UDC 681.5

**S.K. Stankov**
*Technical university of Varna, Varna, Bulgaria*
*E-mail: stum_b@yahoo.com*

# RESISTANCE TO VOLTAGE CONVERTER WITH INCREASED SENSITIVITY

*This paper presents resistance to voltage converter with linear conversion, full compensation for the lead wires resistance when using three wire connection, single ended output, low output resistance, high sensitivity, accuracy and simplicity of the design. The proposed converter is based on very popular schematic but with one disadvantage – the lack of sensitivity. The circuit diagram presented in this article clears this disadvantage by adding just one additional resistor to the design. For the proposed converter mathematical analysis is made and the transfer function is worked out. Simulation and experimental results are presented that confirms the analysis.*

***Keywords:*** *converter, high sensitivity, resistance, three-wire connection.*

## I. INTRODUCTION

When it comes to measuring temperature, one of the most common approaches is to use RTD (resistance temperature detector) which informative parameter is the resistance. To measure this parameter, it has to be transformed into uniform output signal which in most cases is DC voltage. For that purpose a resistance to voltage converter is used. For practical applications these converters must meet a few requirements: linear conversion of the informative parameter, single ended output, single supply voltage, low output resistance, full compensation for the lead wires resistance when using three-wire connection, high sensitivity and accuracy and last but not least, simplicity of the design. In this work on the base of existing schematic a new circuit is proposed that fulfils all the mentioned requirements.

## II. EXISTING SCHEMATIC SOLUTION

A converter that covers most of the mentioned requirements is shown on Fig.1. [1–3] The schematic consist of a constant current source *Iref*, RTD element marked with $R_X$ and measuring amplifier formed with the elements: OA, $R_1$, $R_2$. Since the resistance range of a typical RTD element is relatively low, wires resistance and wires resistances drift over temperature can skew the measurement. In this order a three wire RTD sensor is used to minimize or ideally to eliminate this error. The elements $r_1$, $r_2$ and $r_3$ represent the wire resistance of the sensor.

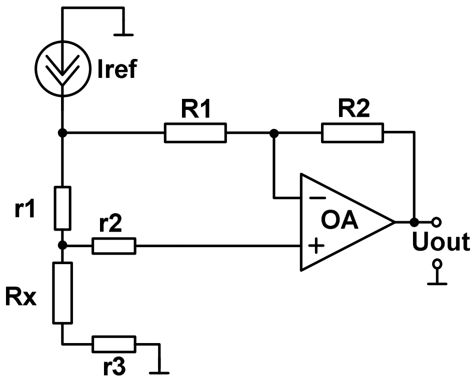


Figure 1 – Existing schematic for resistance to voltage converter

For the output voltage of the converter, expression (1) can be written:

$$U_{OUT} = I_{REF}\frac{1}{R_1}\left(R_X R_1 + r_3 R_1 - r_1 R_2\right). \quad (1)$$

From the equation it can be seen that the output voltage is invariant to the wires resistance when $r_1 = r_3$ and $R_1 = R_2$. The resistance of the connection wires is equal by rule so to eliminate the error from the three additional resistances, the parity of the two resistors – $R_1$ and $R_2$ has to be implemented:

$$R_1 = R_2. \quad (2)$$

The second wire resistance $r_2$ is not introducing error because it is connected to the high impedance non-inverting input of the operational amplifier.

Considering (2), the output voltage of the converter is presented with:

$$U_{OUT} = I_{REF} R_X. \quad (3)$$

However, this circuit has one disadvantage. The sensitivity is low – the output voltage is equal to the voltage drop across the RTD and cannot be amplified. In order to increase the sensitivity another operational amplifier has to be used which makes the design more complicated.

Another issue that has to be taken into consideration is that the voltage of the inverting input of the operational amplifier is equal to the non-inverting input voltage, therefore the value of the resistor $R_1$ need to be selected high so to ensure the leakage current through the resistor doesn't introduce additional error in the constant current of $R_X$.

## III. NEW CIRCUIT DESIGN

*III. 1. Circuit design and analysis*

On Fig.2 is shown the circuit diagram of the proposed converter that eliminates the disadvantage of the existing schematic (Fig.1).

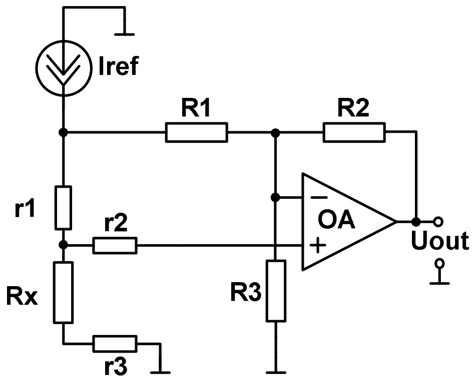


Figure 2 – Resistance to voltage converter with increased sensitivity

The only difference between the two schematics is the resistor $R_3$, connected between the inverting input of the operational amplifier OA and the common ground. For the analysis of the circuit on Fig.2, the operational amplifier will be considered ideal. The output voltage can be determined using the superposition principle:

