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APPLICATION OF THE IMPEDANCE SIMULATORS AS MEASURE OF IMPEDANCE

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***Abstract* – Paper relates about some aspects of application of the metrological impedance simulators (MIS) for high precision impedance measurement. Classification of these devices and the most important requirements are presented, also the essential features of MIS are estimated. The diagram of conversion of the information, the block diagram and the basic scheme of the voltage controlled Cartesian coordinates MIS are presented as example of this class of devices.**

Keywords: *metrological impedance simulators, impedance measurement.*

1. INTRODUCTION

For high – precision measurement of the impedance components the method of simultaneous comparison with measure, implemented in the bridge or resonance measuring circuits, are used [1]. Independently of the type of measuring circuits, the presence of reference element (RE), which executes the function of reproducing of the etalon value, is strictly necessary. Its features directly determines the accuracy of measurement and other usual characteristics of the measuring process.
Traditionally, the high – precision adjustable components, such as resistors, capacitors and inductances, or the boxes of these components are used in this quality. They are characterized by complicated construction, high cost price, discomfort in use.
A new possibilities in this field are opens by using as RE a metrological impedance simulators (MIS) – elements, that provide reproduction of the virtual reference impedances with necessary characteristics.

2. GENERAL FEATURES OF MIS

From the functional point of view, MIS can be considered an device with two poles of entry, on wich they reproduce an virtual impedance $\mathbf{Z_S}$ (or, an admitance $\mathbf{Y_S}$), wich can bee connected into an external circuit with equivalent impedance $\mathbf{Z_E}$ (Fig. 1) [2].

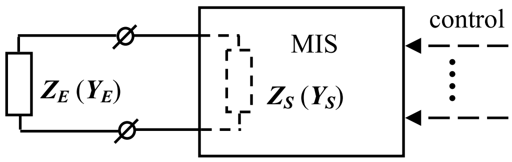

Fig. 1 – Functional representation of MIS

The reproduced passive value (impedance or admittance) may bee represented in the Cartesian or in the polar coordinates:

$$\mathbf{Z} = \mathbf{U}/\mathbf{I} = R + jX = Z\exp(j\varphi) \quad (1)$$

$$\mathbf{Y} = \mathbf{I}/\mathbf{U} = G + jB = Y\exp(j\psi) \quad (2)$$

The field of definition of the components for the simulated impedance are:

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

and similarly for the simulated admitance:

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

As follows from (3) and (4), an simulated impedance (admitance) can be represented by a vector, which can have any position on the whole complex space in Cartezian ±R, ±JX (±G ±jB) or polar Z, φ (Y, ψ) coordinates (Fig. 2) [5].
As it is known, impedance and admittance are the dual values. In virtue of this property, the analysis can be performed only for one of them, for example, for impedance. For the second value the results of analysis can be determined by applying the principle of duality to electrical circuits.
In the general case, MIS are implemented on the basis of amplifiers with positive and negative feedbacks and needs power supply [1]. For our purposes we consider these devices only in terms of

functional devices, that reproduces the values of type (1) or (2).

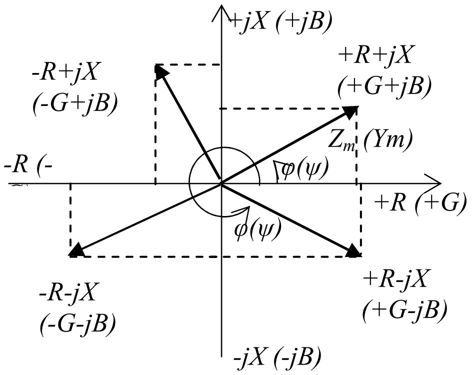

Fig. 2 – Representation of the reproduced by MIS impedances (admittances) on the complex plane

Because MIS are used as reference elements, they are imposed by a number of requirements, determined by the metrological assistance of measurements and by the current state of the technics. The most important are [1]:

- Low error and high stability of the reproduced impedance;
- Known and guaranteed value of systematic error of the reproduced impedance;
- Reproducing of the impedance with any character of the components;
- Independent control of the components of reproduced impedance;
- Digital control of character and values of the components of reproduced impedance;
- Exclusion of the variable reactive elements (variable capacitors, inductances or boxes of capacity and inductance, etc.).

The passive simulated values (PSV) are different from classical passive values by some essential properties:

1. *An PSV can have any character, result by combining the components ± R , ± jX or ±G, ±JB*. This property results from (3) and (4).
2. *The PSV components can have different from classical frequency dependencies of signal.*
3. *An PSV can have one of two types of stability: stability to the no-load regime, or stability to the short circuit regime.* This property determines the mode of use of PSV in the electrical circuit and depends on the type of circuit which it reproduces. An PSV can be used as the RE in the measuring devices only if it ensure the absolute stability at variation of the external circuit parameters in the necessary range. The condition of stability can be determined and in guaranteed mode assured for any type of MIS.
4. *The value range of the signal, which interacts with the PSV, is limited by the linear domain of the VA characteristic of PSV* (domain A on fig. 3).

