METROLOGICAL SIMULATORS OF IMPEDANCE WITH ALGORITHMIC STRUCTURE

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Abstract – *Paper contains systematization of the material in the domain of metrological simulators of impedance with algorithmic structure (MS-A, for simplicity), used as reference elements on impedance measurement. There are presented the general aspects of these devices, the MS-A classification under the relevant criteria, the formal – structural method of synthesis of the simulators with necessary characteristics and the example of synthesis.*
Keywords – *impedance simulator, impedance measurement*

1. INTRODUCTION

The use of metrological simulators (MS) of passive electrical quantities (PQ) as reference elements (RE) in impedance and admittance measurement opens high perspectives for the improvement of devices characteristics in this branch [1]. The most important advantages, resulting there from, are:

- exclusion of adjustable reactive elements and reactance boxes;
- exclusion of the switching in the measurement circuits, determined by the variation of type and character of the measured quantity;
- simplification of measuring circuit equilibration algorithm up to two operations in the case of measuring the both components of passive quantity;
- measurement of PQ with any character (active, reactive or complex) and with any substitution equivalent circuit (series, parallel) without modification of the measuring circuit's structure;
- measurement of the negative resistance;
- digital control and complete automatization of the measuring process;
- possibility of implementation in integrated circuits;
- reduction of the devices price, dimension and weight.

MS with algorithmic structure (MS-A) [1] has a special place in this class of devices. These devices have been specially synthesized for using as RE in the devices for PQ measurement (impedance meters and admittance meters) and possess a technical characteristics, optimized from this point of view. The MS-A structures have been synthesized through the formal – structural method according to the requirements to the RE characteristics, determined by the measuring method and circuit. The most important use's features of them are:

- possibility of reproduction of the PQ, represented in the needed coordinate system (Cartesian or polar) and with the needed character of components (active, reactive, or complex);
- independent control of the components of PQ;
- guaranteed stability at the variation of external impedance in the determined values domain;
- possibility of reproduction of the simulated PQ (SPQ) placed in the entire complex plan: (±R, ±**j**X) for impedances, or (±G, ±**j**B) for admittances;
- the guaranteed and determined systematic error.

2. MS-A. GENERAL OVERVIEW

Functionally, the metrological simulator of passive electrical quantities with algorithmic structure represents a device with two poles, which assures the reproduction of SPQ, represented in the necessary coordinates system and the possibility of independent control of the components (Fig. 1) [2]. The PQ reproduced by MS-A (impedance $\mathbf{Z_i}$, or admittance $\mathbf{Y_i}$) may be represented [1] in Cartesian coordinates:

$$\mathbf{Z_i} = R_i + \mathbf{j}X_i \text{ , } \mathbf{Y_i} = G_i + \mathbf{j}B_i, \tag{1}$$

or, alternatively, in the polar coordinates:

$$\mathbf{Z_i} = Z_i \exp(\mathbf{j}\varphi_i) \text{ , } \mathbf{Y_i} = Y_i \exp(\mathbf{j}\psi_i) \tag{2}$$

where R_i, X_i (G_i, B_i) – respectively, the active and the reactive component, Z_i, φ_i (Y_i ,ψ_i) –the module and the phase of the reproduced impedance (admittance).
Therefore, the Cartesian coordinates MS-A (MS-C) must assure the independent control of the active R_i and the reactive X_i components (respectively, G_i, B_i for admittances) and the polar coordinates MS-A (MS-P) – the independent control of module Z_i (Y_i) and phase φ_i (ψ_i) of the reproduced on the input poles PQ.

