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MULTITRANSDUCER WITH FREQUENCY OUTPUT FOR COMPUTERIZED MEASUREMENT SYSTEM APPLICATION

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Summary: This paper presents a Multitransducer with frequency output for computerized measurement system application. It describes the construction of the Multitransducer for the measurement of single-phase loads. Metrological properties were examined and analyzed for the implemented system. Finally a multitransducers didactic and practical usefulness have been discussed.

Keywords: multitransducer, transducer, method of least squares, analysis of the metrological property, measuring system computerized, LabVIEW

1. INTRODUCTION

Currently, it is necessary to analyse multiple electrical quantities. For this purpose, multitransducers that consist of integrated transducers for different single electrical signals are most commonly used. On its outputs, the multitransducer generates standard voltage or current signals, depending on the type of device. Additionally multitransducers possess the transmission ports (RS232, USB), which can transfer the measured values via transmission protocol directly to your PC. In the computerized measurement system the most common way to convert analog signals to digital form is via measurement card, which allows to readi, collect and process the data. One of the unconventional approaches is to use the multitransducer with frequency outputs. In this type of device, we get the opportunity to make simple isolation for safe analysis. The measurement is dangerous when the device is powered with mains voltage, ie. 230V AC. An important fact is that the signals levels on frequency outputs are usually compatible with TTL. This allows connecting them directly to a PC. With this solution, the obtained measurement system is cheaper, less complex and does not require the use of a measuring card. This results in greater reliability of such a measurement system. Therefore, it is reasonable to create a multitransducer with frequency outputs for single-phase loads electrical parameters. In addition, it is recommended that this device should usea small number of components, with a relatively simple and compact design. The miniaturization of the device improves its dynamic performance and stability. Nowadays the miniaturization is an integral part of any modern device structures.

2. CONSTRUCTION OF MULTITRANSDUCER FOR SINGLE- PHASE LOADS MEASUREMENT

The multitransducer consists of four blocks for conversion of measured values in the time-frequency signals (Figure 1), which allows processing of electrical parameters such as:

- active power consumed by the receiver,
- supply voltage,
- the current flowing through the receiver,
- phase shift between voltage and current.

In order to minimize the number of components, following processing constant coefficients were used:

- 10 Hz for 1 W of active power P (range 0-300 W),
- 10 Hz for 1 V of true voltage value URMS (range 200-250 V),
- 3 Hz for 0.1 mA of true value of the current IRMS (range 0-130 mA) or 3 Hz for 1 mA (range of 0-1.3 A),
- 20 Hz for 1° of the phase shift angle (range 0-90 °).

The structure of the measuring system was based on the author's experience with similar types of systems. Naturally other solutions were considered, but their prototypes were crucial for finding defects and allowed to choose a solution from the first picture.

Converter block for the active power consumed by the pulse frequency converter is based mainlyon the AD7755 chip, which is a comprehensive solution which provides the desired effect. This system allows miniaturization of the multitransducer. Thanks to this, it is possible to omit the following functional blocks of the converter:

- block for processing sinusoidal voltage and current signals to their rms values,
- multiplication block for signals comprising the active power,
- voltage to frequency converter block.

Function blocks described above are digitally implemented by AD7755. It is very convenient that by using this system there is no need to calibrate individual analog blocks. The AD7755 usage is a compromise between fixed errors caused by the conversion of the current and voltage signal into digital form via a built-in ADC, and the lack of need for laborious calibration. The production of the applied system has been discontinued, but due to its very good properties it continues to be used. He lived to see its own copy with the same BL6503S parameters. AD7755 system and BL6503S in this unit behave virtually identically. The differences are negligible, as in the case of the same circuits with different production batches. Analog Devices company now offers systems similar to AD7755, and even better, but the drawback would be the service speed of SPI. This type of serial communication enforces the need for a microcontroller which, overall, could become a more expensive solution than the proposed one.

