Auto-balancing System for Measurement of Extremely Small Changes of High Impedances

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Abstract

The paper is devoted to the description and experience with the equipment for the measurement of permittivity of gases. As the relative permittivities of gases are very close to 1 and sensors for this purpose have the capacity in order of pF, this measuring task leads in fact to the measurement of extremely small changes (1 ppm from the range) of extremely high impedances.

Keywords

Auto-balancing measurement system, high impedance measurement, capacitive sensor, dielectric constant of gases

Introduction

The problem of the accurate high impedance measurement is very similar to the problem of exact measurement of the extremely small currents. For exact measurement of the small AC currents contaminated by noise the principles of the coherent demodulation are used because of its ability to reduce the noise in the processed signal that is the inherent property of the coherent demodulation. The general method in order to enhance the metrological properties of the measurement is the application of the compensation procedures, which are performed practically by "balancing" of unknown quantity using the proper value of known reference quantity. The manual balancing methods have been often used, but the process of the balancing is complicated and time-consuming procedure. The manual-balancing system could be replaced by the automatic procedure using the proper type of feedback controller. When parameters of feedback loop are set optimally, the equilibrium state is achieved more quickly and accurately.

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The measuring system used for this purpose was designed and its conception verified by the implementation of the programmable measuring instruments controlled by PC via GPIB bus, [1]. The structure of auto-balancing measurement system is depicted in the Fig. 1 and Fig. 2.

Fig. 1: The structure of auto-balancing measurement based on PC and GPIB interface

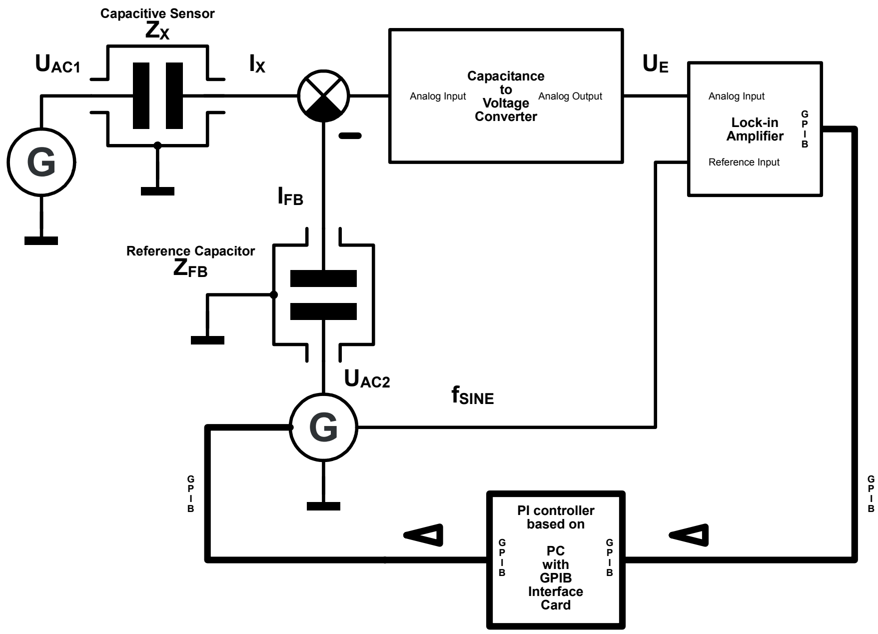
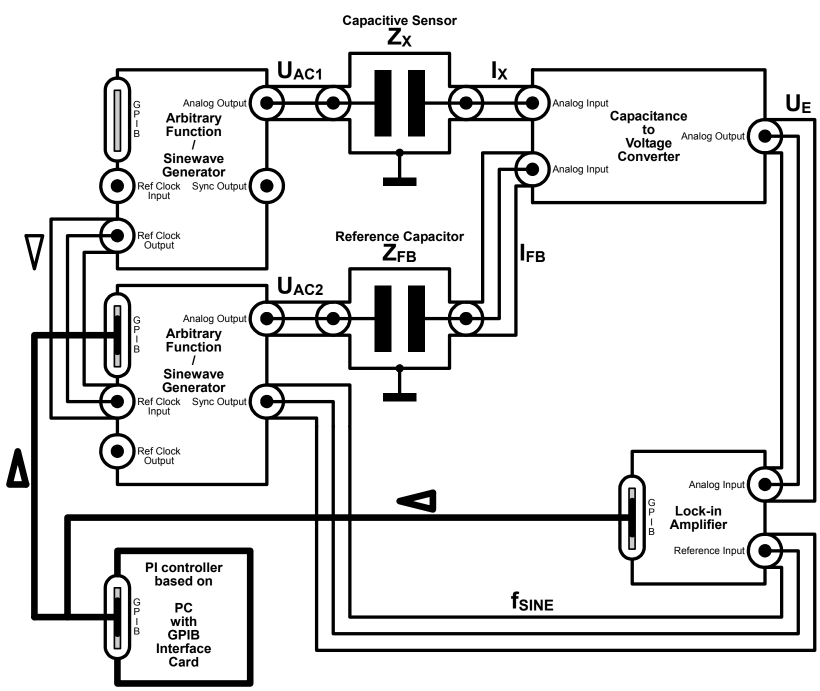


