Parametric Analysis of Input Circles of Measuring Transducers Impedance of Potentiometric Type

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Параметричний Аналіз Вхідних Кіл Вимірювальних Перетворювачів Імпедансу Потенціометричного Типу

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***Анотація*—В роботі розглянуто особливості параметричного аналізу вхідних кіл вимірювальних перетворювачів імпедансних потенціометричного типу, на основі SPICE – моделювання. В процесі моделювання використано потенціометричного метод вимірювань який грунтується на основі визначення часової залежності миттєвого значення струму при заданій напрузі модуляції. При низьких значеннях ширини смуги частот операційних підсилювачів частотні характеристики вимірювального перетворювача імпедансу проявляють резонансні процеси, які, в свою чергу, призводить до певної втрати стабільності кола від'ємного зворотного зв'язку. Ці виявлені закономірності необхідно враховуються при виборі елементної бази та схемотехнічній оптимізації розроблюваних вимірювальних перетворювачів імпедансу.**

***Abstract*—In this paper we examine the peculiarities of parametric analysis of input circles of measuring transducers impedance of potentiometric type based on SPICE - simulation. This simulation uses potentiometric measurement method which is based on the determination of time depending on the instantaneous value of the current at a given voltage modulation. The frequency response of measuring transducers impedance has resonance process, which in turn leads to the loss of stability of a circle negative feedback, at low value of bandwidth of operational amplifiers. These identified rules should be taken into account at a choice of components and further optimize the circuit of measuring transducers impedance.**

***Ключові слова*—параметричний аналіз, вхідні кола, вимірювальний перетворювач імпедансу, потенціометричного питу, імпедансана спектроскопія, SPICE модель, діаграма Найквіста.**

***Keywords*—parametric analysis, input circles, measuring transducers impedance, potentiometric type, impedance spectroscopy, SPICE model, Nyquist plot.**

I. Introduction

The field of information and computer technology, especially with the development of a new direction - the Internet of Things (IoT) or Physical World Internet [1], based on a new generation of microelectronic sensor devices is in constant progress. Sensor devices provide various measurement parameters - temperature, humidity, lighting substances, environmental pollution, these parameters are performing as the interface between the physical world and the Internet [2, 3].

A significant segment of modern sensory devices are based on impedance spectroscopy methods, informative parameters which are frequency dependent of active and reactive components of electrical or electro-chemical impedance [4, 5]. Specialized transducers provide formation of informative parameters of impedance spectroscopy sensor devices [6, 7]. These measuring transducers are based on two methods - galvanostatic and potentiostatic. In the galvanostatic method, informative value of measured impedance is time-dependent instantaneous voltage $V_Z(t)$ at the investigated two-terminal test at predetermined modulation current through it. The informative value of the potentiostatic method is time-dependent instantaneous value $I_Z(t)$ current modulation specified voltage. During the result of transformation, both methods of measuring have two components of the impedance of the research object: - its active resistance ($\mathrm{Re}\,\hat{Z}$) and its reactive resistance ($\mathrm{Im}\,\hat{Z}$).Using components of impedance an impedance hodograph in the complex area was built, it is also called Nyquist plot. A form of the Nyquist plot allows you to define the structure and parameters of the two-terminal [8].

The actual problem that arises in the development process of sensor devices based on methods of impedance spectroscopy is analyzing the impact of the characteristics components for precision measuring transducers impedance operation. This work is directed to the problem of parametric analysis input circles of impedance measuring transducers of potentiometric type. The basis of these research is schematic simulation SPICE [9] using real mathematical functions Re and Im imaginary signal components. Such specialized functions of impedance analysis can be used in modern versions of software packages circuit simulation, in particular - package MicroCAP [10].

II. Block Diagram of Potentiostatic Type Impedance Measuring

In potentiostatic method of impedance measuring the main value is time-dependent instantaneous value of the current at a given modulation voltage. The main units of measurement transducers are (Fig. 1): VS – Voltage Source, with controlled frequency; CTA – Current Transducer and Amplifier; SD – Synchronous Detector; INT – Integrator; LFA – Low Frequency Amplifier; ADC – Analog-to-Digit Converter; MC – Microcontroller, which manages the device and the subsequent conversion of digital signals – CT and DS – Control and Digit Signal.

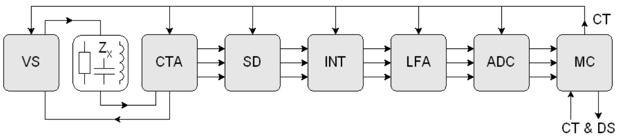


Fig.1. Generalized block diagram of potentiostatic type impedance measuring

The main criteria for the choice of components of impedance measuring is the compliance with the requirements of microelectronic devices to minimize the size while still providing high efficiency, functioning with galvanic low-voltage power sources and the implementation of low cost modes of operation by rail-to-rail.

