Dorota KOŁAKOWSKA[1], *Krystian KRAWCZYK*[1], *Michał LISOWSKI*[2], *Marian KAMPIK*[3],
Marcin ORZEPOWSKI[4], *Dorota DOMAŃSKA MYŚLIWIEC*[4], *Janusz TOKARSKI*[3]
[1] *Wroclaw University of Science and Technology, Department of Electrical Engineering Fundamentals*
[2] *Wroclaw University of Science and Technology, Faculty of Technology and Natural Sciences*
[3] *Silesian University of Technology, Department of Measurement Science, Electronics and Control*
[4] *Central Office of Measures, Laboratory of Electricity and Magnetism, Electrical Quantities Standards Section*

INITIAL TESTS OF AN ACTIVE ARM BRIDGE DESIGNED TO COMPARE HIGH RESISTANCE STANDARDS

Results of initial tests of an active bridge composed of two independent voltage sources and a two-channel voltage source are presented. The active arm bridge will be used in the resistance standard scaling system in the Central Office of Measures (GUM) in the range from 100 MΩ to 100 TΩ. Comparison of measurements done with the bridge based on Inmel 7000 calibrators and new two-channel source is presented.

Keywords: Active arm bridge, high resistance, unbalanced bridge.

WSTĘPNE BADANIA MOSTKA AKTYWNEGO DO PORÓWNYWANIA WYSOKOOMOWYCH WZORCÓW REZYSTANCJI

Przedstawiono wyniki wstępnych testów mostka aktywnego złożonego z dwóch niezależnych źródeł napięcia (kalibratorów Inmel 7000) oraz nowego dwukanałowego źródła napięcia. Mostek aktywny znajdzie zastosowanie w systemie przekazywania jednostki rezystancji w Główmy Urzędzie Miar (GUM) dla rezystancji od 100 MΩ do 100 TΩ.

Słowa kluczowe: mostek aktywny, wysokie rezystancje, mostek niezrównoważony

1. INTRODUCTION

The most accurate high resistance measurements are carried out with bridge methods. These methods base on a modified Wheatstone's bridge with precision binary dividers or an active arm bridge. These bridges allow precise measurements of resistance in the range from 10^3 Ω to 10^{15} Ω.

Problems of resistance measurements above 100 MΩ with the highest precision call for use of the active bridges with two DC sources in the arms of the bridge. Two arms of the bridge contain calibrated voltage sources U_1 and U_2, and the other two arms – measured resistor R_X and reference resistor R_N [1]. When the bridge is balanced, the voltage ratio U_1/U_2 equals the resistance ratio R_X/R_N, and the value of measured R_X is given by:

$$R_X = R_N\left(U_1 / U_2\right). \tag{1}$$

A specific valuable feature of this system is that the null detector D and source voltages U_1 and U_2 can be grounded at one point, therefore leakage currents are minimized. The accuracy of such bridge depends primarily on the accuracy of the voltage sources and the sensitivity of the null detector. Therefore, one should use the most accurate DC voltage sources and high sensitivity null detector.

Balancing of a bridge causes significant extension of measurement time. If the standard resistors R_X and R_N would be of the same nominal value and voltages $U_1 \approx U_2$, the active arms bridge would be close to balance and then in the calculation of the resistance R_X, reading from detector should be considered. The null detector can be either a high resolution nanovoltmeter or electrometer.

The designed active arm bridge, which will be used in the transfer of the unit of resistance in the Central Office of Measures in Poland (GUM) [2], should allow calibration of resistance standards in the range from 100 MΩ to 100 TΩ.

2. ACTIVE ARM BRIDGE

Usually balancing of a bridge is a time consuming procedure. If both compared resistors: R_X and R_N, will be of the same nominal value and the voltages generated by the sources $U_1 \approx U_2$, the active arms bridge will be close to balance and then the resistance R_X can be calculated from detector current I_0 (Fig. 1), i.e. from the equation:

$$R_X = R_N \frac{U_1 - I_0 R_0}{I_0 R_N + I_0 R_0 + U_2}, \tag{2}$$

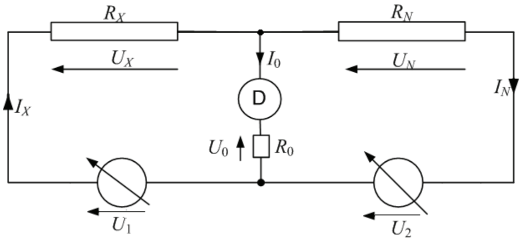

Fig. 1. Schematic circuit of active arm bridge

The bridge developed by authors will be used to compare high resistance standards of similar values in the 1:1 ratio by means of transposition method. Measured resistance R_X in this method is determined in two steps, described in details in [3].

