

IMPEDANCE METER WITH SIMULATED RESONANCE

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INTRODUCTION

By using the method of simulated resonance for impedance measurement [1], it is possible developing of impedance meters with high metrological and operating characteristics and low cost [2, 3]. Among the technical characteristics available to these meters are listed: high measurement accuracy, simple structure and measurement algorithm, automated measurement process, ability to connect to PC, low weight and sizes [3].

Impedance-meter with simulated resonance is composed of three modules: signal source, measurement module and command module.

Signal source (SS) is an external energy source that provides power measurement circuit. This is a sinusoidal signal generator that comply the conditions:

- The known and stable value for frequency of generated signal;
- The possibility of automatic adjustment of signal level according to the measured impedance value.

In order to assure the high stability of the frequency of signal as a signal source is used a microcontroller-based digital generator with stabilization quartz.

Measurement module (MM) is the block of impedance-meter that performs the measurement of impedance components by means of the simulated resonance method. MM is based on a resonance measuring circuits (RMC), and the measurement process consists in its partial or full balancing. The balancing is according to the algorithm described in [4]. MM forms the signal of imbalance and the signal of reference for command module and the signal of level of amplitude for SS.

Command module (CM) provides automation of measurement through the following functions: fixing the amount of frequency of SS signal; automatic balancing of the RMC; storage, processing and display of results and assuring connection to PC. To assure balancing of the RMC, CM compares the phases of the reference signal and the imbalance signal from MM and depending on the amount of phase shift, it provides adjustment of impedance components reproduced by a metrological impedance simulator (MIS).

1. SIGNAL SOURCE OF THE IMPEDANCE METER

Signal source provides power for MM for the conversion of the measured impedance in active electrical size. According to the analysis [5] to comply with conditions of functional stability of the MIS and to achieve an effective balancing process, it is necessary to power the circuit to a stable source of current with internal impedance of active character. In practice, this can be achieved by using a stable source of voltage that has connected a high value resistor R_G at the output.

To assure the frequency and amplitude conditions, it is necessary to use a digital generator with automatic adjustment of the amplitude. The block diagram of such a SS is shown in fig. 1.

The microcontroller μC assures forming of signal with pulse-width modulation (PWM) according to the sinusoidal signal law. The high stability of frequency the PWM signal is assured by the quartz element. By means of the "Setting frequency" bus is insured a multiplication coefficient corresponding to the clock frequency, and consequently it changes the frequency of the PWM signal. By means of the control unit, it insures the setting of frequency the measurement signal at one of wanted values.

Low-pass filters are set to the frequencies listed above respectively and they insure forming of the sinusoidal signal from PWM signal.

To assure an appropriate level of the measurement signal, SS has a block for automatic adjustment of the amplitude (AAA) which depending on the level of the signal from MM adjusts transfer coefficient of a programmable amplifier PA.

2. MEASUREMENT MODULE OF THE IMPEDANCE METER

The measurement module is the main block that insures the measurement of the unknown impedance and metrological characteristics of the device depends on its parameters. Due the simulated resonance, method of the impedance measurement is possible to develop a measurement module with

