

# Impedance meter in Cartesian coordinates

Nicolaev Pavel

Telecommunications Department  
Technical University of Moldova  
pavel.nicolaev@tlc.utm.md

**Abstract** — The paper is dedicated to the problems of automatic measurement of the impedance components in Cartesian coordinates. In paper is presented the structure and the operating principle of the impedance meter with simulated resonance that is characterized by simplicity, accuracy and low cost. A particular attention was given to the components of the impedance meter that enables the automation of the measurement and the processing of the results.

**Index Terms** — Impedance meter, simulated resonance, resonance measuring circuits, metrological impedance simulator.

## I. 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).

## II. 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  $\mu C$  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.

## III. THE MEASUREMENT MODULE OF THE IMPEDANCE METER

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90° (BPS90°) (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:

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

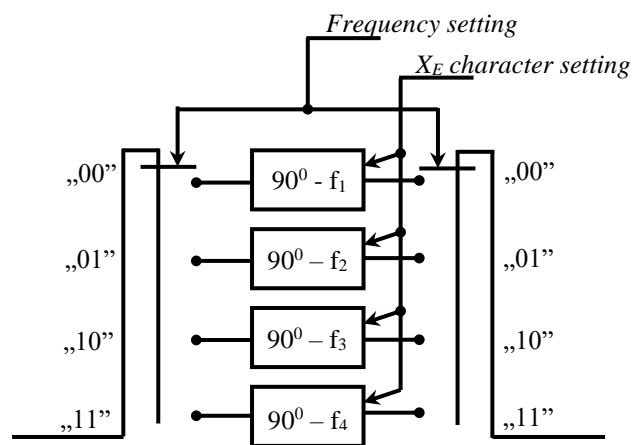


Fig 3. The structure of the block of phase shifters at 90°

According to relation (1), if is selected the corresponding values for the elements of R<sub>3</sub> and C<sub>1</sub>, the phase shift introduced by the circuit in fig. 4 will be 90° [12].

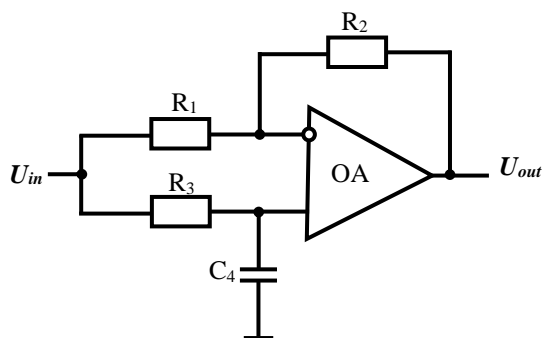


Fig. 4. The circuit of the phase shifter based on OA

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<sub>1</sub> and K<sub>2</sub> (fig. 5) through the digital code "X<sub>E</sub> character setting" from CM.

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<sub>E</sub>, PA1 must assure an amplification factor in range of the values -1 ÷ +1. PA2 will assures an amplification factor in range of the values 0 ÷ +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.

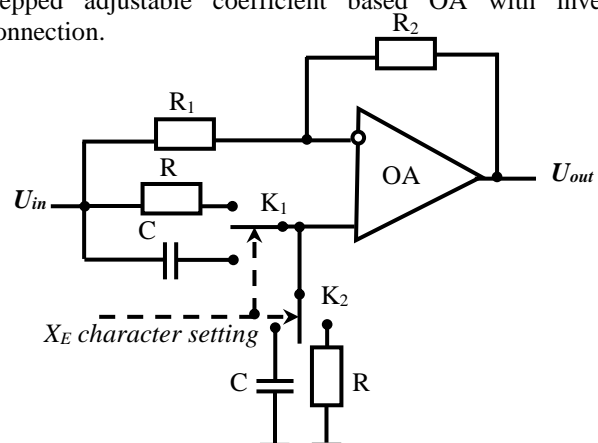


Fig. 5. The circuit of the programmable phase shifter based on OA

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].

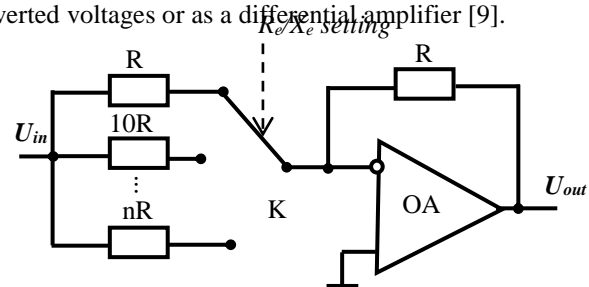


Fig. 6. The circuit of the PA with stepped adjustable coefficient based OA

To achieve the balancing process in measuring circuit, it is analyzed the evolution of the phase shift between the imbalance signal U<sub>im</sub> and the reference signal U<sub>ref</sub>. 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.

#### IV. THE COMMAND MODULE OF THE IMPEDANCE METER

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.

