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A study of the metrological properties of a two-channel sampling module for an AC standard resistor calibration system

***Abstract**. The paper presents the concept of a measurement system for the calibration of AC standard resistors with low resistance values and the selected research results of a commercial sampling module constituting a key element of the system which is being developed. Among others there is presented the results of a 24-hour stability study of the analog-to-digital processing paths of a sampling module.*

***Streszczenie.** Przedstawiono koncepcję systemu pomiarowego do wzorcowania rezystorów wzorcowych prądu przemiennego o małych wartościach rezystancji oraz wybrane wyniki badań komercyjnego modułu próbkującego stanowiącego podstawowy element opracowywanego systemu. Między innymi przedstawiono wyniki badań 24-godzinnej stabilności torów przetwarzania analogowo-cyfrowego modułu próbkującego. (**Badanie właściwości metrologicznych dwukanałowego modułu próbkującego do sytemu wzorcowania rezystorów wzorcowych prądu przemiennego**).*

Keywords: analog-digital conversion, sampling module, impedance measurement, phase measurement.
Słowa kluczowe: przetwarzanie analogowo-cyfrowe, moduł próbkujący, pomiary impedancji, pomiary fazy.

Introduction

The growing role of AC resistance standards in systems for the comparison of impedance component standards results from new abilities that are associated with the use, in recent years, of quantum standards of voltage and resistance in AC circuits. An application of the quantum Hall effect in realizing the AC resistance standard (AC QHR) and the building of quantum impedance bridges (the Josephson bridges) on the basis of quantum AC voltage standards with Josephson junction arrays has led to the situation where AC resistance measurement uncertainty is currently at a level close to DC resistance measurement uncertainty [1, 2]. In the case of the calibration of low value ac resistors, comparisons of standards are carried out at relatively high values of current. This requires the solution of additional problems related to the stability of a current source and the power dissipated by the compared resistors. In addition, the currently available standards are most often the AC/DC resistors for which is known only the permissible difference between the DC resistance and impedance magnitude at a given frequency. This does not allow determination of the reactance component of a calibrated resistor. On the other hand, precision low value AC resistors are important elements of alternating current measurement systems and instruments. For this reason, in recent years many national metrology institutes have been developing their own measurement systems dedicated to the calibration of low-value AC resistors with a sufficiently small uncertainty in the magnitude and argument of the impedance.

The authors, in cooperation with the Central Office of Measures in Warsaw, are working on a project whose goal is to build a system for the calibration of low-value AC standard resistors in the acoustic frequency band. The system is intended to provide the calibration of resistors, the nominal values of which range from 1 mΩ to 10 Ω, over a frequency bandwidth from 40 Hz to 10 kHz.

Measurement system

In the developed system, the principle of an impedance measurement of a standard resistor R_X consists in direct comparison with a standard resistor R_N (Fig. 1). The presented solution is based on a modular PXI measurement system. Its main element is the PXI-NI4461 module which consists of two digital-to-analog channels (a generation block) and two analog-to-digital channels (sampling module). A voltage signal generated in one channel of a two-phase sinusoidal voltage generator, built on the basis of

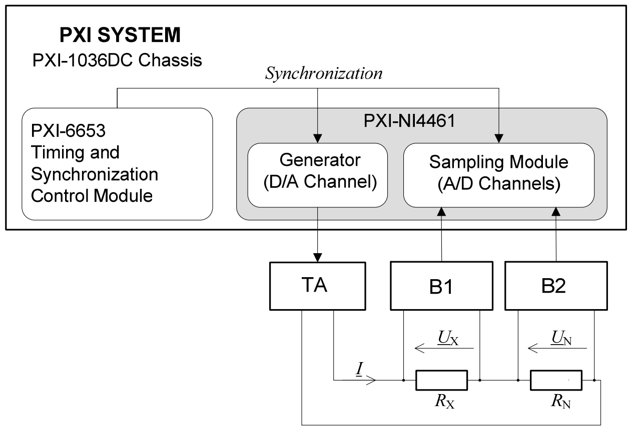

Fig. 1. Simplified diagram of the system for resistor calibration

the generation block [3], is fed to the input of a transconductance amplifier TA (developed by the authors) with programmable gain. The compared standard resistors are connected in series and fed to the output terminals of the amplifier. The voltage drops $\underline{U}_X$ and $\underline{U}_N$ across the compared resistors are provided by the buffers (B1 and B2 respectively), developed within the confines of the project, to the inputs of the two-channel sampling module. The buffers provide the ability to measure floating voltages. The output voltages of the buffers are sampled and quantized by the sampling module and undergo further digital processing. A complex voltage ratio $(\underline{U}_X/\underline{U}_N) = A + jB$ is computed by the discrete Fourier transform, allowing calculation of the parameters of the calibrated standard resistor: the resistance R_X and the time constant τ_X with respect to the resistance R_N and the time constant τ_N of the standard resistor by the equation [4]:

$$R_X = R_N A\left(1 - \omega\tau_N \frac{B}{A}\right) \quad (1)$$

$$\tau_X = \frac{1}{\omega} \cdot \frac{\omega\tau_N + (B/A)}{1 - \omega\tau_N (B/A)} \quad (2)$$

where ω is the angular frequency of the measured signal.