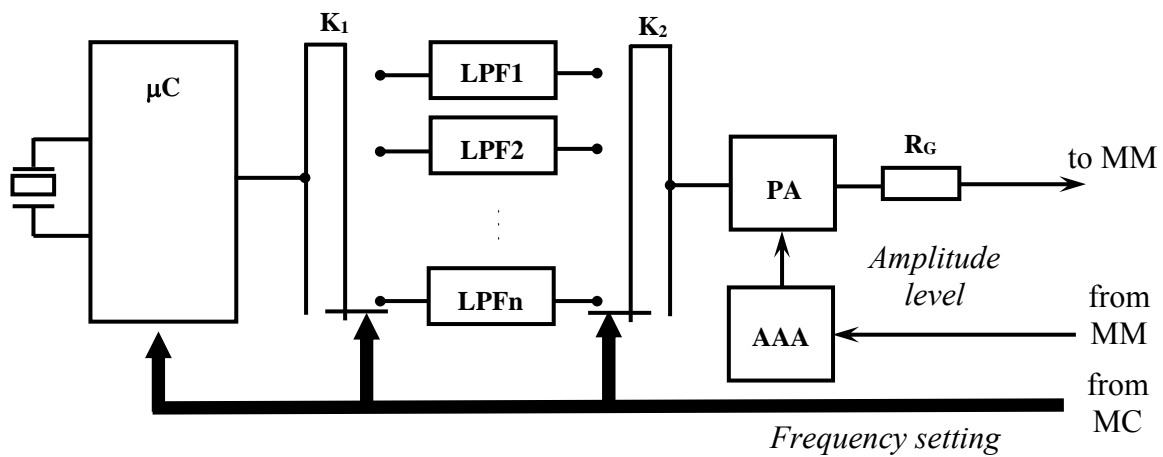


Figure 1. Block diagram of the signal source.