Taking into account the residual unbalancing current, I_0, the equation for R_X, is determined by the expression:

$$R_X = R_N \sqrt{\frac{(I_{01} \cdot R_0 - U_1)(I_{02} \cdot R_0 + U_2)}{(I_{01} \cdot R_N + I_{01} \cdot R_0 + U_2)(R_N \cdot I_{02} - U_1 + I_{02} \cdot R_0)}}, \tag{3}$$

where I_{01} and I_{02} are currents measured with the detector in the first and the second step.

If the resistance of the current detector would be negligibly small ($R_0 = 0$), then the expression (3) will take the form:

$$R_X = R_N \sqrt{\frac{1}{\left(\frac{U_2}{U_1} + \frac{I_{01} R_N}{U_1}\right)\left(1 - \frac{R_N I_{02}}{U_1}\right)}}, \tag{4}$$

If the bridge was balanced ($I_0 = 0$), then after replacing the reference resistors R_X with R_N, the source voltage U_2 will increase to $U_2' = U_2\,(1 + \delta U_2)$ and:

$$R_X = R_N \sqrt{\frac{U_2'}{U_2}} = R_N \sqrt{1 + \delta U}, \tag{5}$$

where $\delta U_2 = (U_2' - U_2)/U_2$ is the relative voltage difference.

The dependence (5) shows that the value of the determined resistance is calculated with the $R_X/R_N \approx 1$ ratio and therefore it is accurate. In the case of balanced bridge R_X depends on the accuracy of the R_N standard and the voltage ratio, which in this case differs from 1 by a small value of δU. However, if the bridge is unbalanced, one should take into account additionally the values of currents I_{01} and I_{02} indicated by the detector (Eq. 4).

3. ACTIVE ARM BRIDGE TESTS

The measuring range has been specified for the resistance unit transfer system [2], which should be from 100 MΩ to 100 TΩ. It was assumed that the voltage ranges of voltage sources in this range of measured resistances should be from 10 V to 1000 V.

3.1 First test measurements

In the first tests as voltage sources Inmel 7000 calibrators were used, and - as an detector - Keithley 6517B electrometer (Fig. 2 a).

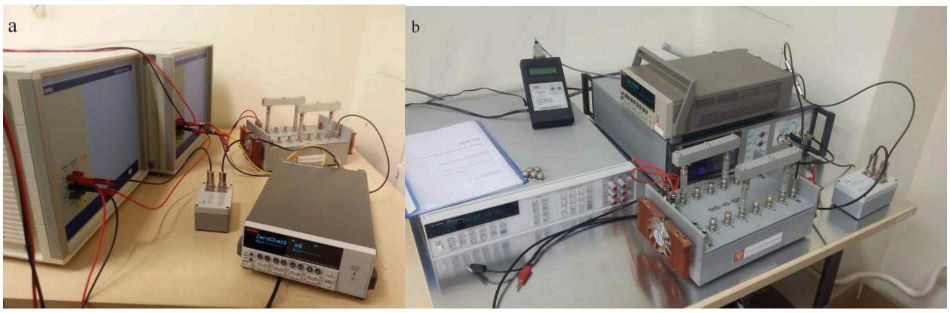

Fig. 2. View of the active-arm bridge with: a) two Inmel 7000 calibrators,
b) the dual channel programmable DC voltage source developed at SUT

In order to eliminate interference from mains, the measuring system was connected to the power supply via the uninterruptible power supply (UPS), which is equipped with filters that minimize interference from the power grid. Special cables with double shielding were used with Triax connectors.

Measurements for the same sets of resistors were performed with a balanced and unbalanced bridge and then it was checked whether the resistance ratios obtained were compatible. The next stage of the research was an attempt to transfer the resistance values from 100 MΩ to 100 TΩ using transfers [2] and using the active bridge. As a result of tests, it was found that for TΩ resistance it is possible to obtain satisfactory results using medium-class voltage sources. In the case of resistance of the order MΩ and GΩ to get the measurement results with the appropriate accuracy, it is necessary to use sources with the highest parameters. Results are presented in Fig. 4.