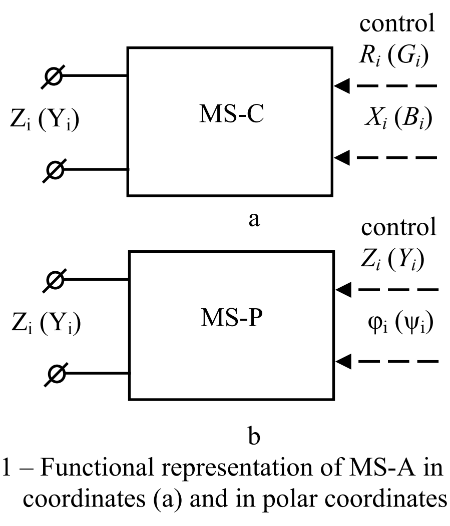


Fig.1 – Functional representation of MS-A in Cartesian coordinates (a) and in polar coordinates (b)

For assurance the MS universality in order to reproduce the PQ with any character, the domains of variation of the reproduced PQ components must be [1]:

- for simulated impedances:

$$R = \{-R_{\max} \div +R_{\max}\}; X = \{-X_{\max} \div +X_{\max}\}$$
$$Z = \{0 \div Z_{\max}\}; \varphi = \{0 \div 360^{O}\} \quad (3)$$

- for simulated admittances:

$$G = \{-G_{\max} \div +G_{\max}\}; B = \{-B_{\max} \div +B_{\max}\}$$
$$Y = \{0 \div Y_{\max}\}; \psi = \{0 \div 360^{O}\} \quad (4)$$

In this case, the coverage of the entire complex plan is being assured, and, due to this – the possibility of reproduction of simulated PQ with any character.

As it is known, there are many types of MS with various features, according to the classification proposed in [1: classical MS, MS-A, MS with ladder structure, MS type gyrator, etc.

MS-A forms a class of devices with synthesized through the formal – structural method structure according to the requirements, determined by its concrete application in measuring circuits. The MS-A classification by relevant criteria is represented in the table 1.

For designation of type of MS-A in the table, the qualifying abbreviations have been used. For example, for the simulator represented in the table as „I-MS-C-As", the signification is:

I – current commanded (U – voltage commanded),

C – Cartesian coordinates (P – polar coordinates),

As–asymmetrical (S–symmetrical) connection.

These devices correspond to the proposed on [1] the general classification and, further, for simplicity three criteria are being considered as relevant:

1. The type of primary input quantity. One of the basic properties of SPQ determines this criterion: to be commanded on current (for I-MS) or on voltage (for U-MS) [3]. As it is known [3], the type of primary input quantity determines some features of MS and the type of its stability.

The principle of SPQ reproduction in I-MS (Fig. 2.a) is based on the process of forming a voltage $\mathbf{U_i}$ from the input current $\mathbf{I_i}$ by means of its conversion under necessary dependence and its application in the input circuit of the SPQ. The entering current $\mathbf{I_i}$ and the voltage $\mathbf{U_i}$ results in the reproduction of the virtual impedance $\mathbf{Z_i}$:

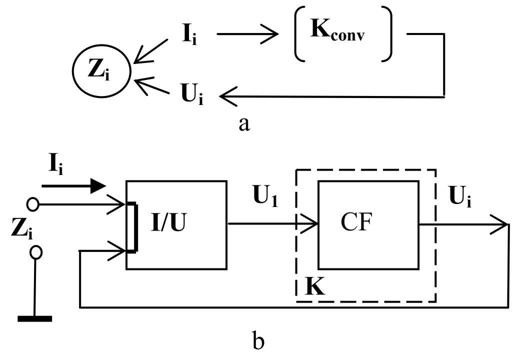


Fig.2 - The information conversion diagram (ICD) (a) and the block-diagram of I-SPQ (b)

$$\mathbf{Z_i} = \mathbf{U_i} / \mathbf{I_i} = (\mathbf{K_{conv}} \cdot \mathbf{I_i}) / \mathbf{I_i} = \mathbf{K_{conv}} \ , \quad (5)$$

where the conversion factor Kconv determines the mode of SPQ representation. The structure of I-MS (Fig. 2.b) contains a current-to-voltage converter I/U and a functional converter CF,which assures the form of $\mathbf{K_{conv}}$. Therefore, as results from (5), I-MS are destined for reproduction of PQ with impedance character and possess the stability up to no-loaded regime [1].

