A New Method for Sensor's Resistance Measurement with High Linearity

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Abstract – **Measuring methods of physical quantities are mostly based on sensors by wich measurand is converted to electrical value, in most cases, to voltage, frequency, time interval. As numerous sensors are the resistance type, it is necessity to convert resistance to dc voltage and then dc voltage to digital data.**

This paper deals with a solution for resistance to voltage converter that is characterized along with other advantages very good linearity. Analyze and experimental verification is shown both simplicity of design and good metrological performances, as for example, linearity better than ±0,001%, voltage resolution full scale of 0-10V is 50μV. Presented solution is convenient for implementation in the intelligent measuring modules or smart sensors that may be integrated easily as one chip microelectronic component.

Keywords – **Measuring sensors, resistance-to-voltage converter, smart sensor, calibration**

I. INTRODUCTION

Methods for measuring parameters of physical world are based, mostly, on sensors that convert non-electrical into electrical quantities. The most of those sensors are resistance type, where output quantity is variable resistance due to measured physical quantity. Therefore, it is essential to develop methods for resistance measurements using modern microelectrical technologies and software tools. Modern transducer design with this kind of sensors requires modularity and universality according to standards emerging for smart sensors in distributed measurement systems. Metrological level of resistance sensors depends on the nature of sensor itself, in other words, it depends on the correct established functional relation between measured physical quantity and output resistance. Conversions based on digital methods require conversion of electrical resistance into appropriate voltage value, which is than converted into digital value using analog-to-digital converters (ADC). Resistance to voltage conversion is usually made using constant-current source, thus the overall resistance measurement accuracy directly depends on accuracy of constant-cuurent value through measuerd resistance. On the other hand, it is not simple to provide the same value of constant-current in wide range of measured resistance.

In this paper, one solution for linear resistance to dc voltage conversion is offered. The solution has capability of linearity factor - sensitivity adjustment changing one parameter of the component in the circuit; in this solution, it is referent voltage level. Proposed solution is characterized by simplicity, good linearity and accurate conversion into standard voltage level for input of the ADC. Furthermore, the presented solution is very suitable for implementation into intelligent measurement modules-smart sensors as cheap component.

In metrological theory and practice, there are numerous ideas and practical solutions for resistance measurement of both various type of the resistors and sensors at wide range of its values. State-of-the-art in the industrial automation characterizes effort to be very economical solutions for connecting transducers in distributed measurement and control applications based on smart sensors. Emerging digital electronics, especially microprocessors and microcontrollers, and data acquisition systems in measurement, a new possibilities of the fundamental block of the transducers - analog-to-digital converters (ADC) - to defferent varieties can be achieved. To convert electrical resistance to digital value it requires to establisch direct relation between that resistance and voltage wich can be converted by ADC. Since high measurement accuracy is achieved in time interval measurement, most converters are based on the voltage-to-time or voltage-to-frequency conversion techniques [1,2]. Many sensors (termistors, strain gauge, etc.) are resistance type where output quantity is variable resistance due to, for example, temperature, force, weight, etc [3]. From there needs to improve a new design of the resistance-to-voltage and voltage-to-digital converter to satisfy all contemporary requirements in respect to optimal metrological and other characteristics and cost efficiency.

II. CASE STUDY

Idea for resistance to dc voltage conversion is based on principal dc voltage calibrator by serial regulator of output dc voltage or dc current and close feedback using low offset operational amplifier (order below 10uV) [4].

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Figure 1. depicts electrical scheme of the resistance to voltage (R-V) converter. The output voltage Vx is function of measurement resistance *Rx*, as follows:

$$V_x = \frac{V_r}{R_0} R_x + \left| V_{OS} - RI_{OS} \right| \cdot \left(1 + \frac{R_x}{R_0} \right), \qquad (1)$$

where: $V_{OS},\ I_{OS}$ - input offset voltage and input offset current of the operational amplifier, respectively.

In ideal case, when the difference $\varepsilon = V_{OS} - RI_{OS}$ is equal to zero, relation in Eq.1 $Vx=f(R_x)$ is linear, but in real conditions the error, ε, depends on offset voltage and current of used operational amplifier. However, choosing the proper value of resistor *R*, second part of Eq.1 can be optimised, i.e. the error ε can be redused close to zero or to certain minimum.