The main approaches to parametric analysis of input circles impedance measuring transducers potentiostatic type based on operational amplifiers are described in this work.

III. Methods of Parametric Analysis

Precision of impedance conversion measuring will be measured by qualitative and quantifiable value distortion Nyquist plot. Such research is advisable to carry out on an example elementary RC two-terminal with a characteristic frequency f_0, which is on the verge of frequency measurement range. Active Z_{RE} and reactive Z_{IM} impedance components are equated $Z_{RE}(f_0) = Z_{IM}(f_0)$ on the characteristic frequency. The value f0 is expedient to set tenfold smaller than the gain bandwidth (GBW) of the operational amplifier.

For example, consider a modern CMOS (Complementary Metal-Oxide-Semiconductor) an operational amplifier of general purpose AD8541/2/4 (Analog Devices), which meets the criteria of Rail-to-Rail (low-voltage devices with full-scale signal - from the negative to the positive supply voltage) and minimum power consumption.

Thus, when GBW = 1MHz (such as is the case in the AD8541/2/4) and research is carried out on RC link with the characteristic frequency $f_0 = 1/(2\pi RC) = 0.1$ MHz, we obtain the frequency dependence of active Re and reactive Im impedance components and the Nyquist plot shown in Fig. 2.

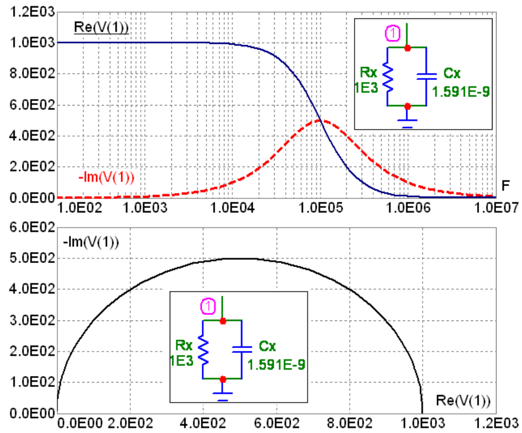


Fig.2. Frequency dependence of active Re and reactive Im impedance components and Nyquist plot of the RC circle with the characteristic frequency = 0.1 MHz

The research influence of amplifier cascades in characteristic impedance synthesizing SPICE equivalent circuit (Fig. 3) involve a source of sinusoidal voltage Vi, voltage controlled current source G1 with the transmission coefficient K_I=1, RxCx link with the characteristic frequency f0=0,1 MHz (Rx = 1 KΩ, Cx = 1,591 nF), isolating amplifier X0 with idealized parameters and two researched cascades at the operational amplifier X1, X2. The first amplifier is non-inverting with a voltage gain of $K_V = 1 + R2/R1$, and the second is inverting with $K_V = -R4/R3$. Isolating amplifier X0 is a supplementary and has two functions: first, to prevent parasitic shunting RxCx link researched amplifier cascades, and secondly, provides a nominal (idealized) input voltage values. The input voltage is inverse to values the gain of K_V. The value of output voltage amplifiers is constant at changing K_V that is providing correct methods of research.

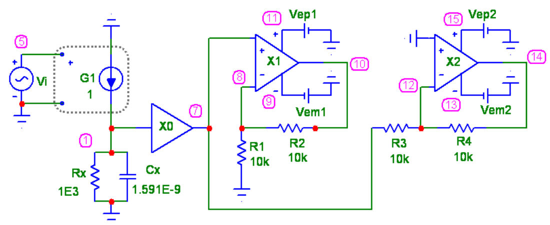


Fig.3. Scheme model research of amplifier cascades

An example result of research of parasitic influence of the amplifier cascade (in this case non-inverting amplifier with an output voltage V(10)) is shown in Fig. 4. The research was conducted at five values of gain K_V = 1, 2, 3, 4, 5, which set the appropriate value of resistor R_2 circle non-inverting amplifier feedback: R_2 = 0, 10, 20, 30, 40 KΩ. Simultaneously with the change of values of the resistor by transmission gain of isolating amplifier X0 was simultaneously changed - X0.E1 = 1, 1/2, 1/3, 1/4, 1/5. Thus, the nominal value of informative signals remained constant.