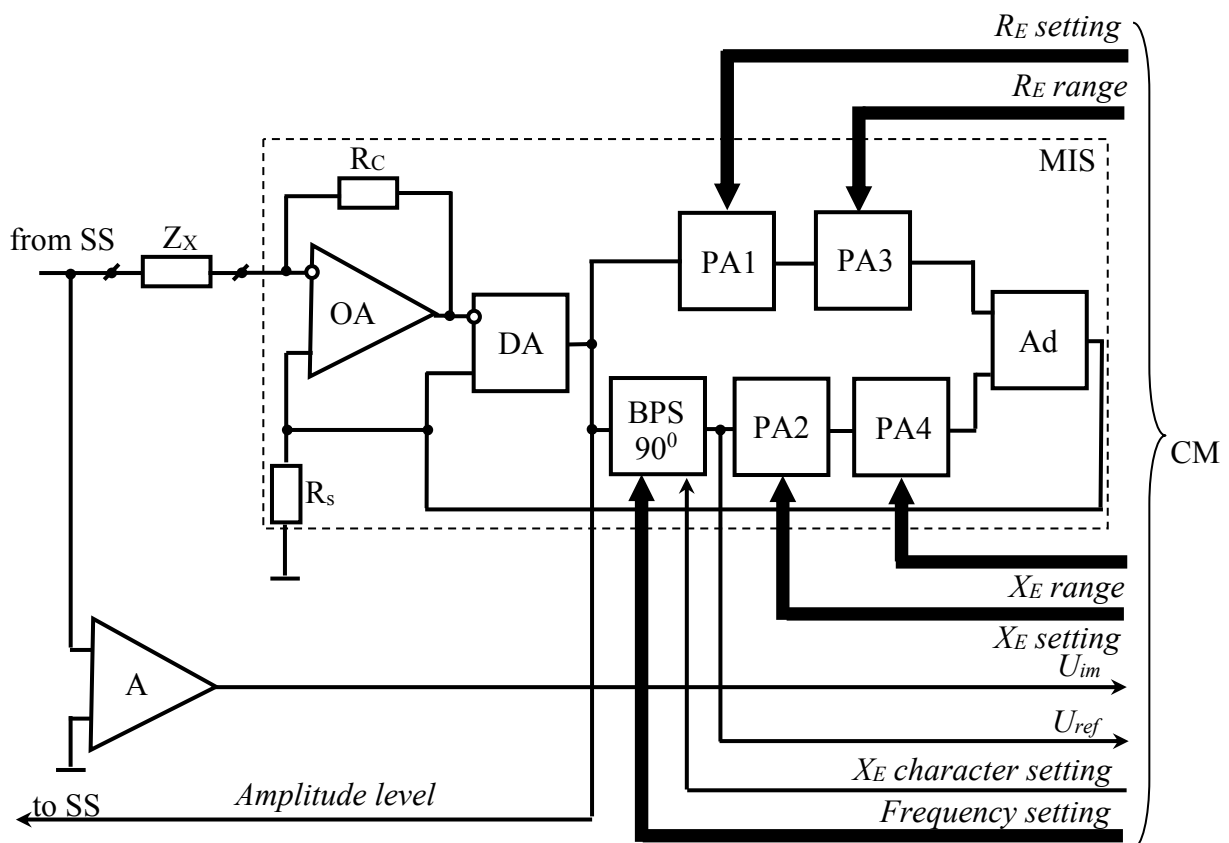


Figure 2. Block diagram of the measurement module.

higher characteristics than to other devices [6]. The block diagram of this module is shown in fig. 2. MM is based on a series-type RMC with a metrological impedance simulator (MIS) in its construction [7]. MIS insures reproduction of the reference impedance with adjustable value and character [8]. All MIS components are implemented on the basis of operational amplifiers (OA) [9]. For digital adjusting of the value and of the character for reference impedance, in MIS structure can be used

the digital potentiometers or the digital programmable amplifiers (PA1, PA2) with the smooth and linear adjustment of the amplification coefficient [10].

According to MIS structure (fig. 2) the operational amplifier OA and the resistance R form a voltage-current converter. The resistance value R is selected according the condition of stability [5]. The differential amplifier DA has a unitary transfer coefficient and it assures summing the signal

applied to the non-inverting input with the signal applied to the inverting input [11].

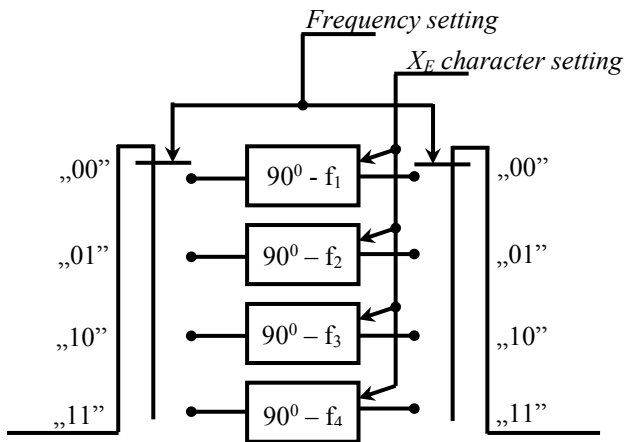


Figure 3. The structure of the block of phase shifters at 90°

The formation of the reactive components in the circuit is performed by means of the block of phase shifters at 90° (BPS 90°) (fig. 3). This block consists from four phase shifters each of them is based on an operational amplifier (fig. 4) and assures a phase shift according to the relation:

$$\Delta \varphi = -2 \arctg 2 \omega R_3 C_4 \quad (1)$$

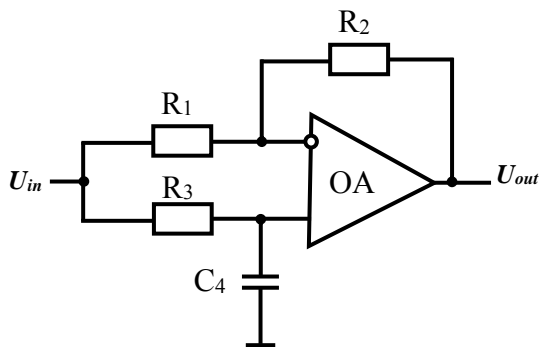


Figure 4. The circuit of the phase shifter based on OA

According to relation (1), if is selected the corresponding values for the elements of R_3 and C_4 , the phase shift introduced by the circuit in fig. 4 will be 90° [12].