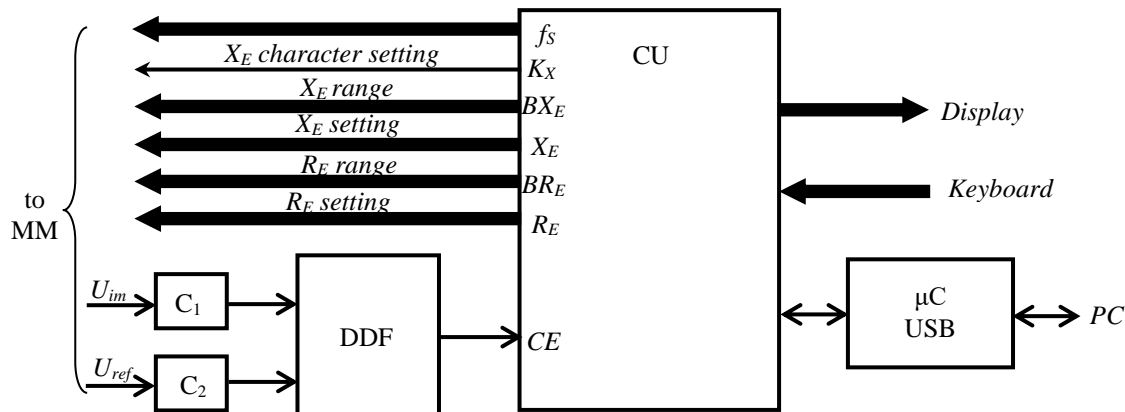


Fig. 7. The block diagram of the command module

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 ( $\mu C$  USB) that assures the interface between the CU and PC.

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.

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

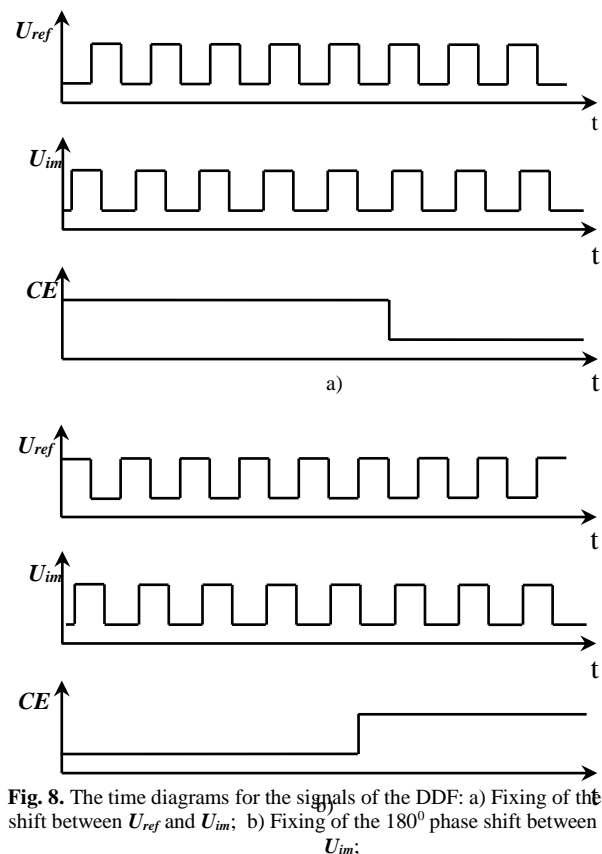


Fig. 8. The time diagrams for the signals of the DDF: a) Fixing of the  $0^\circ$  phase shift between  $U_{ref}$  and  $U_{im}$ ; b) Fixing of the  $180^\circ$  phase shift between  $U_{ref}$  and  $U_{im}$ ;