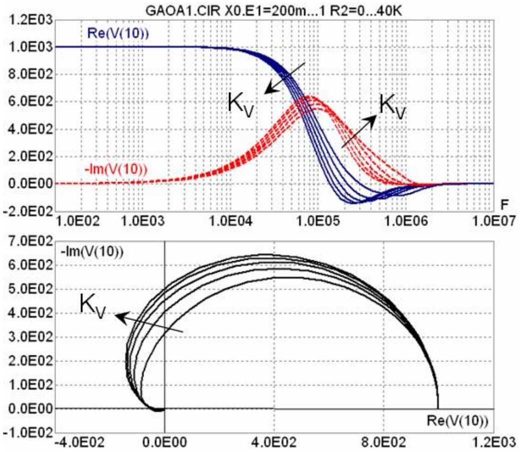


Fig.4. The drift impedance component and Nyquist plot

at K_V = 1,2,3,4,5

The results show that the above values of GBW = 1 MHz, f_0 = 0,1 MHz present a fairly significant drift of the active Z_{RE} (informative signal - Re(V(10)) and the reactive Z_{IM} (informative signal - Im(V(10)) components of impedance. Nyquist plot undergoes substantial changes deformation at high frequencies in the area of negative values of the active component of impedance. Such drift and deformation have a place even at unity gain K_V = 1 (voltage follower mode). The increase KV leading to a corresponding increase in error informative voltage amplification of the measured impedance. Accordingly, in the design of impedance measuring transducers it is necessary, first, to consider these errors and, secondly, to set the gain to the lowest possible value.

Similar research was conducted for inverting amplifier. Inasmuch as qualitatively results of this research identical to the above research non-inverting amplifier and for reducing the volume of the presented material no expediency in their detailed consideration. Comparison of the inverting amplifier and the non-inverting amplifier are reasonable. Such comparison shown in Fig. 5 and Fig. 6, where, the following symbols: A_0 - signal at the input amplifiers, A+ signal on the output of non-inverting amplifier with K_V = 1, A- signal at the output of inverting amplifier with K_V = -1. The transmission gain-controlled current source G1 is $K_I = 10^{-3}$ at the amplitude voltage of controlled source V(Vi) = 1 V and the amplitude of the current I (G1) = 1 mA.

The obtained results allow the formulation of the following important rules and conclusions:

- first of all, the gain signals in the input circles of broadband transducers should be the minimum possible, and it should only a single signal.
- secondly, frequency distortion characteristics of the impedance inverting amplifier with KV = -1 compared to non-inverting amplifier at KV = 1 (a voltage) is somewhat larger.

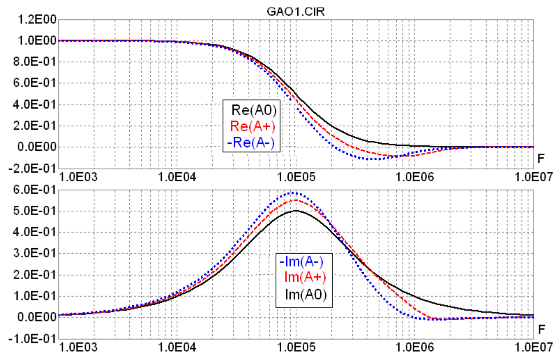


Fig.5. Frequency dependence of impedance components in circles A0, A1, A2

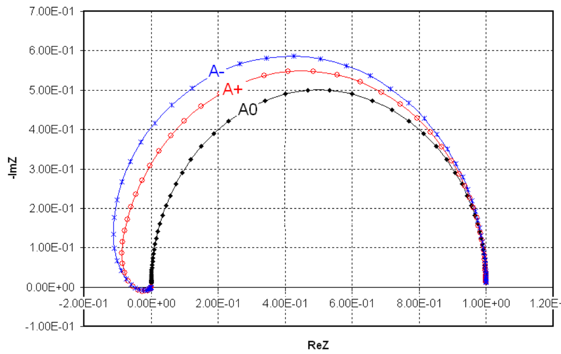
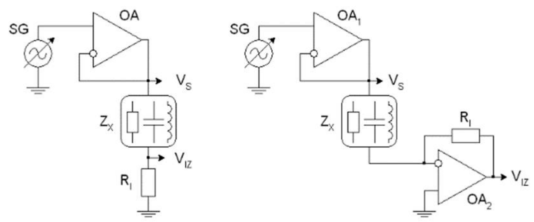


Fig.6. Nyquist plot in circles A0, A1, A2

IV. Parametric Analysis of Input Circles of Potentiometric Type

Functional scheme of input circle of measuring transducers of potentiometric type generates harmonic voltage fluctuations on the investigated two-terminal ZX two-terminal Z_X, where the current is informative on the value of its conductivity. As presented earlier, the general block diagram of potentiostatic type (Fig. 1) perform the function of the source voltage VS and manageable broadband transducer input CTA.