Whereas, that phase shift will be dependent of frequency, it takes 4 such phase shifters each of which is tuned to one of the frequencies of the SS signal according to the "Frequency setting" digital code from CM. To assure inductive character for reference impedance Z , the phase shift introduced by the phase shifter must be 90° , but to assure

capacitive character - 90° . This is assured by switches K_1 and K_2 (fig. 5) through the digital code "XE character setting" from CM.

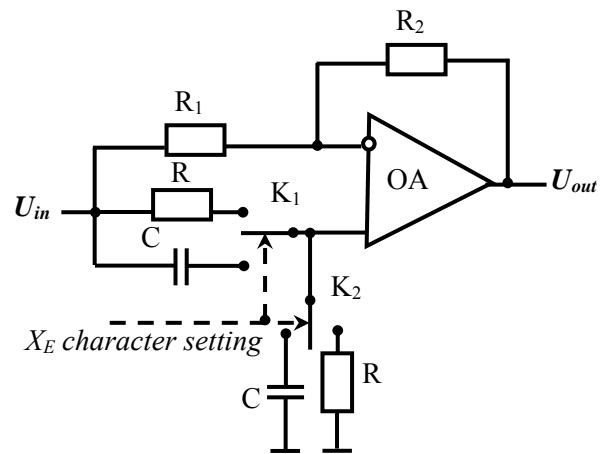


Figure 5. The circuit of the programmable phase shifter based on OA

The programmable amplifiers PA1 and PA2 in fig. 2, assure smooth adjustment to reference impedance components. To assure any character for active component of the reference impedance Z_E , PA1 must assure an amplification factor in range of the values $-1 \div +1$. PA2 will assure an amplification factor in range of the values $0 \div +1$ [13]. In addition, to could be conducted by CM, the adjustment of the amplification coefficient must be made via a digital code. The length of the digital code of adjustment for the reproduced impedance components determines the error of fixing the moment of resonance in RMC This error will be determined according to the relation:

$$\delta_{regl} = 2^{-N} \quad (2)$$

where: N – the number of bits in the composition of the digital code.

The programmable amplifiers PA3 and PA4 (fig. 2) assure the adjustment of the range of values for the components of reference impedance, by assuring a stepped amplification coefficient. They can be realized based of OA for that amplification coefficient depends only on the values of the resistances in the feedback loop and does not depend on the OA parameters. In fig. 6 shows the structure of an PA with stepped adjustable coefficient based OA with inverting connection.

The adder Ad (fig. 2) assure the summation of the voltages from two branches of adjustment of components of the reference impedance. It is based on an AO and can be realized as an adder of the

direct voltages, as an adder of the inverted voltages or as a differential amplifier [9].

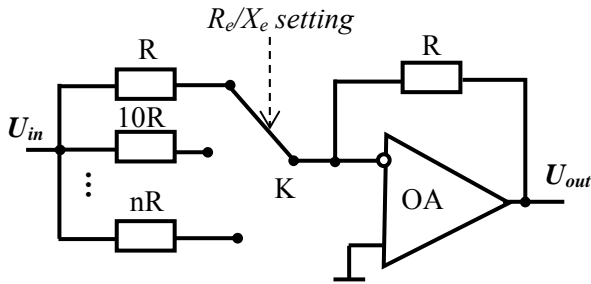


Figure 6. The circuit of the PA with stepped adjustable coefficient based OA.

To achieve the balancing process in measuring circuit, it is analyzed the evolution of the phase shift between the imbalance signal U_{im} and the reference signal U_{ref} . The reference signal is formed by the IMS and it represents the voltage at the output of DPS90°. The imbalance signal is obtained from MM input and to assure increased sensitivity, this signal is amplified by an amplifier A (fig. 2). CM realizes the process of determining the phase shift between these two signals and the balancing of the measuring circuit.

3. COMMAND MODULE OF THE IMPEDANCE METER

The command module is used to assure an automatic measurement process. This module assures the control of the functionality for entire device through the following functions:

- Assuring the user interface
- Fixing the frequency of signal from SS
- Balancing after the active component of RMC from MM;
- Balancing after the reactive component of RMC from MM;
- Processing results after balancing
- Transmission of results to the device interface.