For U-SPQ [1] the voltage $\mathbf{U_i}$ is used as a primary input quantity. It is consecutively passed through the functional converter CF and through the voltage-to-current converter U/I. The reproduced passive quantity $\mathbf{Y_i}$ possesses the character of admittance and is obtained as a result of interaction of the entering voltage $\mathbf{U_i}$ and the current $\mathbf{I_i}$, produced by the converter U/I:

$$\mathbf{Y_i} = \mathbf{I_i} / \mathbf{U_i} = (\mathbf{K_{conv}} \cdot \mathbf{U_i}) / \mathbf{U_i} = \mathbf{K_{conv}} \ , \quad (6)$$

As it results from (6), the U-MS are destined for reproduction of PQ with character of admittance and possess the stability up to short – circuit regime [3]. Obviously, under the principle of duality between the quantities with impedance and admittance character, the PQ reproduced by I-MS and U-MS, may also be represented in the dual forms in comparison with those from (5), (6), according to the known relation ($\mathbf{Z} = \mathbf{Y}^{-1}$). However, this affects the mutual influence of SPQ components control: functionally, in order to assure the independent control of the components it is necessary to assure the directly proportional dependence between the SPQ components and the conversion factor $\mathbf{K_{conv}}$.

Tab. 1 – Classification of MS-A

Character of poles	The primary input quantity	The type of coordinates for SPQ representation	
		Cartesian coordinates	Polar coordinates
Asymmetrical connection	**U** – commanded	**U-MS-C-As**	**U-MS-P-As**
	I – commanded	**I-MS-C-As**	**I-MS-P-As**
Symmetrical connection	**U** – commanded	**U-MS-C-S**	**U-MS-P-S**
	I – commanded	**I-MS-C-S**	**I-MS-P-S**

2. The type of coordinates for SPQ representation. The importance of this criterion is determined by the necessity of using MS as RE in two types of measurements of passive quantities: measurements in Cartesian coordinates and in polar coordinates. So, for SPQ represented in Cartesian coordinates the conversion factor $\mathbf{K_{conv}}$ must assure the independent control of the active and reactive components, according to (1):

$$\mathbf{K_{conv.Z}} = N_R + \mathbf{j}N_X \text{ , } \mathbf{K_{conv.Y}} = N_G + \mathbf{j}N_B \text{ ,} \tag{7}$$

and, for SPQ represented in polar coordinates, – the independent control of the module and phase of SPQ, according to (2):

$$\mathbf{K_{conv.Z}} = N_Z \exp(\mathbf{j}\varphi), \mathbf{K_{conv.Y}} = N_Y \exp(\mathbf{j}\psi) \tag{8}$$

3. The type of poles for connection SPQ in external circuit. According to this criterion, MS can have one pole connected to ground in internal mode (asymmetric connection, in MS-As) (Fig. 3.a), or the both poles to be free (symmetric connection, in MS-S) (Fig. 3.b). MS-As have the simplest structures, determined by using of the operational amplifiers with internal ground connection. In MS-S the symmetric character of the PQ poles it obtains by means of precision differential amplifier [17], which complicates the devices structure. In spite of the more complicated structure, MS-S has found the practical application in some circuits and some measuring cases of PQ, where the RE with symmetric poles are necessary (for example, in the bridge circuits).
In accordance with the mentioned above criteria, there has been defined a class, that consists of eight types of MS-A (Tab. 1).

3. SYNTHESIS OF THE MS-A STRUCTURES

3.1. The formal – structural method of synthesis

For synthesis of the MS-A internal circuit the formal – structural method (FSM) of synthesis [4] has been used.
The method ensures obtaining of the internal structure of MS-A at the level of internal circuit according to its type from tab. 1. The method includes the following steps [6]:
1. Determination of the initial requirements to MS-A. This is made according to the use of features through designation of the type of MS from tab. 1. It includes:
- determination of the primary input quantity (I-type or U-type);
- determination of coordinates type for representation of SPQ (C-type or P-type);
- existence of the ground connection of the input pole of MS-A (As-type or S-type).