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

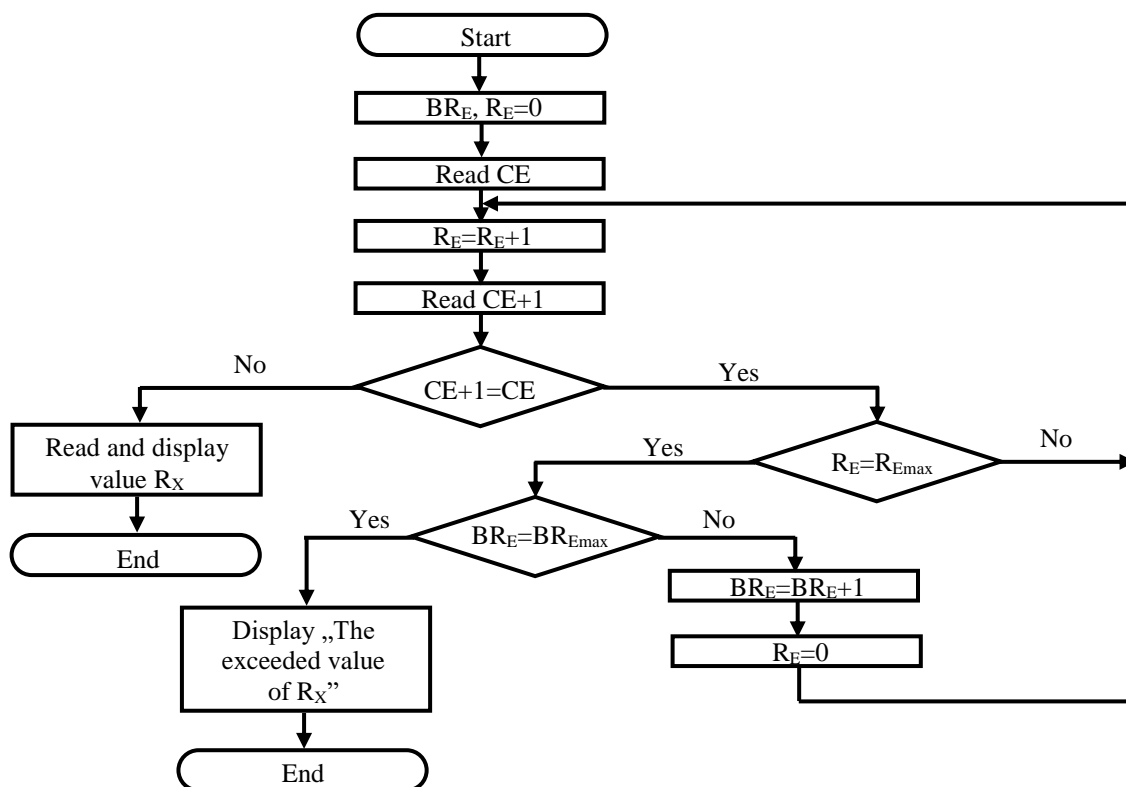


Fig. 9. The measurement algorithm for the active component

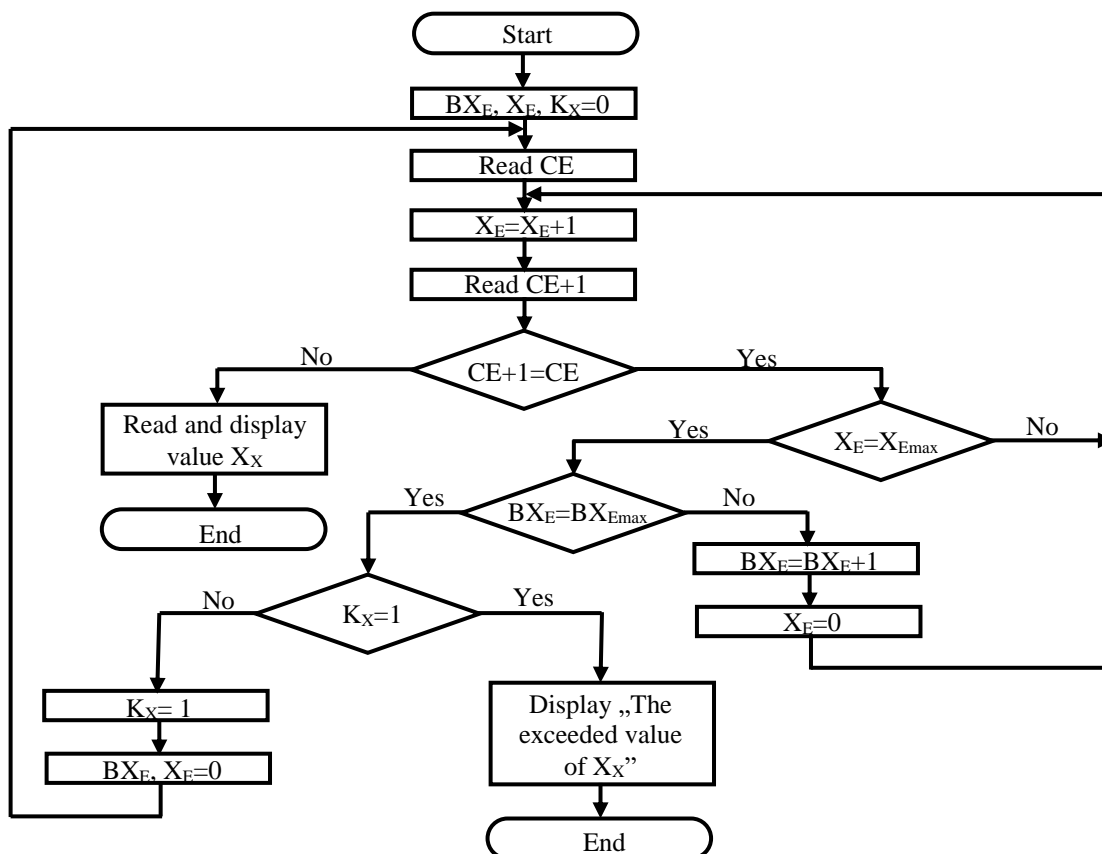


Fig. 10. The measurement algorithm for the reactive component

impedance. If the CE value is not modified, CU will increment the value of the RE code until this value will be signal, CU will change the value range and will repeat the process. To switch to a higher value of the range, CU assures modified. If the value of  $R_E$  code reaches the maximum value and does not assure the modification of the CE 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 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].

## V. 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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