The block diagram of the CM is shown in fig. 7. The basic element of the CM, which is the "brain" of the impedance meter, is the control unit (CU) based on the microcontroller. CM contains two comparators C_1 and C_2 , to convert sinusoidal signals into a series of rectangular pulses, a dynamic D-type flop (DDF) which forms the signal CE for fixing the moment of resonance at balancing and a microcontroller USB (μC USB) that assures the interface between the CU and PC.

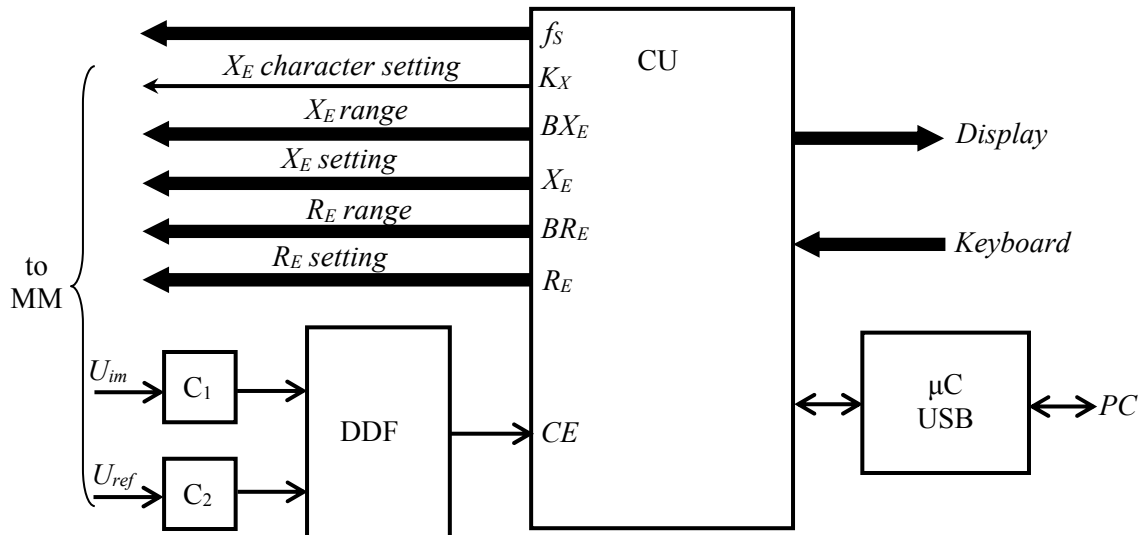


Figure 7. The block diagram of the command module.

According to the analysis [11], the balance process for RMC is achieved by varying the values of the components for the reference impedance and the tracking of the evolution of the phase shift between the imbalance signal and the reference signal. This is accomplished by using the DDF. The time diagrams for the input and output signals of the DDF is shown in fig. 8.

According to [12] the timing of balancing for RMC coincides with the appearance of a 0° (fig. 8

a) or 180° (fig. 8 b) phase shift between U_{ref} and U_{im} . In the moment of these values of the phase shift, DDF changes its state, and the CE signal at its output is used as a signal for fixing the moment of the resonance in the balancing process.

CU assures the formation of the command signals for other modules and the automatic data processing. Once with the power connection, CU determines the type of the operator interface. Initially, it checks the connection to the PC via USB

port. If the impedance meter is not connected to the PC, CU will activate the ports at that are connected the display and the keyboard. After determining the user interface, CU asks the setting for the amount of the measurement signal frequency. This value of the frequency is encoded and transmitted to the corresponding blocks from SS and MM. At the same time, this frequency value is memorized and then it is used by CU for processing results.