$$U_{OUT} = I_{REF}\left(R_X + r_3\right)\frac{R_1R_2 + R_1R_3 + R_2R_3}{R_1R_3} - I_{REF}\left(r_1 + R_X + r_3\right)\frac{R_2}{R_1}, \quad (4)$$

$$U_{OUT} = I_{REF}\left[R_X\left(\frac{R_1R_2 + R_1R_3 + R_2R_3}{R_1R_3} - \frac{R_2}{R_1}\right) + r_3\frac{R_1R_2 + R_1R_3 + R_2R_3}{R_1R_3} - \left(r_1 + r_3\right)\frac{R_2}{R_1}\right]. \quad (5)$$

Considering the parity of the two wires $r_1 = r_3$, the second and the third terms in the square brackets can be eliminated under the following condition:

$$\frac{R_1R_2 + R_1R_3 + R_2R_3}{R_1R_3} = 2\frac{R_2}{R_1}. \quad (6)$$

After simplification of the expression:

$$R_1 = \frac{R_2R_3}{R_2 + R_3}. \quad (7)$$

Applying (7) in (5), the expression for the output voltage becomes:

$$U_{OUT} = I_{REF}R_X\left(1 + \frac{R_2}{R_3}\right). \quad (8)$$

It is seen, from equation (8), that the converter on Fig.2 realizes full compensation for the lead wires resistance and the sensitivity of the output voltage can be set to the desired value by the two resistors $R_2$ and $R_3$. It has to be taken in mind that in this schematic the leakage current through the resistor $R_1$ is also causing additional error in the constant current of $R_X$. Therefore, the value of this resistor has to be chosen so that this current can be neglected.

*III. 2. Simulation results*

The schematic on Fig.2 is simulated with values for the components as shown on Fig.3, using OrCAD PSpice. The RTD is assumed to be Pt100 (platinum 100). The constant current source is chosen with value 1 mA in order to avoid self-heating of the sensor. The results are shown in Table 1. The simulations are for temperature range 0-400ºC – column 1 with step 50ºC. Column 2 shows the corresponding to the temperature sensor's resistance. The values are taken from the Pt100 reference table. The calculated values Uout for the output voltage are shown in column 3, according to equation (8). In column 4 are the simulated values *Uout_si* for the output voltage when the operational amplifier is ideal, without the interference of the lead wires resistance. In column 5 are the simulated values *Uout_sr* for the output voltage when the operational amplifier is real – LM358, without the interference of the lead wires resistance. In column 6 are the simulated values *Uout_sl* for the output voltage when the operational amplifier is real and the lead wires are taken into consideration. Column 7 represents the percent error of range γ calculated by the formula:

$$\gamma = \frac{U_{OUT\_SL} - U_{OUT\_SR}}{U_{OUT\_SR(MAX)} - U_{OUTS\_SR(MIN)}} 100\% \ . \qquad (9)$$

From Table 1 it can be seen that the simulation results confirm the analysis. The error caused by the lead wires is negligible and is probably due to roundings of the program. Moreover, the correlation between the calculated and the simulation results for the output voltage confirms the correctness of the analysis made in the previous part.

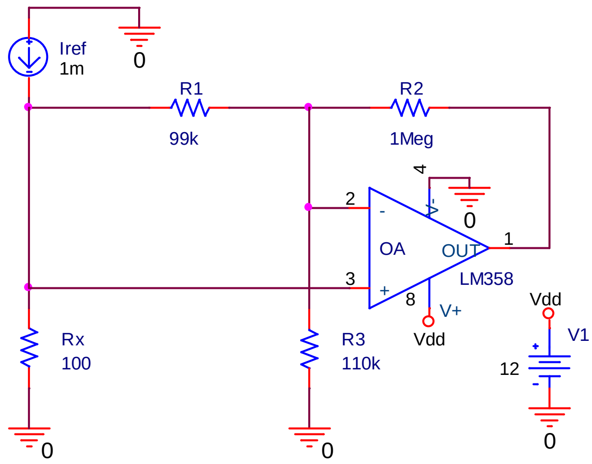


Figure 3 – Schematic of the converter for the simulation experiment

Table 1 – Simulation results

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| *T*,◦C | $R_X$, Ω | *Uout*, V | *Uout_si*,V | *Uout_sr*, V | *Uout_sl*,V | γ, % |
| 0 | 100,00 | 1,009 | 1,009 | 0,998 | 0,998 | 0,00 |
| 50 | 119,40 | 1,205 | 1,205 | 1,194 | 1,194 | 0,00 |
| 100 | 138,51 | 1,398 | 1,398 | 1,387 | 1.386 | -0,07 |
| 150 | 157,31 | 1,587 | 1,587 | 1,576 | 1,576 | 0,00 |
| 200 | 175,84 | 1,774 | 1,774 | 1,763 | 1,763 | 0,00 |
| 250 | 194,07 | 1,958 | 1,958 | 1,947 | 1,946 | -0,07 |
| 300 | 212,02 | 2,139 | 2,139 | 2,128 | 2,127 | -0,07 |
| 350 | 229,67 | 2,318 | 2,318 | 2,306 | 2,305 | -0,07 |
| 400 | 247,04 | 2,493 | 2,493 | 2,481 | 2,480 | -0,07 |