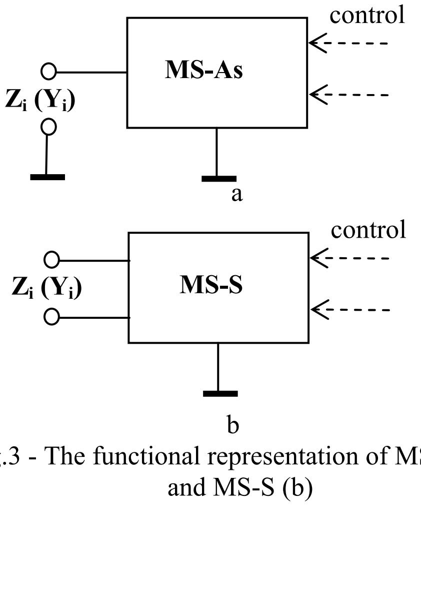


Fig.3 - The functional representation of MS-As (a) and MS-S (b)

2. Elaboration of the ICD inside the structure of MS-A. At this step, it is represented in the form of diagram the consecution of operations with the physical quantities in SM-A structure. The used operations are the conversion of voltages and currents, which can be made with functional links, based on electronic circuits or on other devices. The next types of information conversion operations are usually used:
- voltage-to-current, or current-to-voltage conversion,
- voltage-to-voltage conversion with constant, or variable conversion factor,
- voltages sum or subtraction,
- introduction of the fixed or variable phase angle,
- functional conversion of the quantities, etc.

3. Elaboration of the MS-A functional structure. The step includes the elaboration of the internal structure of MS-A at the level of functional units according to the presented ICD. The available functional units correspond to the information conversion operations.
4. Elaboration of the internal circuit of MS-A. It represents the last step of the synthesis, in which the functional units from MS-A structure are being substituted with circuits, that implement the respective functions. The based on operational amplifiers (OA) units are used in the low frequencies MS-A for implementation of the above mentioned operations. In the high – frequencies circuits, where the OA accuracy decreases considerably, the functional units of the MS-A can be implemented on the basis of other components.

3.2. Synthesis of U-MS-P-As

In order to confirm the possibility of the presented above method for MS-A synthesis, we shall examine as example the process of synthesis of the internal circuit of voltage-commanded (U-) MS for reproduction the SPQ with asymmetrical connection (-As) in the polar coordinates (-P) [5]. This process is being executed in the following order of actions.
1. Determination of the initial conditions. Since the voltage $\mathbf{U_i}$ is the primary input quantity, SPQ will have the character of admittance $\mathbf{Y_i}$ [1]. The necessity of the SPQ representation in polar coordinates defines the expression for the reproduced admittance $\mathbf{Y_i}$ as type (2). So, MS must assure the independent control of the components Z_i, ψ_i and to possess one pole with the internal connection to the ground.
2. *Elaboration of ICD*. Reproduction of the required type of simulated admittance $\mathbf{Y_i}$ may be obtained in the following order of operations (Fig. 4.a):
- variation of the voltage $\mathbf{U_i}$ module in order to control the SPQ module Y_i,
- variation of the voltage $\mathbf{U_1}$ phase in order to control the phase of SPQ ψ_i,
- conversion of the voltage $\mathbf{U_2}$ into input current $\mathbf{I_i}$,
- introduction of the current $\mathbf{I_i}$ into input circuit of MS, where it, together with the voltage $\mathbf{U_i}$, reproduces the simulated admittance $\mathbf{Y_i}$.

The information conversion diagram (Fig. 4.a) assures the execution of these operations in the needed order.
3. *Elaboration of the MS functional structure*. The internal structure for implementation of the above determined operation from ICD contains (Fig. 4. b):

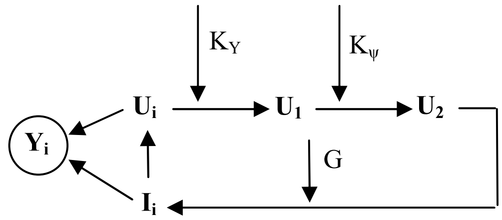
- The programmable amplifier PA with the transfer factor K_{PA} for control of the module Y_i. The voltage at its output constitutes: $\mathbf{U_1} = K_{PA} \cdot \mathbf{U_i}$;
- The programmable phase shifter PΦ with transfer factor $\mathbf{K_{P\Phi}}=1 \cdot exp\ (\mathbf{j}\psi_i)$, which produces the voltage $\mathbf{U_2} = \mathbf{K_{P\Phi}} \cdot \mathbf{U_1} = K_{PA}\ exp\ (\mathbf{j}\psi_i) \cdot \mathbf{U_i}$ at its output;
- The voltage-to-current converter U/I with conversion factor G for conversion of the voltage $\mathbf{U_2}$ in the current: $\mathbf{I_I} = G \cdot \mathbf{U_2} = G \cdot K_{PA}\ exp\ (\mathbf{j}\psi_i) \cdot \mathbf{U_i}$.