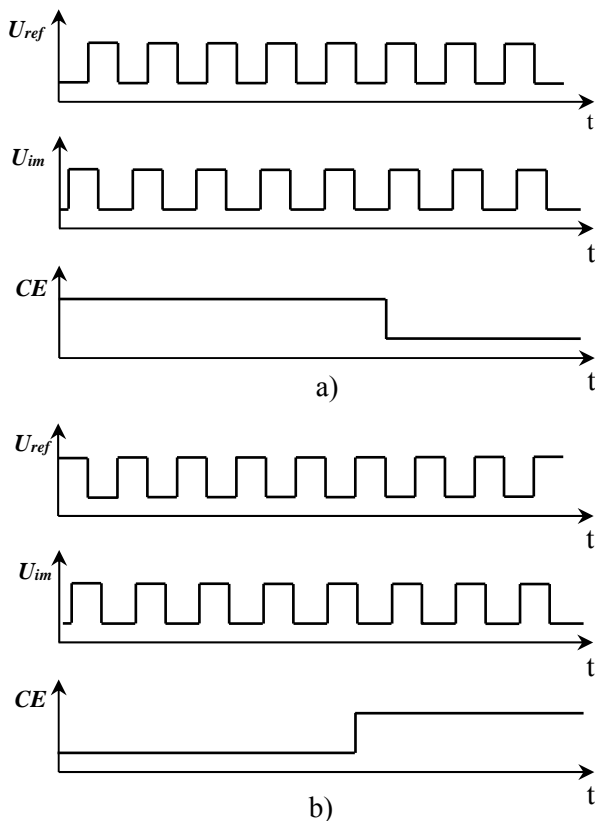


Figure 8. The time diagrams for the signals of the DDF: a) Fixing of the 0° phase shift between U_{ref} and U_{im} ; b) Fixing of the 180° phase shift between U_{ref} and U_{im} .

After setting the value of the measurement signal frequency, CU begins the process of balancing for RMC. According to [13] the balancing process realizes in two stages: the balancing of the active component and the balancing of the reactive component. As these two stages are independent of each other, they may be made as two separate processes.

In order to assure the balancing process of the active component, CU varies the value of the active component of the reproduced impedance through the channels „ R_E setting” and „ R_E range” until the value of the CE signal changes. The algorithm for balancing of the active component is shown in fig. 9.

Initially, CU fixes the value zero for R_E and BR_E codes. Then CU reads the value of the CE signal and memorizes this value. Forwards, CU increments the value of the R_E code, reads again the value of CE signal and compares it with the memorized value. If the CE value is modified, CU will assure the balancing of the circuit and the respective values of R_E and BR_E codes will determine the value of active component of the reference impedance. If the CE value is not modified, CU will increment the value of the RE code until this value will be modified. If the value of R_E code reaches the maximum value and does not assure the modification of the CE signal, CU will change the value range and will repeat the process. To switch to a higher value of the range, CU assures the incrementing of the BR_E code. If CU exhausts all the values of the range and the balancing of the active component is not assured, CU will display "The exceeded value of R_E " on the interface of the impedance meter.

After ensuring the process of balancing of the active component or after displaying on the interface of the message "The exceeded value of R_E ", CU initiates the process of balancing of the reactive component (fig. 10). To do this, CU varies the value of the reactive component for the reference impedance through the channels „ X_E setting”, „ X_E range” and „ X_E character setting”. As opposed to balancing process of the active component, for balancing of the reactive component is necessary and the setting of the character of the reference reactance. This is ensured by the CU through the K_X signal transmitted via the „ X_E character setting” bus. Initially, CU checks the balancing of the reactive component, setting the inductive character of the reference reactance. ($K_X=0$). In this case the balancing process is similar to that shown in fig. 11, with the difference that the CU increments the value of the X_E and BX_E codes. If the balancing process of the reactive component is not ensured, CU will set the capacitive character of the reference reactance ($K_X=1$) and will repeat the same procedure as for the inductive character.