To ensure an acceptable degree of uncertainty of resistor comparison, a key role is played by the metrological properties of the sampling module used [5, 6, 7]. In accordance with the assumptions about the system being developed, the sampling module should provide a measurement of the magnitude and phase of the complex voltage ratio with an acceptably small degree of uncertainty in the frequency band of 40 Hz to 10 kHz. It is also assumed that the magnitude of the complex voltage ratio will vary from 0.1 to 1 (the ratio of the compared resistors from 1:10 to 1:1), and that its phase, arising from the assumed time constants of compared resistors, will not exceed 50 m° (for 10 kHz).

The sampling module, selected for the implementation of the presented system, is equipped with a dual-channel, 24-bit, sigma-delta analog-to-digital converter. It can operate at a sampling rate up to 204.8 kS/s, and for each channel allows the selection of one of three ranges: ±0.1 V, ±1 V and ±10 V. In the proposed solution the sampling module cooperates with the precise source of a 10 MHz clock signal (NI-PXI6653). The developed measurement software allows the computation of the magnitude and phase of the fundamental harmonics voltage ratio sampled synchronously by both channels of the sampling module.

Experimental results

The PXI-NI4461 sampling module has been comprehensively studied. Although the manufacturer's technical specification [9] provides a lot of important data, such data is insufficient in the case where the sampling module is used at its boundary capabilities. In addition, the study did not always confirm the information provided by the manufacturer [3, 7]. The study included determination of the temperature and time stability of the two channels of the sampling module, determination of the frequency characteristics of the magnitude and phase of the complex voltage ratio (CVR) measured by the sampling module, determination of linearity in the measurement of CVR magnitude ranging from 0.1 to 1, and determination of the measurement resolution of the CVR phase at nearly 0°. Presented below are some selected research results.

Research results of the temperature properties of the sampling module combined with its long term stability are shown in Figs. 2 – 4.

a)

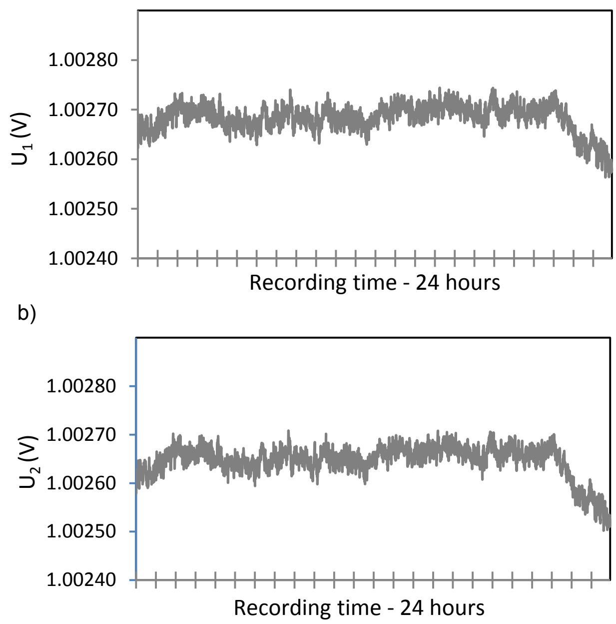

Fig. 2. Voltages measured by: a) channel 1, b) channel 2 of the digitizer; the measuring range is ±1 V

a)

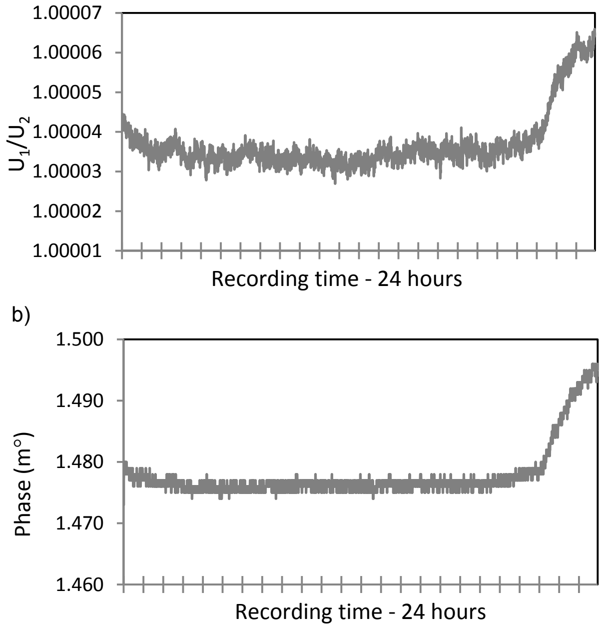

Fig. 3. Magnitude (a) and argument (phase) (b) of a complex voltage ratio

During measurement to both inputs of the sampling module were provided the same sinewave voltage signal about 1-V amplitude and 1-kHz frequency. As a voltage source one channel of the two-phase generator was used. In this way full synchronization between the source signal and the sampling module was obtained. The sampling rate was equal to 51.2 kHz. In the experiment a PXI chassis was placed in an air conditioned room, and the temperature was measured inside the chassis (Fig. 4).