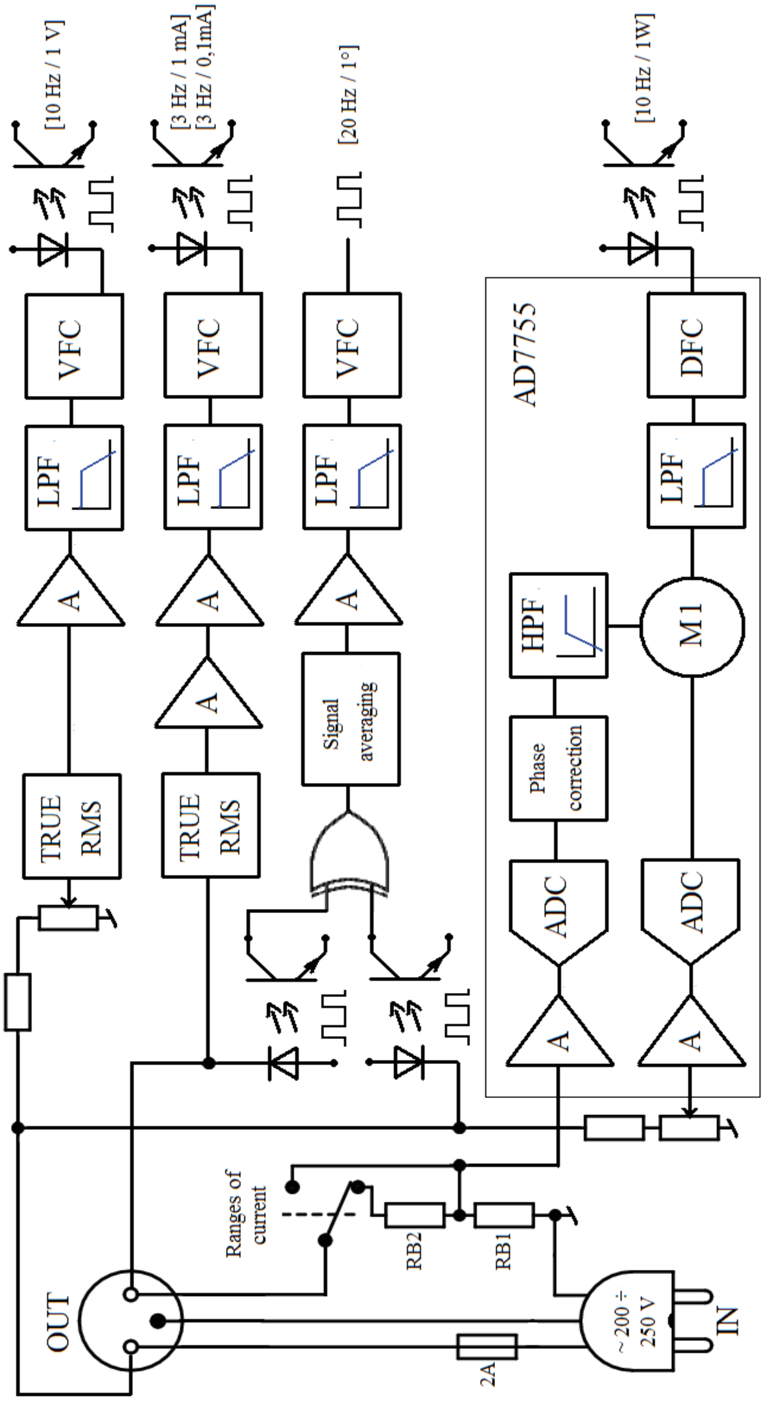


Fig. 1. Multitransducer schematic block

Multitransducer module which is responsible for processing the voltage (230 V AC) to a frequency signal has been designed with low complexity and very good parameters. Due to this, it consists of a voltage divider, from which the output signal goes to the rms value of TRUE RMS AD736 transducer. Signal outputted from AD736 transducer is conditioned and filtered for the last part of the processing, which is the LM331 chip. It serves as a converter of voltage signal into frequency signal. The resulting signal conversion module is provided for processing a signal voltage between 0 V and 250 V TRUE RMS. Unfortunately, for miniaturization of multitransducer purpose, the processed voltage is also a power supply voltage. Therefore, it can be safely assumed that effective voltage range of the processed signal should range from 200 V to 250 V.

