capacitance measurements after conversion and mathematical processing by microcontroller was not worse than ± 0.05pF.

The developed system was calibrated for measuring the volume concentration of anhydrous ethanol+de-ionized water mixture to find out the system's capabilities. Since water has a higher dielectric constant than ethanol, with increasing water content in the mixture the measured capacitance increases.

Readings of the measuring device show that it is possible to provide stable results for the volume percent of ethanol in the mixture at ± 0.01% resolution (for details see upcoming articles).

Under test was also the system's ability to separate only the imaginary capacitive component of the total current flowing through the sensor which correlates with sensor capacitance $C_x$ and liquid concentration. For this purpose the sensor was replaced by variable capacitor and resistors $R_1$ and $R_2$. For each of the measured capacitance values *C* two values were obtained for the measuring system's output voltage (in notional units $n_1$, $n_2$). In this case, resistors $R_1$ = 200 kΩ and $R_2$ = 10 kΩ were sequentially connected in parallel with the variable capacitor. Such 20-fold raised resistance impact on the measured capacitance can be expressed in percent using simple calculations: $\Delta n = ((n_1 - n_2)\cdot 100)/n_1$ and $\Delta C = ((C_1 - C_2)\cdot 100)/C_{1,}$ (Fig. 4), with $C_1$ and $C_2$, measured by the LCR-meter.

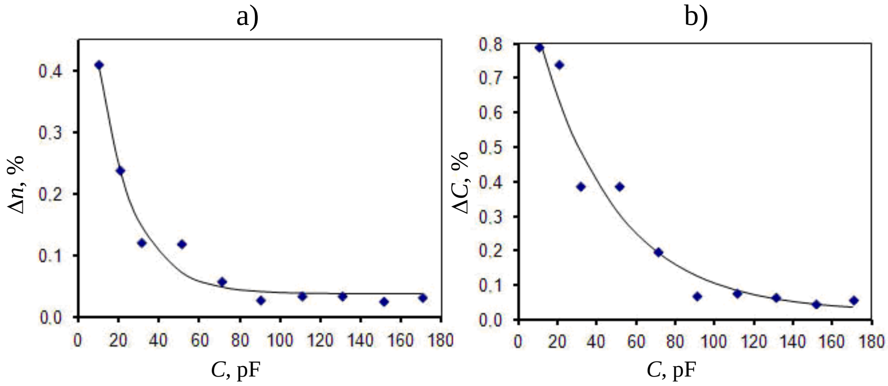


*Fig. 4*. Percentage of capacitance measurement deviations (characteristic parameters $\Delta n$ and $\Delta C$) caused by definite resistance variation in the measuring circuit according to the measured capacitance $C$: *a*) using the proposed measuring system, *b*) using a high-precision LCR-meter.

Comparison of $\Delta n(C)$ and $\Delta C(C)$ in Fig. 4*a* and Fig. 4*b* shows that the developed measuring system is less sensitive to the resistivity variations in the measurement circuit than the professional high-precision LCR-821 meter.

## 4. CONCLUSIONS

We have demonstrated a novel measuring system suitable for measuring the capacitance (ranging from 1 pF to 300 pF) of the sensor for assessment of the dielectric liquid concentration.

The measuring system makes it possible to reduce the effects of parasitic shifts in separate electronic stages and components of measuring circuits. This is achieved with one-time initial adjustment of the required phase conditions using the same measuring system and a specially set procedure, which together provide high accuracy of measurements. The developed measuring system (calibrated for measuring the concentration of anhydrous ethanol + de-ionized water mixture) has been shown a good performance.

Experimental results have demonstrated the stable resolution of ±0.005 pF at measuring the sensor's capacitance, and the reproducible resolution better than ± 0.01% at measuring the ethanol volume concentration. The proposed measuring system can easily be applied as a universal impedance or capacitance meter.

The proposed system is simple enough to be implemented and put into mass production. The circuit components are highly integrated, and the device can be designed compact and small-sized. The adjustment of the system can be carried out easily and fast.

The estimated cost of one measuring unit is not high (even at a batch production ~ 100 EUR); therefore, the proposed measuring system is cheap, besides it is intelligent, precise, adaptable, and portable.

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## DIVU ŠĶIDRUMU MAISĪJUMA SASTĀVA NOTEIKŠANA, IZVĒRTĒJOT TO DIELEKTRISKOS PARAMETRUS 1. PRECĪZA MĒRĪŠANAS SISTĒMA

O. Vilītis, P. Šipkovs, D. Merkulovs

K o p s a v i l k u m s

Rakstā esam parādījuši iespējas izveidot augstas precizitātes, kompaktu, lētu un ērtu lietošanai dielektrisku šķidrumu mērīšanas sistēmu koncentrācijas noteikšanai. Šī sistēma ir piemērojama kapacitīviem sensoriem, kuru kapacitāte ir atkarīga no sensora izveidojuma kā arī mērāmā šķidruma dielektriskās konstantes vērtības, un kapacitāte var tikt noteikta pie frekvences 100,000 kHz robežās no 1 F līdz 300 pF. Mērīšanas sistēmas pārbaudei, sistēma tika kalibrēta etanola koncentrācijas mērīšanai tilpuma procentos sertificēta bezūdens etanola un dejonizēta ūdens maisījumiem. Pārbaužu rezultāti pierādīja, ka sensora kapacitātes vērtības ir stabili nosakāmas ar izšķirtspēju ne mazāku par ±0,005 pF. Sensora kapacitāšu vērtībām atbilstošā etanola tilpuma koncentrācijas atkārtojamu mērījumu izšķirtspēja visā mērīšanas diapazonā nebija mazāka par ±0,01%.

Šajā darbā piedāvātajā jaunajā mērīšanas sistēmas struktūras risinājumā iekļautas divas tiešas signālu digitālās sintēzes mikrosistēmas, kas ar augstu precizitāti ģenerē mērīšanai nepieciešamās formas, fāzes un amplitūdas signālus ar 100,000 kHz frekvenci un tiek vadītas no mikrokontrolera. Mērīšanas sistēmā izmantota mērsignālu sinhronizētās detektēšanas tehnika. Izstrādātās sistēmas kon-

igurācija, mērīšanas režīma uzstādījums un vadība automātiski praktiski izslēdz virkni mērīšanas signālu parazītisko fāzes nobīžu un fāzes uzstādījumu kļūdas.

Izstrādātā mērīšanas sistēma ērti piemērojama vispārējai izmantošanai kapacitātes vai impedances mērierīcēs. Samērā nelielā prognozējamā mērīšanas sistēmas pašizmaksa un kompaktā, portatīvā konstrukcija, kā arī iepriekš minētās priekšrocības paplašina sistēmas lietojumu ne tikai etanola koncentrācijas mērīanai bioetanola ražošanas procesā, bet šī sistēma var tikt izmantota arī eļļas, benzīna un citu degvielu testēšanai, ķīmiskajā, farmācijas un pārtikas industrijā, mikrobioloģijā un medicīnā, lai noteiktu glikozes, antigēnu, antivielu, proteīna, DNS fragmentu un citu vielu saturu šķīdumos u.c.

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