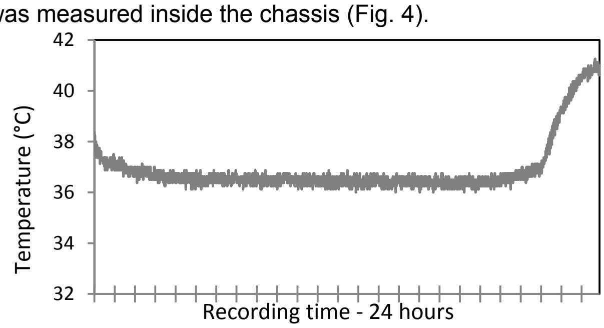

Fig. 4. Results of temperature measurements measured inside PXI-chassis

The temperature influence on the operation of the sampling module was studied by stepwise changes in the room temperature. Determined in this way the gain temperature coefficients (GTC) of both channels of the sampling module are respectively -20.4 μV/V/°C and -27.5 μV/V/°C (Fig. 2). The difference between the two GTCs implies that the impact of the temperature on the CVR magnitude measurement compensates only partially. Hence, the measured CVR magnitude also depends on temperature and changes about 7.4 μV/V/°C (Fig. 3a). However, a similarly determined effect of temperature on the phase value of CVR indicates that its value changes about 0.008 m°/°C (Fig. 3b).

The frequency response of CVR magnitude was determined by providing to the inputs of both channels the same voltage signal. The deviation from the nominal value across the frequency range does not exceed the value of ± 5 μV/V with a standard uncertainty of less than 1 μV/V [8]. Measurements of the CVR phase as a function of frequency show that between the two channels of the sampling module there is a constant time delay. Hence the phase varies linearly as a function of frequency in the range from 0.05 m˚ at 40 Hz to 14.8 m˚ at 10 kHz (Fig. 5). As determined from the frequency characteristics, the value of the time delay is equal to 4.11 ns and is within the range of values given by the manufacturer [9].

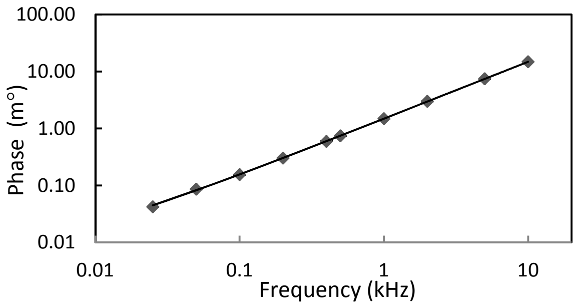

Fig. 5. Frequency dependence on the phase value of complex voltage ratio

The resolution of the phase measurement of the CVR was studied by changing the CVR phase value in the range ± 0.1˚. For this purpose a two-phase generator [3] was used. Exemplary results of the measurements are shown in Table 1.

The obtained measurement results of the CVR phase, given in Table 1, were confirmed using the measurement system with two HP3458A multimeters and integrative sampling method [10, 11 12].

Tab. 1. Phase measurement results of a voltage ratio at frequency 40 Hz

Phase [m˚]	Measured value [m˚]	Difference from nominal value [m˚]	Standard deviation [m˚]
-0.1	-0.0980	0.0020	0.0008
0.0	0.0000	0.0000	0.0006
0.1	0.0987	-0,0013	0.0007
49.9	49.9011	0.0011	0.0006
50.0	49.9971	-0.0029	0.0007
50.1	50.0998	-0,0002	0.0006
99.9	99.8981	-0.0019	0.0009
100.0	99.9999	-0.0001	0.0007
100.1	100.1037	0.0037	0.0009

Conclusion

This paper presents the research results of a commercial two-channel sampling module intended for use in a measurement system for the calibration of standard resistors with low resistance values in the frequency range from 40 Hz to 10 kHz. The obtained results have shown that it is possible to measure the magnitude and phase of the complex voltage ratio with an uncertainty of 5 μV/V and 0.005 m˚, respectively. The study also shows that the temperature influence on the relative accuracy of the measurement of CVR magnitude, which is at the level of 7.4 μV/V/°C, goes significantly beyond the assumptions made for the measurement system under development. The time delay between the channels (4.11 ns), which was determined from measurements, gives rise to a systematic error in the measurement of the CVR argument which is linearly dependent on the frequency. For this reason the correction must be included in the measurement procedure. Further research is aimed at the elimination of these drawbacks of running the sampling module in dual channel mode through the use of only one channel of this module and the application of an external multiplexer in the measurement system.

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