Block for processing the current drawn to frequency pulses is created in a similar way as the voltage processing block. Its primary difference is that it has a more powerful amplification-processing system, where the voltage signal coming from the shunt requires greater attention due to the very low values and the necessity to process current value from 0 mA. In a situation where the processed quantity can take a zero value, it is advisable to raise its signal level. In the designed block, the output frequency signal for 0 mA is 1 kHz. In order to obtain higher processing resolution, two ranges of current drawn by the receiver were introduced. The first scope covers values from 0 mA to 130 mA, and the second from 0 mA to 1300 mA. The ranges are changed by a switch that turns the relay on or off, by which the measurement shunt value is changed. The resistor value 0.3 Ω 1% is used to measure the current in the range up to 1300 mA, and the shunt value of 3 Ω 1% is dedicated to the range below 130 mA.

The converter module of phase angle into frequency pulses is mainly based on a classical EX-OR logic gate. The rectangular signal representing the supply voltage and the rectangular signal representing the current are connected to the two inputs of the gate. In order to convert the sine wave into a square wave signal, an optocoupler is used, in which the LED is fed through resistors directly from the mains voltage. Square wave signal corresponding to the level of the current is formed with the use of the comparator, which works as a detector of crossing 0 V by voltage signal coming from the measurement shunt. Thanks to the level regulation of the comparator switching, a threshold can be selected for which the device will work properly with both very low and high current consumption. Subsequently, the signal from the operational amplifier working as a comparator is applied to the optocoupler. The signal on the gate output is in pulse width modulation, which is generally called a PWM signal. That signal is averaged, amplified and filtered accordingly. Thus prepared, the signal is indicated on the LM331 transmitter circuit, whose function is to convert the voltage signal into a frequency signal. In this conversion block, similarly as in the current to frequency conversion, an increase of frequency value for lack of phase shift is used. Therefore, for a value of 0 °, the frequency output value will be 1 kHz. The developed solution is not complicated and at the same time satisfying due to the diligent choice of elements for the proper calibration of optocouplers.

In a comprehensive solution that is the multitransducer, a power supply is necessary. Multitransducer processing accuracy will largely depend on the design of its power supply. In the case of the proposed device, voltage of +/- 5 V and isolated voltage +5 V was required. It is important to note that the power needed for the design must be stable over time, have a low output voltage ripple, and the value of voltage can not vary over time. Additionally, due to multitransducer power supply voltage between 200-250 V AC, power supply systems also have to ensure the stability of the parameters. To obtain a stable voltage +/- 5 V linear circuits stabilizers L7805CV and L7905CV were applied. The resulting voltages are not isolated from the mains supply since the systems forming and processing signals required such a solution. This means that the potential of 0 V (GND) is equivalent to the potential of the neutral N in the mains. Therefore, to ensure safety, all outputs of the individual signal processing blocks are isolated by optocouplers. For properly carrying the signals through optocouplers, safe voltage +5 V was used on the user side. For an isolated +5 V voltage integrated DC / DC converters AM1D0505SZ (Aimtec) powered from not isolated -5 V were applied.

The described processing blocks with multitransducers power form an electronic device which equals its parameters with currently produced multitransducers of this type. During the start of the designed device, it is important to make a thorough calibration of all possible settings of function blocks, in order to minimize signal-processing errors.