Next we consider in the obligatory mode satisfaction of the condition of ensuring the linear regime of PSV.

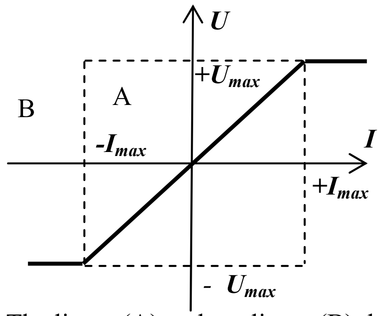

Fig. 3 – The linear (A) and nonlinear (B) domain of VA – characteristic of the PSV

5. *An PSV can form a resonant system with total or partial resonance with another passive value, real or simulated.* By „total resonance" on comprehends the state of resonance for the both components of impedance, active and reactive; by „partial resonance" – the resonance only for one component. At the series connection of simulated impedance $\mathbf{Z_S}$ with an real impedance $\mathbf{Z_X}$ the summary impedance $\mathbf{Z}$ of the circuit:

$$\begin{aligned}\mathbf{Z} = \mathbf{Z_S} + \mathbf{Z_X} &= (R_S + \mathbf{j}X_S) + (R_X + \mathbf{j}X_X) = \\ &= (R_S + R_X) + \mathbf{j}(X_S + X_X)\end{aligned} \tag{5}$$

From (6) results that in such circuit are possible three types of resonance conditions:

- resonance for active components, when:

$$(R_S + R_X) = 0\,, \quad R_S = -R_X \tag{6}$$

- resonance for reactive components, when:

$$\mathbf{j}(X_S + X_\mathbf{X}) = 0\,, \quad X_S = -X_\mathbf{X} \tag{7}$$

- total resonance, when:

$$(R_S + R_X) = 0 \quad \text{and} \quad \mathbf{j}(X_S + X_X) = 0$$

$$R_S = -R_X \;\;,\; X_S = -X_X \tag{8}$$

Under the principle of duality, the similar to (5) - (8) relationships can take place for the admitances in the parallel circuit. This property is the basical for using the PSV in the measurements of impedance components by method of simulated resonance.

6. *For PSV it is possible the independent control of the components, both in the Cartezian and in the polar coordinates.* The independent control of the module and phase of pasive value is very important at using the PSV for measurement the impedance and admittance in the polar coordinates.

As a result of analysis of the devices, which potentially can be used as a MIS, was proposed the MIS classification by relevant criteria (Tab. 1). In terms of practical application, particularly interest some types of MIS.

After *the type of primary entrance value* (crit. 1, Tab. 1) (Fig. 4) there are two types of MIS:

- *the current comanded MIS* (I-MIS), wich reproduces an simulated impedance and for wich:

$$\mathbf{Z_i} = \mathbf{U_i}/\mathbf{I_i} = R \cdot \mathbf{K_{regl}}\,, \tag{9}$$

- *the voltage comanded MIS* (U-MIS), wich reproduces an simulated admitance and for wich:

$$\mathbf{Y_i} = \mathbf{I_i}/\mathbf{U_i} = G \cdot \mathbf{K_{regl}} \tag{10}$$

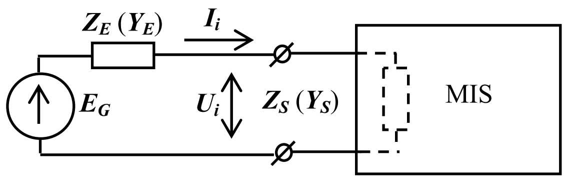

Fig. 4 – Connection of MIS in external circuit

In dependence of $\mathbf{K_{regl}}$ (crit. 4, tab. 1), the reproduced value may bee represented in Cartesian, or in polar coordinates, in correspondence with (1) and (2).