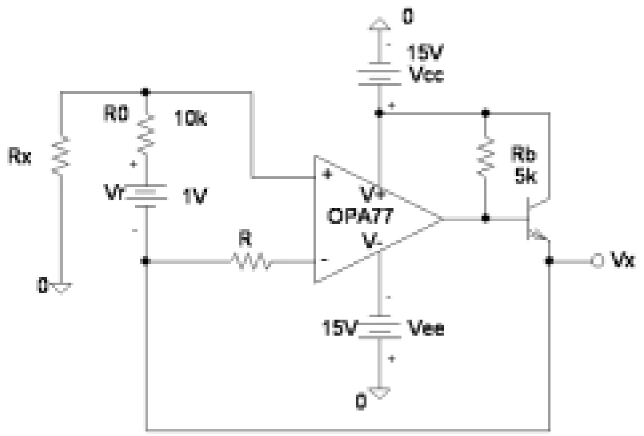

Figure 1. Electrical scheme of R-Vconverter

Critical components for providing good linearity and high stability are voltage reference V_r and resistor R_o. Both of those components must be higher stability (order 10^{-5} of nominal value), but not required higher accuracy. Accuracy is provided by automated calibration procedure by means aquisition module ADAM4000 and virtual instrument Lab View4.01, so it is one of important advantage of presented solution.

III. Simulation procedure

By simulation software PSPICE, the electrical shema of circuit on Figure 1 is simulated in various conditions. Results of simulation are shown in Figure 2 and Figure 3. Figure 2 depicts relation between output voltage V_x and measured resistance R_x. Y-axis shows voltage range 0-10V while X-axis is simulated measurement resistance 0-100kΩ. Fig. 3. depicts the simulation diagram of the linearity error reference to ideal line. As it can see, estimated linearity error as diference between simulated real line and fitted straight line is maximum ±10 ppm of the full scale 0-100kΩ.

Block scheme of the converter calibration procedure is shown in Figure. 4. By switch, SW, in position 1, standard resistance R_s is replaced with the measured resistance R_x and output voltage V_x from ADAM module [7] can be displayed on the PC monitor as Front panel of the Virtual instrument. Then, for this voltage value, virtual instrument calculates proper resistance as nominal value R_x from Eq. 1. If there is difference between the nominal and measured resistance, the correction of the referent voltage V_r is done to appropriate direction (depending on the difference sign).

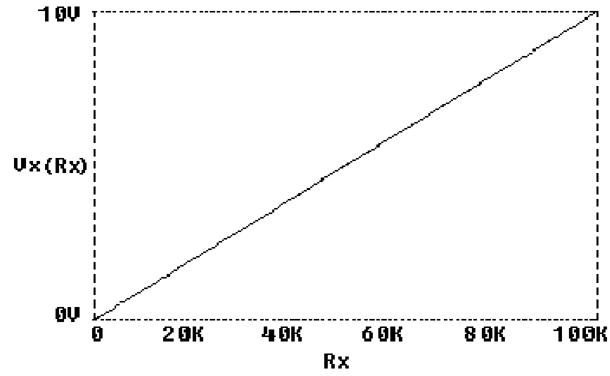

Figure 2. Diagram $V_x=f(R_x)$

When the autocalibration is finished, PC turns on switch, SW, in position 2, and starts measurement process of the R_x and shows results of measurements on the Front panel. The calibration procedure is made with LabView5 software [8] and automated, so that the converter is provided with selfcalibration function.

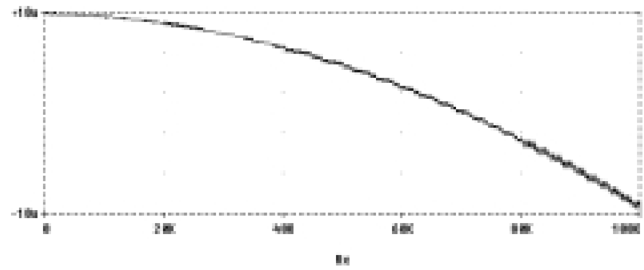

Figure 3. Linearity error

IV. Experimental results

To confirm the metrological performance of proposed converter as previously described, an experimental R-V converter whose electrical scheme is shown in Fig.1, was constructed using LF 347 instead of OPA77. Experimental verification of measurement method with evaluation of linearity is done. Converter is connected by ADAM module (Data Acquisition Modules) to personal computer (PC). Voltage calibrator METRAtop53 is used as referent voltage V_r. R_o is presented as resistor with high stability. Instead measured resistance R_x standard resistance decade is used.