3. RESEARCH AND ANALYSIS OF THE METROLOGICAL CHARACTERISTICS OF THE REALIZED DEVICE

To perform examination of multitransducer (Fig. 2) a measurements system consisted of the following components has been set up:

- oscilloscope GDS-1022 GWINSTEK,
- frequency counter U2000 PROTEK,
- laboratory autotransformer AL-2500,
- wattmeter LW-1,
- ammeter TLEM-2,
- digital voltmeter BM805 BRYMEN,
- adjustable resistor with a value of 770 Ω OL2/400,
- light bulb 100 W,
- light bulb with switch 100 W,
- multiransducer,
- one-phase receiver RLC.

This allowed the system to calibrate all processing channels of the multitransducer. Tuning accuracy will depend on the adopted method of measurement and the measuring instruments. Calibration for each channel took place in the middle or near the middle of the processing range of every individual transducer. This procedure allowed to show the non-ideal linearity of processing characteristics Verification of the calibration process is made by the least squares method. For this purpose, it was necessary to perform measurements. Number of the measurements points is very important, because it affects the accuracy of determining the processing characteristics of the transducers.

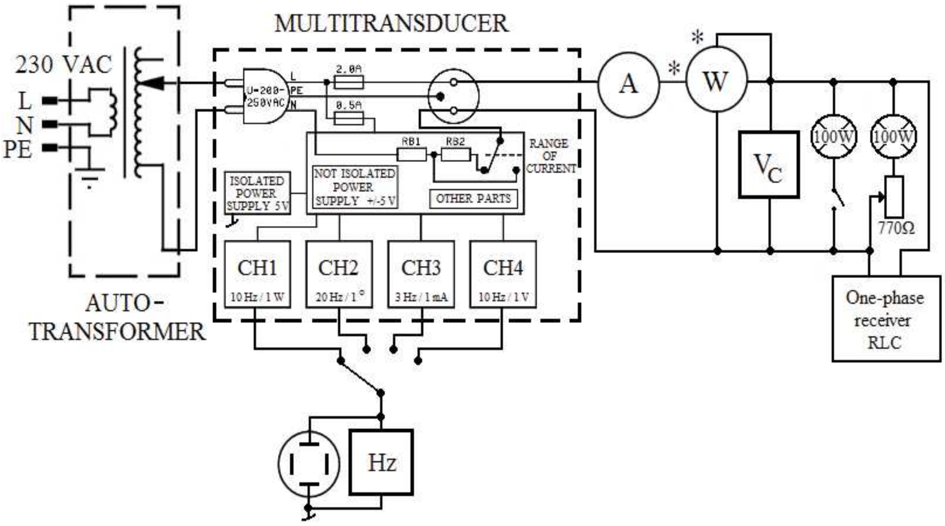


Fig. 2. Schematic of the measurement experiment of the multitransducer

The general mathematical model of the curve, used to determine the functional relationship between the input and the output of individual channel of the multitranscuders, is as follows:

$$\hat{Y} = f(X) \tag{1}$$

where:

X – the value of input transducer,
$\hat{Y}$ – the value of output transducer.

The least squares method is used to determine the regression line, which symbolizesthe functional processing relationship of each channel of the multitransducer. This article presents in-depth analysis of one processing path for measurements and least squares method. Other channels of the multitransducer are shortly reviewed and judged on their usefulness.

The multitransducer functions properly when the processed voltage ranges from 200 V to 250 V. Due to the use of LM331 transducers, which average the signal at its output, there is no need for a voltage stabilizer during the test. This was confirmed by repeatedly testing the same value in a randomly varying intervals of time. Table 1 shows the results of setting the voltage, measurement frequency, calculated processed constant for a given measurement. Additionally, the following table shows the absolute and relative errors relating to the predetermined processing constant of 10 Hz/V.