According to the criterion 3 (Tab. 1), MSI may have one of two types of stability [2]:

- *MIS with stability to the no-load regime*, for wich the stability is ensured at the condition:

$$Re(\mathbf{Z_E}) > Re(\mathbf{Z_S}), \tag{11}$$

- *MIS with stability to the short circuit regime*, for which the condition of stability is:

$$Re(\mathbf{Z_E}) < Re(\mathbf{Z_S}) \tag{12}$$

Table 1 – Classification of MIS

<table>
<tr><th>Classification criteria</th><th colspan="8">Types of MIS</th></tr>
<tr><td>1. Primary input value</td><td colspan="4">a. I-comaned simulators
(I-MIS)</td><td colspan="4">b. U-comaned simulators
(U-MIS)</td></tr>
<tr><td>2. Type of reproduced passive value</td><td colspan="4">a. For reproducing of impedance (MIS – Z)</td><td colspan="4">b. For reproducing of admitance (MIS – Y)</td></tr>
<tr><td>3. Type of stability</td><td colspan="4">a. MIS with stability to the no-load regime</td><td colspan="4">b. MIS with stability to the short circuite regime</td></tr>
<tr><td>4. Type of coordinates</td><td colspan="4">a. Cartesian coordinates MIS
(MIS – C)</td><td colspan="4">b. Polar coordinates MIS
(MIS – P)</td></tr>
<tr><td>5. Type of equivalent circuit of the reproduced value</td><td colspan="4">a. MIS with serial equivalent circuit</td><td colspan="4">b. MIS with paralel equivalent circuit</td></tr>
<tr><td rowspan="3">6. Character of the components of the reproduced value</td><td colspan="4">a. MIS for reproducing the values with character of active resistance (MIS – R)</td><td colspan="4">b. MIS for reproducing the values with character of reactive component (MIS – X)</td></tr>
<tr><td colspan="2">positive
(MIS – R^+)</td><td colspan="2">negative
(MIS – R^-)</td><td colspan="2">inductive
(MIS -X_L)</td><td colspan="2">capacitive
(MIS -X_C)</td></tr>
<tr><td colspan="8">c. MIS for reproducing the values with complex character (MIS – Z, Y)</td></tr>
<tr><td rowspan="2">7. Internal circuit</td><td colspan="3">a. MIS based on the classical structure</td><td colspan="2" rowspan="2">b. MIS with algorithmical structure
(MIS -A)</td><td colspan="3">c. MIS with arbitrarily structure</td></tr>
<tr><td>- with one level</td><td colspan="2">- with recursive structure</td><td colspan="2">- type girator</td><td>- any types of structure</td></tr>
<tr><td>8. Type of frequency dependence</td><td colspan="4">a. MIS for the values with „classical” dependence on frequency</td><td colspan="4">b. MIS for the values with „non-traditional” dependence on frequency</td></tr>
<tr><td>9. Connection to ground of the reproduced value</td><td colspan="4">a. MIS for grounded values
(MIS -M)</td><td colspan="4">b. MIS for floating values
(MIS -F)</td></tr>
</table>

There is a correlation between the primary input value of MSI (crit. 1), the type of reproduced passive value (crit. 2), the type of its equivalent circuit (crit. 5) and the type of the MSI stability. I-MSI possesses stability to the no-load regime and reproduces passive values type of impedance with series equivalent scheme [3], U-MSI – stability to the short circuit regime and reproduces the admitance with parallel equivalent circuit [4].

A very important type of MIS is *MIS with algorithmical structure* (MIS-A) (crit. 7). MIS-A forms a class of circuits designed in accordance with the requirements above. In developing the MIS – A structures a method of formall - structural synthesis has been used, which has provided obtaining of MIS for different conditions of use. This class of devices contains 8 types of circuits, which combines all possible combinations of the following properties: grounded or flotant MIS, Cartezian or polar coordinates, current or voltage control.

The reproduced by MIS passive values, unlike the classical passive values, may have *the different dependencies of signal frequency* (crit. 8). There are known, for example, simulated impedances with inductive character wich posses directly proportional, inversely proportional, or more complicated dependencies of the signal frequency.

3. MIS IMPLEMENTATION

In the general mode, the typical structure of MIS can bee obtained on the basis of an amplifier with combined positive and negative feedbacks [2]. However, by introducing of some modifications in this structure, can be provided various features of MIS, in compliance with the formulated in the p. 2 requirements.

As follows from crit. 7, of tab. 1, there are different types of internal structure of MIS. So, there are known MIS based on the classical structure, with one level and with recursive structure [5]; MIS type gyrator and MIS with different arbitrary structures. But the greatest interest, in terms of use it in the meters of passive values, it presents MIS with algorithmic structure (MIS-A). As mentioned above, MIS-A possess the structures, synthesized by formal - structural method.

As an example, in fig. 5.a is represented the algorithm of conversion of information, in fig. 5.b – the block-diagram and in fig. 5.c – the basic scheme for the voltage – commanded polar – coordinates MIS.