If CU does not ensure the balancing process after setting the capacitive character of the reference impedance, CU will display "The exceeded value of X_E " on the interface of the impedance meter [12].

If CU ensures the complete balancing of the RMC, it will initiate the procedure for processing the results and displaying them. If the operator interface is accomplished via PC, the procedure for processing the results can be made by computer using a special application. In this case, CU sends

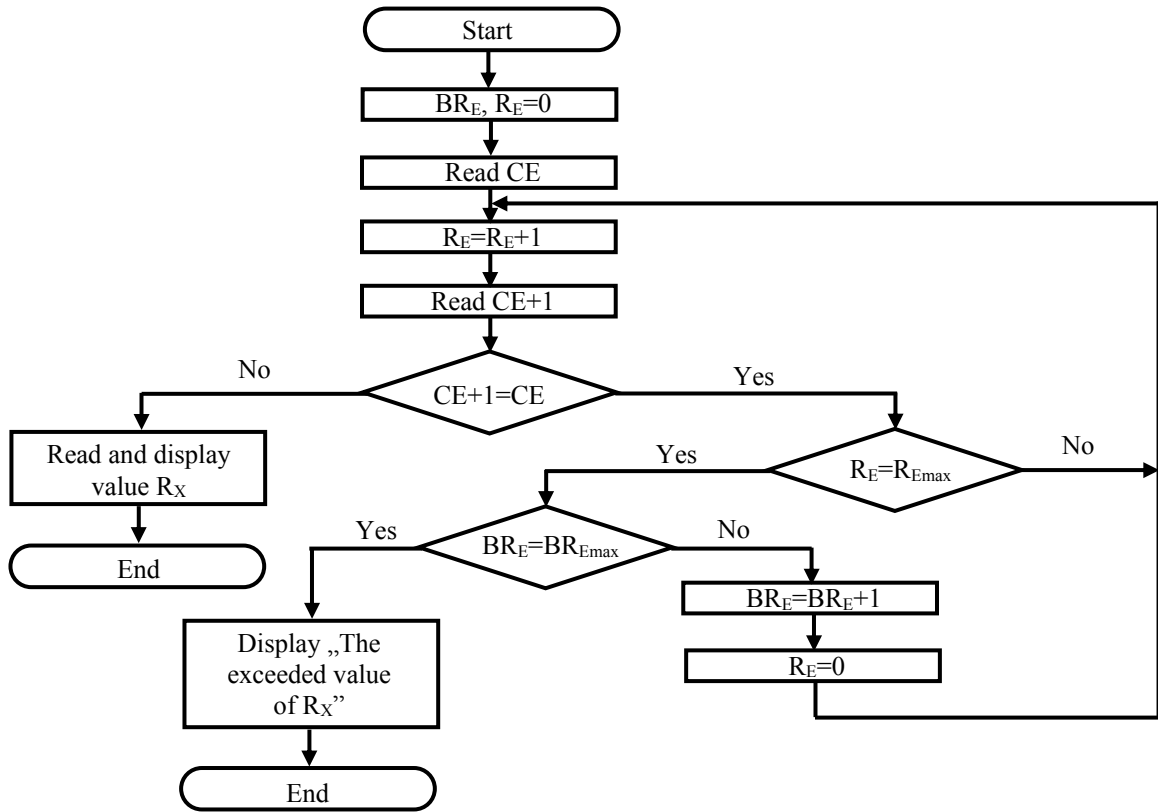


Figure 9. The measurement algorithm for the active component.