Table 1. Results of measurements and calculations for „voltage – frequency" channel

U (V)	*f* (Hz)	*f/U* (Hz/V)	*Δf/U* (Hz/V)	*δf/U* (%)
200,2	2017	10,07	0,07	0,75
205,3	2064	10,05	0,05	0,54
210,2	2114	10,06	0,06	0,57
215,0	2161	10,05	0,05	0,51
220,1	2214	10,06	0,06	0,59
225,4	2262	10,04	0,04	0,35
230,4	2318	10,06	0,06	0,61
235,4	2373	10,08	0,08	0,81
240,0	2420	10,08	0,08	0,83
245,0	2468	10,07	0,07	0,73
250,0	2527	10,10	0,10	0,96

Basing on the results from Table 1, a regression curve of the transducer was calculated by least squares method. Figure 3 shows a graph in which, aside from the specific points of processing, the regression curve of the transducer was also presented (voltage to frequency).

For the other processing channels metrological analysis was conducted in the same manner, with the results of a satisfactory level. Because of its low complexity, the voltage to frequency transducer turned out to be of a very good quality.

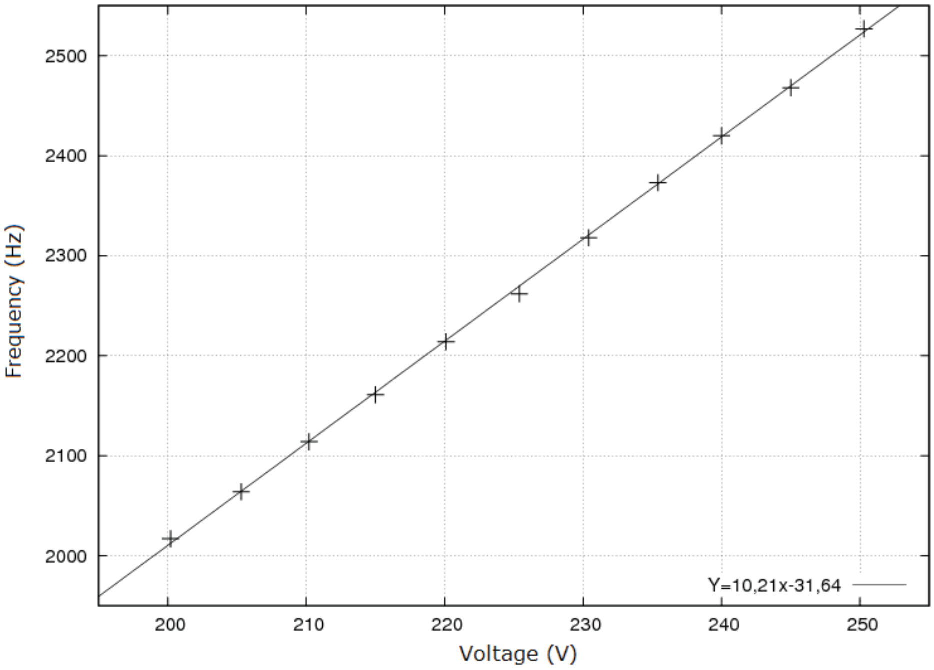


Fig. 3. Graph of the transducer – voltage to frequency

An important fact is the use of voltage-to-frequency LM331 converters, which results in averaging output signals. However, after the analysis of the projected measurement, it was concluded that it has no impact in the context of the measurement of static values.

4. COMPUTERIZED MEASUREMENT SYSTEM WITH PRESENT MULTITRANSDUCER

Multitransducer has been integrated into the modern measuring system whose additional components were a “frequency – code” multi-converter and a PC with LabVIEW software installed. The block diagram of the system is shown in Figure 4.

The application written in LabVIEW allows to simultaneously read from four outputs of the multitransducer. The screenshot of the running application is shown in Figure 5. The software allows to enter the regression coefficients for the given channel of multitransducer via the least squares method. The way of a specific channel processing curve change is determined by mathematical formula for the quadratic function:

$$Y = Ax^2 + Bx + C \tag{2}$$

where:

Y – value of the function,
x – argument of a function,
A, B, C – coefficients.