Applying LabView4.01 software tool, evaluation of linearity and stability of the output voltage *Vx* is made related to the change of the resistance decade values, R_x. By means virtual instrument, whose front panel is shown in Fig. 5., for ten values of resistance decade fitting line coefficients are computed using the least squares method. Linearity error and standard deviation of the output voltage $V_x=f(R_x)$ are estimated in reference to the fitting line previously calculated. It is shown that linearity was better than $\pm$ 0.001% and standard deviation 50μV. Proposed design of resistance-to-voltage converter can be applied to resistance transducers of physical quantities, and special to smart-sensors into multisensor distributed measurement and control systems.

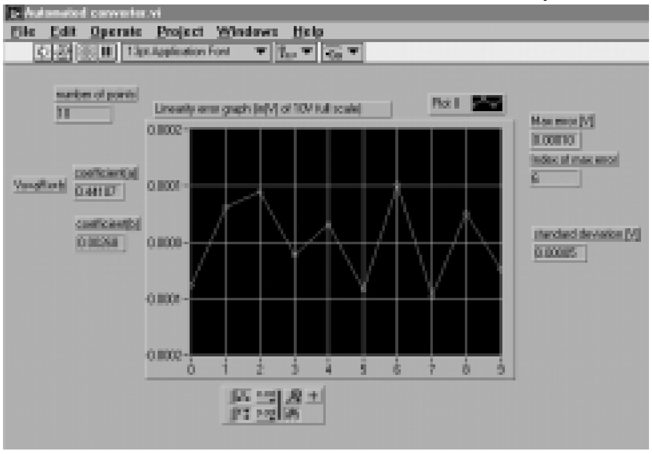

Figure 5. Front panel

V. AUTOMATED CALIBRATION PROCEDURE

Calibration procedure of the experimentally realized converter is presented in Fig.5. Data Aquisition ADAM module with analog output with high stability is used for the referent voltage setting V_r. Analog input of ADAM module is used for voltage V_x measuring. Algorithm of the calibration procedure is developed as follows. First, by PC and ADAM module, reference voltage V_r is set up and switch SW is turn on to position 1, so that the standard resistance R_s is connected instead of measured resistance R_x. Output voltage V_x is measured, and meaasured results are stored and displayed on the PC monitor.

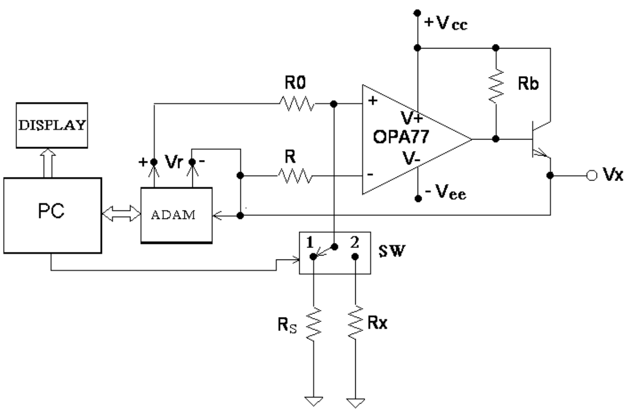

Figure 4. Block scheme of the calibration procedure

Virtual instrument compares nominal and measured resistance value R_s related to measured voltage V_x. If the nominal and measured resistances are not equal, the correction of the referent voltage V_r is done in appropriate direction (depending on the error sign), until the nominal and measured value of the standard resistance R_s is equal. When the autocalibration is finished, PC turns on switch, SW in position 2, and starts measurement of the R_x, and results of measurement data are shown on the PC monitor. Thus, automated calibration procedure is provided by the LabView software, so that the proposed converter includes self-calibration function for traceability measured resistance *Rx* with standard values of former quoted components (V_R, R_0).

VI. CONCLUSION

By simulation procedure, using PSPICE and virtual instrument LabView 4.01 and experimental solution are shown that the proposed converter has capability of sensitivity adjustment, changing only the reference voltage value V_r in the circuit. Critical components for obtaining appropriate accuracy are reference voltage, one resistor with good stability, but not obliged high accuracy and operational amplifier with low current and voltage offset. Converter is characterized by simplicity, good linearity and accurate conversion into standard voltage level for input of the ADC. Also, the presented solution, as cheap component, is very suitable for implementation into intelligent measurement modules smart resistive sensors with self-calibration possibility.

From the practical view, this converter is aimed to inteligent weighing instruments based on the force and mass strain gauges trancdusers that are used at Institut for Electrotechnics “Nikola Tesla” in Belgrade.

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