Fig. 2: The schematics of the auto-balancing measurement circuit



In accordance with terms used in feedback regulating systems, the actuator (programmable generator) delivers balancing current I_B to the summing point (input of the capacity to voltage converter). The signal proportional to the difference of unknown current through the measured impedance I_X and balancing current I_B serves as an error signal U_E. The error signal U_E is then processed by the digital coherent demodulator (Stanford Research Systems). SR830 DSP [2] that controls the amplitude of the balancing generator voltage. In the steady state and for high gain of feedback loop the following equation is valid:

$$I_X = I_{FB}$$

$$\frac{U_{AC1}}{Z_X} = \frac{U_{AC2}}{Z_{FB}}$$

Where U_{AC1}, U_{AC2} are amplitudes of the driving sine signals, Z_{FB} is known impedance and Z_X is unknown impedance under the test.

Then the value of unknown impedance could be calculated by means of following equation:

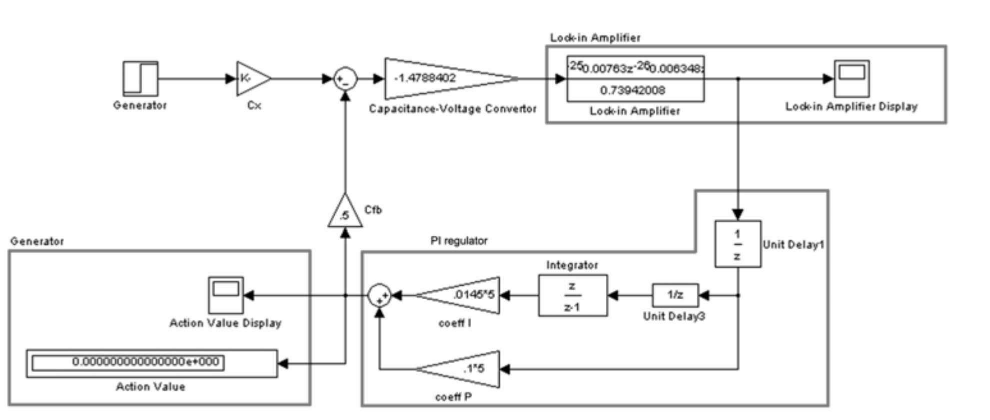
$$Z_X = \frac{U_{AC1}}{U_{AC2}} Z_{FB}$$

The dynamic properties of the system are determined mainly by the transfer characteristic of the low pass filter used in the lock-in amplifier instrument. In order to avoid oscillations of the loop and to optimize its response to the step change of measured impedance, the transfer function of the regulator (control algorithm) had to be found. The Z-transform and Ziegler Nichols criterion was used for designing of optimal transfer function of regulator.

Results

The design was verified by means of the Simulink application package and subsequently by the measurement. The hardcopy of the Simulink system model is shown in Fig 3.

Fig. 3: Simulink system model of auto-balancing measurement system



The Fig. 3 shows the structure of system that consists the proportional-integration regulator and the digital coherent demodulator (the lock-in amplifier) that can be described by Eq.1 in Z-transform as FIR filter.