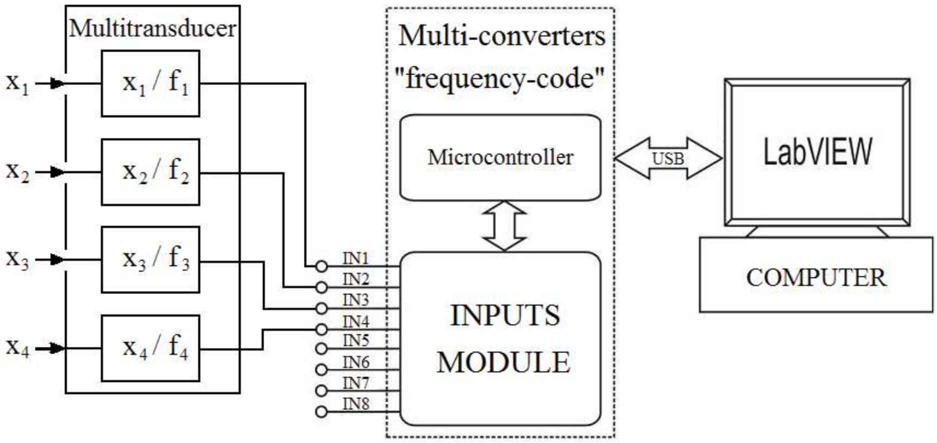
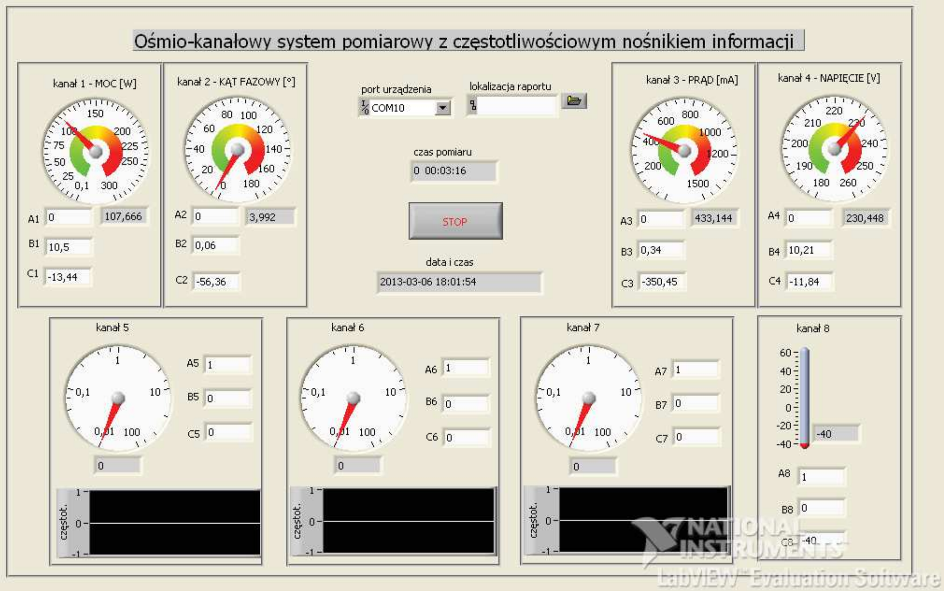


Fig. 4. Computerized measurement system block diagram

This solution saves time spent on writing or correcting the measurement system software when change of multitranscuder design is needed. The resulting processing characteristics of all channels in the device are linear and therefore the A coefficient equals zero.