The elementary variant of the input circle (Fig. 7, a) contains only: controlled voltage source SG, the investigated two-terminal ZX and supplementary resistor RI, voltage drop V_{IZ} which is the informative value of measuring conversion.



a) b)

Fig.7. Schemes of input circles of potentiometric type

However, one should note the following features. Firstly, it is necessary to use a voltage follower (OA) to minimize the shunting influence of the investigated two-terminal on the controlled voltage source SG. Secondly, voltage drop on the resistor R_I is backwards function to the measuring impedance (conductive two-terminal) and this must be considered in the model researches (as shown in Fig. 8, informative signals components of impedance is the value of Re(1/V) and Im(1/V). Thirdly, voltage drop should be minimized on the resistor R_I. The transimpedance transducer at the operational amplifier OA2 (Fig. 7, b) performs these tasks, that just also is aforementioned broadband transducer CTA of the input current to the output voltage (Fig. 1). The operational amplifier inverts the phase of the input current and informative signals change their sign: Re (-1/V) and Im (-1/V).

Scheme model research of the input circles of the potentiometric type shown in Fig. 9.A family of impedance characteristics shown in Fig. 10.

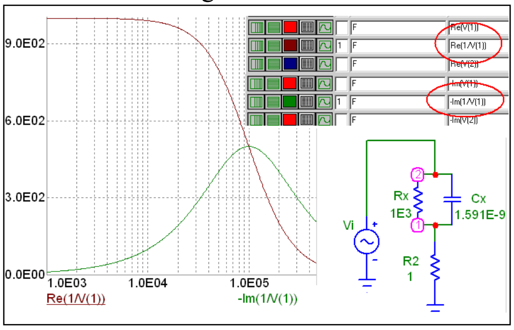


Fig.8. Demonstration process of forming informative signal

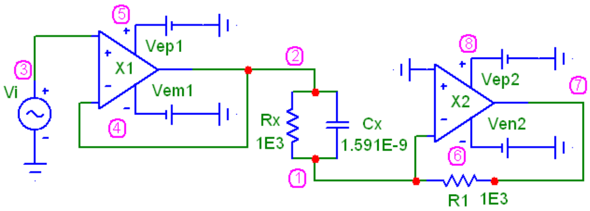


Fig.9. Scheme model research of input circles of potentiometric type

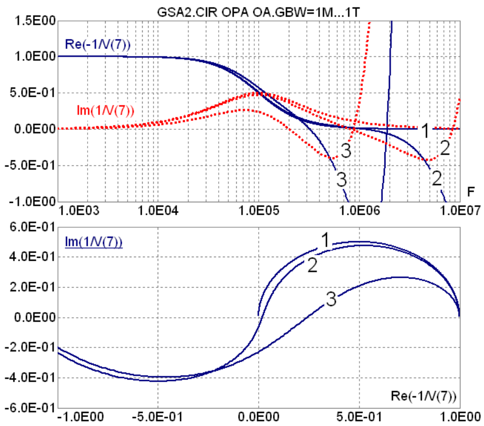


Fig.10. The family of impedance characteristics of input circles of potentiometric type at GBW = 1E12 (1), *1E7 (2). 1E6 (3)*

The frequency response of measuring transducers impedance has resonance process, which in turn leads to the loss of stability of a circle negative feedback, at low value of bandwidth of operational amplifiers. Thus, Nyquist plots not only deformed but also move into the region inductive reactance. These identified rules should be taken into account at a choice of components and further optimize the circuit of measuring transducers impedance.

V. CONCLUSION

The proposed new approaches of parametric analysis of measuring transducers impedance are using SPICE models. The precision of measuring conversion impedance is assessed by qualitative and quantifiable value distortion Nyquist plot. It is shown that parametric analysis is appropriate to use as the research object RC two-terminal with a characteristic frequency f_0, which is on the verge of frequency measurement range. Active Z_{RE} and reactive Z_{IM} impedance components are equated $Z_{RE}(f_0) = Z_{IM}(f_0)$ on the characteristic frequency.

The obtained results allow the formulation of the following important rules and conclusions: first of all, the gain signals in the input circles of broadband transducers should be the minimum possible, and the best single; secondly, frequency distortion characteristics of the impedance inverting amplifier with $K_V = -1$ compared to non-inverting amplifier at $K_V = 1$ (a voltage) is somewhat larger. These identified rules should be taken into account at a choice of components and further optimize the circuit of measuring transducers impedance.

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