*III. 3. Experimental results*

To confirm the simulation results, experimental model was made for the circuit on Fig.3. To simulate the resistance of the platinum sensor, exemplary decade MCP-60M with accuracy 0.02 was used. Resistors with tolerance ±1% and TCR ±50 ppm were placed for the elements $R_1$–$R_3$. The component values and the operational amplifier are the same as in the simulation. The results are given in Table 2. Column 3 is with the measured values *Uout_m* for the output voltage. Column 4 is with the measured values *Uout_ml* for the output voltage when the lead wires are taken into consideration. Resistors with value 10Ω and tolerance ±1% are used to simulate the lead wires resistance, which were not specially selected with same values. In column 5 is the percent error of range γ calculated by the formula:

$$\gamma = \frac{U_{OUT\_ML} - U_{OUT\_M}}{U_{OUT\_M(MAX)} - U_{OUTS\_M(MIN)}} 100\% . \quad (10)$$

It can be seen that there is compliance of the experimental and simulation results. The insignificant error caused by the lead wires is due to the tolerance of the resistors used to simulate them.

Table 2 – Experimental results

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| *T*, ºC | $R_X$, Ω | *Uout_m*,V | *Uout_ml*, V | γ, % |
| 0 | 100,00 | 0,9998 | 0,9995 | -0,02 |
| 50 | 119,40 | 1,1965 | 1,1960 | -0,06 |
| 100 | 138,51 | 1,3894 | 1,3885 | -0,05 |
| 150 | 157,31 | 1,5891 | 1,5817 | 0,04 |
| 200 | 175,84 | 1,7677 | 1,7670 | -0,05 |
| 250 | 194,07 | 1,9516 | 1,9510 | -0,04 |
| 300 | 212,02 | 2,1332 | 2,1335 | 0,02 |
| 350 | 229,67 | 2,3122 | 2,3118 | -0,02 |
| 400 | 247,04 | 2,4874 | 2,4872 | -0,01 |

## IV. CONCLUSIONS

This paper proposes new circuit for resistance to voltage converter with single ended output, full compensation of the connection wires and high sensitivity with very simple circuit design. With simulation and experimental results, the performed analysis and conclusions are confirmed. The converter can take place in serial devices. Thorough examination can include metrological analysis which will show the interference of the parameters of the operational amplifier to the final result.

**ACKNOWLEDGEMENTS**

The proposed circuit applied for a patent in Bulgaria.

***List of bibliography***

1. Peace R.A. Analog Circuits World Class Designs / R.A. Peace. — NY.: Elsevier Inc., 2008. — 436 p.

2. Baker Bonnie C. AN687. Precision Temperature-Sensing With RTD Circuits. / C.B. Baker. — Microchip Technology Inc. 2008. — Vol. DS00687C. — P. 1–8.

3. Pallas-Areny R. Sensor and Signal Conditioning Second Edition / R. Pallas-Areny, J.G. Webster. — NY.: John Willey&Sons Inc., 2001. — 571 p.

***Received 29.01.2013***

**Станков С.К. Перетворювач типу опір – напруга з підвищеною чутливістю**

У статті розглядається перетворювач типу опір-напруга з повною компенсацією опору з'єднувальних проводів, з синфазним виходом, з низьким вихідним опором, з високою чутливістю і з простою схемою реалізації. Запропонований перетворювач заснований на широко розповсюдженій схемі, головний недолік якої – низька чутливість. Даний недолік ліквідовується шляхом включення в схему додаткового опору. Зроблено математичний аналіз і виведено рівняння перетворення. Показані результати моделювання та експериментальної перевірки.

**Ключові слова:** перетворювач, висока чутливість, опір, трьохпровідний зв'язок.

**Станков С.К. Преобразователь типа сопротивление – напряжение с повышенной чувствительностью**

В статье рассматривается преобразователь типа сопротивление-напряжение с полной компенсацией сопротивления соединительных проводов, с синфазным выходом, с низким выходным сопротивлением, с высокой чувствительностью и с простой схемой реализации. Предложенный преобразователь основан на широко распространенной схеме, главный недостаток которой – низкая чувствительность. Данный недостаток исключается путем включения в схему дополнительного сопротивления. Сделан математический анализ и выведено уравнение преобразования. Показаны результаты моделирования и экспериментальной проверки.

**Ключевые слова:** преобразователь, высокая чувствительность, сопротивление, трехпроводная связь.