Ośmio-kanałowy system pomiarowy z częstotliwościowym nośnikiem informacji

kanał 1 - MOC [W]
A1 0 107,666
B1 10,5
C1 -13,44

kanał 2 - KĄT FAZOWY [°]
A2 0 3,992
B2 0,06
C2 -56,36

port urządzenia COM10
lokalizacja raportu
czas pomiaru 0 00:03:16
data i czas 2013-03-06 18:01:54

kanał 3 - PRĄD [mA]
A3 0 433,144
B3 0,34
C3 -350,45

kanał 4 - NAPIĘCIE [V]
A4 0 230,448
B4 10,21
C4 -11,84

kanał 5
A5 1
B5 0
C5 0

kanał 6
A6 1
B6 0
C6 0

kanał 7
A7 1
B7 0
C7 0

kanał 8
A8 1
B8 0
C8 -40

Fig. 5. Application for computerized measurement system

The measurement values were taken via Computerized measuring system, which aimed to examine the mapping error of values measured by different measuring instruments. For example, consider the voltage measurement, when the measurement of both absolute and relative error does not have a clear character, as shown in Table 2. The worst value of the relative error is 1%, which is classifies the method as a promising one.

Table 2. Results of the measurement of the voltage True value RMS and the errors

Ur (V)	*Um* (V)	*ΔU* (V)	*δU* (%)
200,0	200,53	0,53	0,27
210,0	210,51	0,51	0,24
220,0	221,47	1,47	0,67
230,0	231,44	1,44	0,63
240,0	242,41	2,41	1,00
250,0	252,38	2,38	0,95

where: *Ur* – value of reference voltage, *Um* – value of measure voltage, *ΔU* – absolute error voltage, *δU* – relative error voltage.

The reference voltage value is read from the class 0.5% voltmeter and the measured voltage is the result of a computer readout of the measurement system.

Others processing channels of multitransducer unfortunately fared worse, which means that the number of performed calibrations was insufficient or that the multitransducer requires minor adjustments to its design.

However, it is worth noting that the above test results were performed for different lengths of wires sending the frequency signals. The results did not differ between connection one meter long and the ones one hundred meter long, which proves that the described multitransducer performs its role well.

5. CONCLUSIONS

The multitransducer presented in this article has a large potential for both educational and practical purpose. It shows a lot of metrological dependencies in the individual processing channels. At the present time, the multitransducer is used in the computer system presented in section four, as a laboratory exercise in "Computerized measurement system" classes. If the processing channels were further refined, in such a way, that the values of processing errors and errors resulting from the values read from the measuring computer system were the same or better than the processing error of voltage to frequency transducer, this entire device would be so attractive that it could compete with the solutions currently available for purchase. It could not only match or even exceeded its accuracy class, but its price would be attractive as well. Total price of the components of the multitransducer described above should not exceed 300 PLN, considering the multitransducers prices that range from about 2000 PLN to 5000 PLN. This multitransducer has a chance to become an alternative for expensive solutions which are currently on the market. While summarizing the metrological properties of the multitransducer, it is important to use a maximum number of calibration steps for each block, so that we can achieve the maximum accuracy of the processed values.

Transducers with frequency output can be a solution for the future because of their versatility and flexible application. One of the many possible stages of development of the described issue, are fully programmable multitransducers that will supersede dedicated solutions, such as those described in the article. However, the price of the dedicated solutions will always be lower, so it will be reasonable to create multitransducers like the one discussed in this publication.

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MULTIPRZETWORNIK Z WYJŚCIAMI CZĘSTOTLIWOŚCIOWYMI DO ZASTOSOWAŃ W KOMPUTEROWYM SYSTEMIE POMIAROWYM

Streszczenie

W pracy omówiono multiprzetwornik z wyjściami częstotliwościowymi do zastosowań w komputerowym systemie pomiarowym. Opisano budowę multiprzetwornika realizującego pomiar parametrów odbiorników jednofazowych, a także dokonano badania oraz analizę właściwości metrologicznych zrealizowanego układu. Finalnie omówiono przydatność opisywanego multiprzetwornika pod kątem dydaktycznym oraz praktycznym.

Słowa kluczowe: multiprzetwronik, przetwornik pomiarowy, metoda najmniejszych kwadratów, analiza własności metrologicznych, komputerowy system pomiarowy, LabVIEW