The entry voltage $\mathbf{U_i}$ pass through the repeater A_1 and forms the voltages $\mathbf{U_4}$ for the active component and $\mathbf{U_3}$ for the reactive component. From $\mathbf{U_3}$ and $\mathbf{U_4}$ the voltage-to-current converter DUIC forms the entrance current I_i, which, together with $\mathbf{U_i}$, reproduces the admittance $\mathbf{Y_i}$:

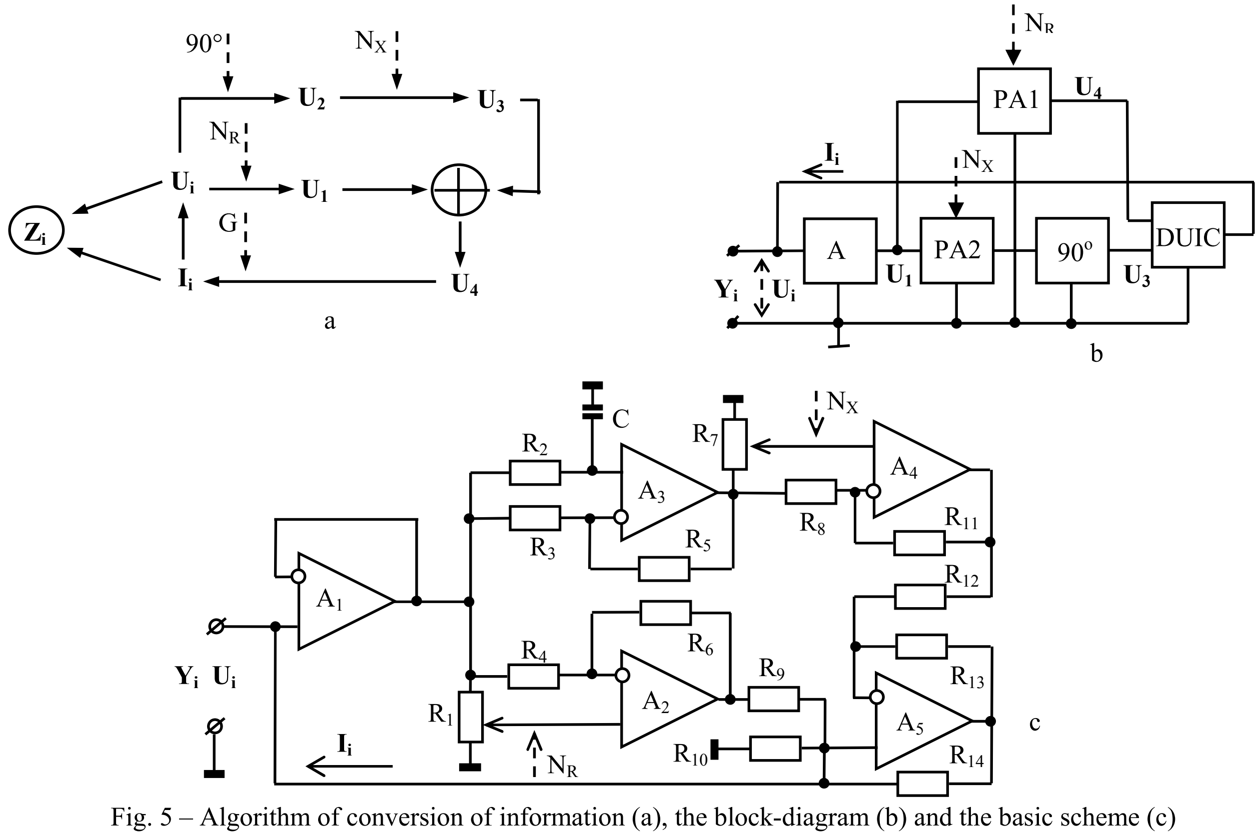

Fig. 5 – Algorithm of conversion of information (a), the block-diagram (b) and the basic scheme (c) for the voltage – commanded Cartesian – coordinates MIS

$$\mathbf{Y_i} = \mathbf{I_i} / \mathbf{U_i} = G(N_R - \mathbf{j}N_X), \quad (13)$$

where: G – the conversion factor of DUIC, N_R, N_X - respectively, the gain factors of programmable amplifiers PA1, PA2. As results from (13), the reproduced admittance $\mathbf{Y_i}$ is represented in Cartesian coordinates and ensures the separate regulation of reactive and active components by means of regulation the factors N_R, N_X.

4. CONCLUSIONS

1. The metrological simulators of impedance and admittance (MIS) can bee used as the reference elements in the devices for measurement of these values.
2. For practical application of MSI it can take into consideration some characteristics, such as type of coordinates, type of stability, type of reproduced passive value and other, specified in table 1.
3. Application of MIS as reference element ensures simplicity of the measuring devices and measuring algorithms, high precision of measurements and low cost.

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