The reproduced by MS admittance constitutes [19]:

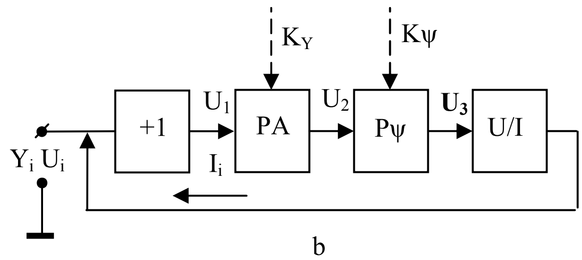
$$\mathbf{Y_i} = \mathbf{I_i} / \mathbf{U_i} = G \cdot K_{PA}\ exp\ (\mathbf{j}\psi_i) \equiv Y_i\ exp\ (\mathbf{j}\psi_i) \qquad (9)$$

As it results from (9), the reproduced admittance $\mathbf{Y_i}$ is represented in polar coordinates and assures the independent control of module Y_i, through the variation of the programmable amplifier PA transfer factor K_{PA} and of the phase ψ_i, through the variation of introduced by the phase shifter Pψ the phase angle ψ_i.

4**.** *Elaboration of the internal circuit of U-MS-P-As*. The functional units based on OA have been used at the implementation of the structure from fig. 4.b (Fig. 5).



a



b

Fig. 4 -ICD for the structure synthesis (a) and the internal structure (b) of U-MS-P-As

4. CONCLUSIONS

1. The metrological simulators of passive quantities with algorithmic structure can be used as reference elements for the impedance measurement. Compared to the classical RE, they possess such advantages as: possibility of reproduction of reference impedances with any character, possibility of expression of the reproduced quantities in the Cartesian or polar coordinates, possibility of the reproduced quantity components independent control.

2. The Cartesian coordinates SM-A ensure reproduction of simulated passive quantities *located throughout the entire complex plane ±R, ±jX (±G, ±jB for admittances) with possibility of independent control of active and reactive components and with smooth variation of the character.* The polar coordinates SM-A ensures reproduction of the same type passive quantities in coordinates system Z, φ (Y, ψ for admittances) with independent control of the module and phase values in bands Z, Y = (0 ÷ max), φ, ψ = (0 ÷ 360 °).

3. For synthesis of the MS-A internal structure in accordance with determined by the conditions of use requirements, the formal – structural method was used.

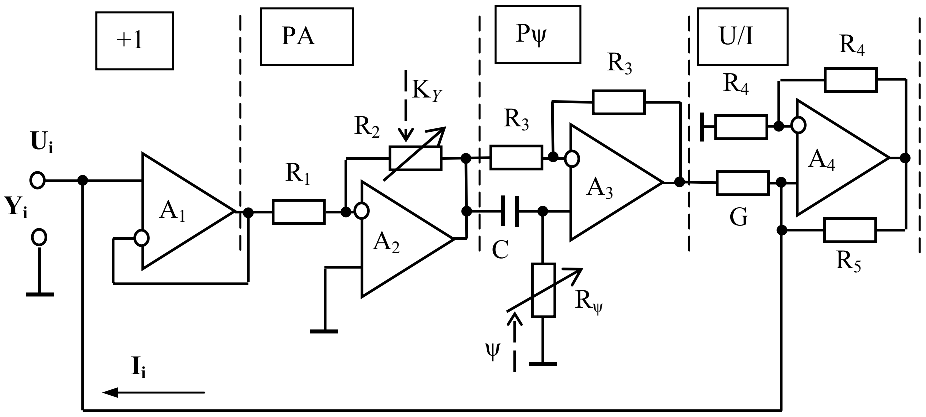


Fig. 5 - The internal circuit of U-MS-P-As

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