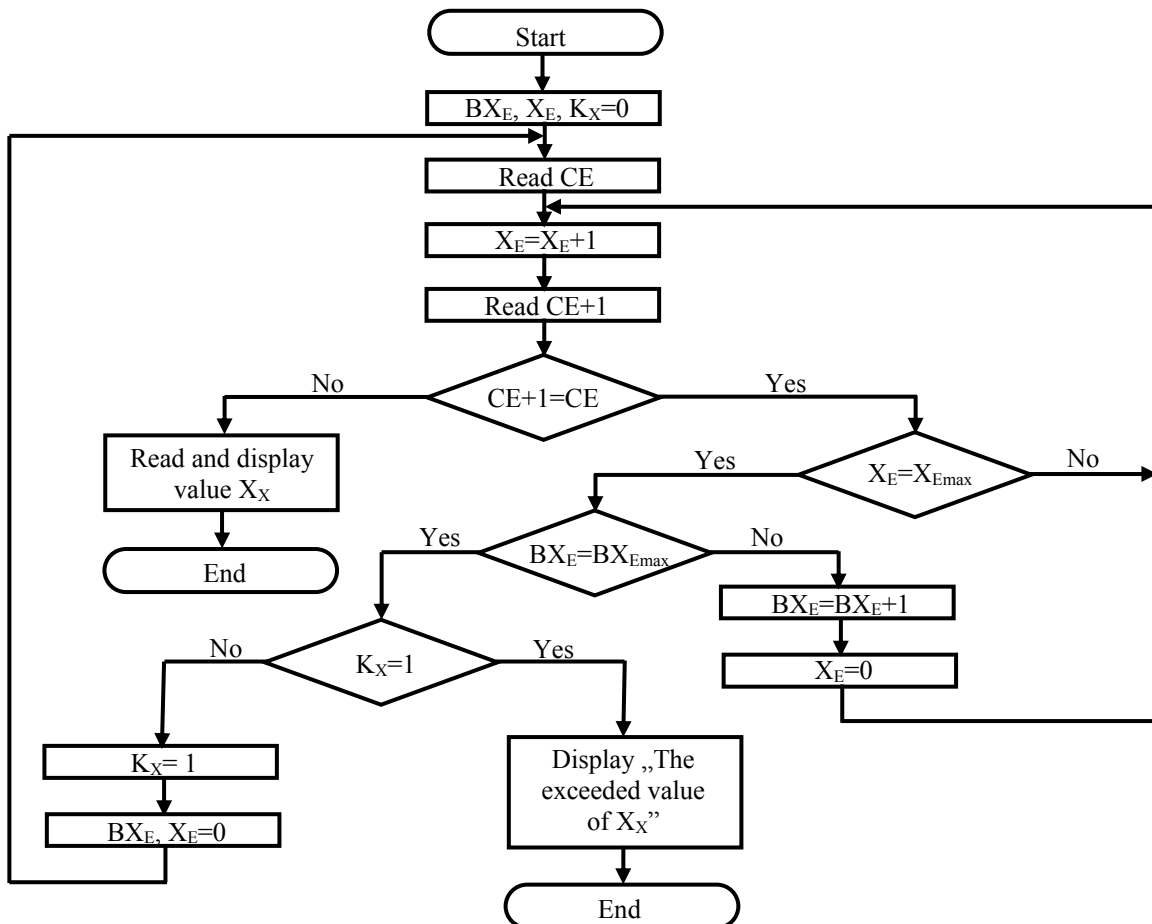


Figure 10. The measurement algorithm for the reactive component.

to the PC the values of the codes: R_E , BR_E , X_E , BX_E , K_X and f_s . If the results are indicated on the display of the impedance meter, then CU will ensure and the processing of the results [14].

CONCLUSIONS

The impedance measurement using the simulated resonance method ensures a high precision, simplicity of the measurement process and its automation. The high precision is determined by the precision of the metrological impedance simulator.

The use of impedance simulator with independent components adjustment ensures a simple measurement algorithm for impedances of any nature. The balancing of the measurement circuit is completely automatic, is realized in two stages: the balancing of the active component and the balancing of the reactive component. The impedance meter permits to measure the components of the impedance in Cartesian coordinates for four frequencies of the signal. The results can be indicated on the display of the impedance meter or on the PC.

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