3.2 The second setup

In the second setup a dual channel DC voltage source developed at the Silesian University of Technology (SUT) was used. High mid- and short- term stability of the voltage ratio generated by the source was achieved with ovenizing the most critical modules and by embedding two voltage sources into one enclosure. The source developed at SUT is digitally programmable through GPIB, USB or RS232 interfaces [4]. Programming can be done via a computer or directly from the LCD touch panel. Sources stability tests were carried out in such a way, that the same voltages were set on the both channels and their difference was measured with the Keysight 3458A multimeter. Results of stability tests are shown in Fig. 3.

As a null detector the Keithley 6517A electrometer was used. The measuring system was connected to the power supply via UPS, like in the first setup.

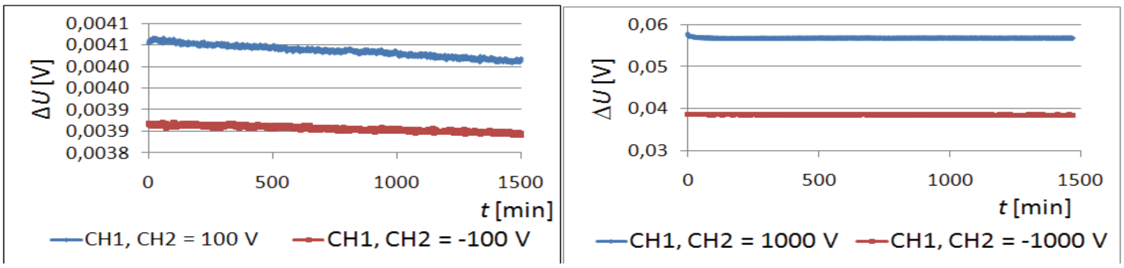

Fig. 3. Time stability of dual channel programmable DC voltage source used in the bridge

Next the measurements with unbalanced bridge, for the same sets of resistors, were performed to check whether the resistance ratios obtained were similar. The exemplary results of these tests are presented in Fig. 4. It can be concluded from results presented in Fig. 4 that the resistance ratios R_X/R_N, determined by the unbalanced and balanced bridge with the two channel programmable DC voltage source can be considered as correct.

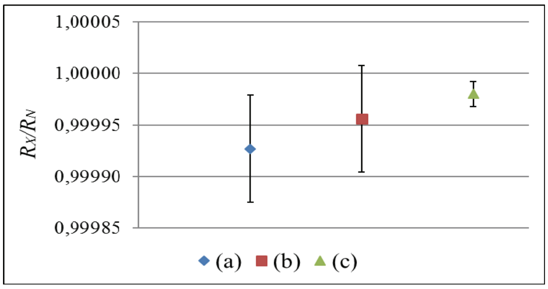

Fig. 4. Results of measurements of the ratio of two 100 GΩ standards performed with: unbalanced (a) and balanced (b) bridge with two Inmel 7000 calibrators, (c) unbalanced bridge with the new two-channel voltage source developed at SUT. Result are given with expanded uncertainty for p=0.95, k=2

4. CONCLUSION

As part of the work carried out, an active arm bridge with the two channel voltage source was developed. As a result of tests, it was found that the use of voltage sources with better parameters, stable in time allowed to obtain correct values of resistance ratios for MΩ and GΩ resistances.

The work was financed with the means of Applied Research Programme of the National Centre for Research and Development in years 2015-2018, PBS3/A4/11/2015

REFERENCES

1. L. C. A. Henderson: „A new technique for the automated measurement of high valued resistors”, J. Phys. Electron. Sci. Instrum. 20, pp. 492-495, Sept. 1987.
2. M. Lisowski, K. Krawczyk.: „Resistance Scaling from 10 kΩ up to 100 TΩ with New Designs of Hamon Transfer Devices”, IEEE Trans. on Instr. and Meas., Vol. 62, No. 6, pp. 1749-1754, 2013.
3. D. Kołakowska, K. Krawczyk, M. Lisowski: „Analysis of unbalanced active arm bridge in precise comparisons of high resistance standards”, PPM'16, 2016, pp. 20-24.
4. M. Kampik: Two Channel Source of DC Voltage. Operators Manual and Remote Programming Reference, v.1, June 2017.