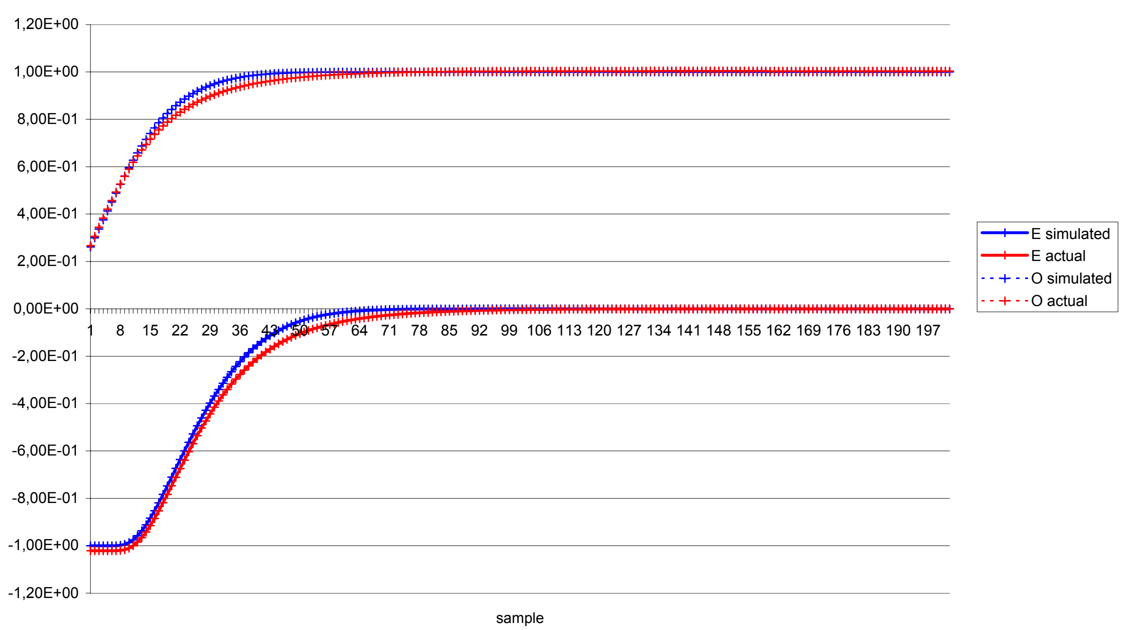
Eq.1: $$H_{LIA}(z) = \frac{\sum_{i=1}^{53} b_i z^{-i}}{\sum_{i=1}^{1} a_i z^{-i}}$$

The coefficients a_i and b_i were calculated from the data measured on the real lock-in amplifier. The b_i polynomial has got the order equal to 53 and the minimum and the maximum of b_i in the absolute value are $b_{i\text{-}min}=0.00006$ and $b_{i\text{-}max}=0.03717$.

The verifying experiments proved the good agreement with the values simulated by means of the Simulink application. The data simulated by means of Simulink and the real measured data are shown in Fig. 4.

Where E is the normalized error signal determined by the lock-in amplifier and O is the normalized output signal amplitude of the arbitrary function / sinewave generator that is controlled by GPIB interface.

Fig. 4: Data simulated by means of Simulink and data acquired by SR830 DSP coherent demodulator



The required sensitivity (1 ppm from the range) has been achieved.

Conclusions

The designed and realized measurement system enables to improve the accuracy of the measurement, to speed up the process of the balancing and particularly to automate the setting-up strategy. The application of the GPIB bus facilitates the optimal setting of the parameters of the controller for the given measurement circuit and instrument or device. The control parameters and the output values can be archived in the computer memory in order to optimize the whole auto-balancing process. In further work on the project the commercially available and relatively expensive instruments would be replaced by appropriately designed integrated circuit mostly based on the digital signal processors. Then the modified system can reach the same or better accuracy and moreover its price can be also reduced to the detriment of its universality and the wide range of the measured values. Generally the designed auto-balancing system for the exact measurement of the high impedances proves all advantages of the balanced systems and by virtue of the used instruments the required high accuracy has been achieved.

Acknowledgement

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