СЕНСОРИ ТА ІНФОРМАЦІЙНІ СИСТЕМИ

SENSORS AND INFORMATION SYSTEMS

UDC 621.317
DOI: https://doi.org/10.18524/1815-7459.2020.2.205825

IMPROVEMENT GENERATING OF THE TEST SIGNALS FOR DETERMINATION OF THE IMPEDANCE PARAMETERS IN WIDE FREQUENCY RANGE

V. G. Melnyk[1], P. I. Borschov[1], V. K. Beliaev[2], O. D. Vasylenko[1], O. L. Lameko[1], O. V. Slitskiy[1]

[1]Institute of electrodynamic National Academy of Sciences of Ukraine, 56 Pr. Peremohy, 03057,
Kyiv – 57. E-mail: melnik@ied.org.ua
[2]National University of Life and Environmental Sciences of Ukraine, Heroyiv Oborony st., 15,
Kyiv, 03041, Ukraine

IMPROVEMENT GENERATING OF THE TEST SIGNALS FOR DETERMINATION OF THE IMPEDANCE PARAMETERS IN WIDE FREQUENCY RANGE

V. G. Melnyk, P. I. Borschov, V. K. Beliaev, O. D. Vasylenko, O. L. Lameko, O. V. Slitskiy

Abstract. A brief analysis of modern methods for measuring impedance parameters and error sources that limit their accuracy in a wide range of frequencies is given. An effective way is substantiated to solve the main problem - a significant increase in the errors of the separation of the information signal into quadrature components with increasing frequency. The schemes of construction of the broadband single-phase and multi-phase digital generators of test and reference signals using Johnson's ring counter, which have very small phase errors, as well as the control scheme of the phase ratio of the testing and reference signals are detail considered in the article. The considered structures and principles of operation of the impedance meters with the use of impedance - voltage transformation, of the bridge method with balancing by module and phase of the imbalance signal and their combinations have been developed on their basis.

Keywords: impedance, measurement, phase error, test signal, reference signal

УДОСКОНАЛЕННЯ ГЕНЕРУВАННЯ ТЕСТОВИХ СИГНАЛІВ ДЛЯ ВИЗНАЧЕННЯ ПАРАМЕТРІВ ІМПЕДАНСУ В ШИРОКОМУ ДІАПАЗОНІ ЧАСТОТ

В. Г. Мельник, П. І. Борщов, В. К. Бєляєв, О. Д. Василенко, О. Л. Ламеко, О. В. Сліцький

Анотація. Дано короткий аналіз сучасних методів вимірювання параметрів імпедансу та джерел похибок, що обмежують їх точність в широкому діапазоні частот. Обґрунтовано ефективний шлях вирішення основної проблеми – значного збільшення похибок розділення інформативного сигналу на квадратурні складові при підвищенні частоти. Детально розглянуті схеми побудови широкосмугових однофазних та багатофазних цифрових генераторів тестових і опорних сигналів з використанням кільцевих лічильників Джонсона, які мають дуже малі фазові похибки, а також схема керування співвідношенням фаз тестових та опорних сигналів. Розглянуто розроблені на їх основі структури і принципи дії вимірювачів імпедансу з застосуванням перетворення імпеданс – напруга, мостового методу з балансуванням за модулем і фазою сигналу нерівноваги та їх комбінації.

Ключові слова: імпеданс, вимірювання, фазова похибка, тестовий сигнал, опорний сигнал

СОВЕРШЕНСТВОВАНИЕ ГЕНЕРИРОВАНИЯ ТЕСТОВЫХ СИГНАЛОВ ДЛЯ ОПРЕДЕЛЕНИЯ ПАРАМЕТРОВ ИМПЕДАНСА В ШИРОКОМ ДИАПАЗОНЕ ЧАСТОТ

В. Г. Мельник, П. И. Борщев, В. К. Беляев, А. Д. Василенко, А. Л. Ламеко, А. В. Слицкий

Аннотация. Дан краткий анализ современных методов измерения параметров импеданса и источников погрешностей, которые ограничивают их точность в широком диапазоне частот. Обоснован эффективный способ решения основной проблемы - значительного увеличения погрешностей разделения информационного сигнала на квадратурные составляющие с увеличением частоты. В статье подробно рассмотрены схемы построения широкополосных однофазных и многофазных цифровых генераторов тестовых и контрольных сигналов с использованием кольцевого счетчика Джонсона, которые имеют очень малые фазовые ошибки, а также схема управления соотношением фаз испытательных и эталонных сигналов. Рассмотрены разработанные на их основе структуры и принципы работы измерителей импеданса с использованием преобразования импеданс-напряжение, а также мостового метода с балансировкой по модулю и фазе сигнала дисбаланса и их комбинаций.

Ключевые слова: импеданс, измерение, фазовая ошибка, тестовый сигнал, опорный сигнал

Introduction

To measure passive electrical quantities, in particular the parameters of electrical circuit components, informative parameters of sensitive elements of many types of sensors, characteristics of various substances, materials and biological objects, it is necessary to generate test signals that affect the object of measurement and causes a response (measurement signal) on the output of the measuring circuit, which includes the object of study. The most informative and accurate results are obtained when using sinusoidal test signals in a wide range of frequencies: from infrared (small fractions of Hz) to the radio frequency range (tens and hundreds of MHz).

For practical purposes, the most relevant is the measurement in the sound and ultrasonic frequency ranges (up to 1MHz). There are several well-established ways to solve such problems based on methods of direct transformations of the measuring signal, the use of bridge measuring circuits with balancing, as well as combined methods that combine the best qualities of the first and second ways [1 - 9]. Based on them, it has been created and now manufactures a variety of equipment for measuring impedance parameters: active and reactive resistance or conductivity, modulus and phase angle or phase angle tangent, capacitance, inductance, etc. Such instruments are intended for measuring in a wide range of parameters values and frequency, in different modes and for different equivalent circuits of the measurement object. Among them are known the instruments of Wayne Kerr Electronics, Agilent, GW Instek and of others. From the modern domestic developments should be noted precision RLC-meters MHC-1100 and MHC-1200 [6, 7, 10].

Unfortunately, for many new tasks, existing devices are either metrologically imperfect or very complex and expensive. They are often unsuitable for the using in the sensor systems, for the purposes of an object state diagnostics and process monitoring, especially at high frequencies.

The aim of the work is to expand the possibilities for optimization of technical and economic characteristics of the means of determining the impedance parameters in a wide range of frequencies, taking into account the intended purpose of the equipment.

Status of the question and existing problems

Means for measuring of the parameters of complex resistances - impedances Z or admittances Y, common name - immitances, belong to active measuring systems in which the object of measurement is subjected to a calibrated test effect. The object generates a response signal to this effect (informative current or voltage), proportional to it modulo and has changed by phase. Two its informative components are corresponding to the measuring parameters: active Re and reactive Im, or modulus and phase angle. These components are calibrated by modulo using scale transducers and reference measures (bridge methods [2 - 4]) or a phase-sensitive voltmeter (methods of direct impedance conversion are considered, in particular in [8]). All these operations are performed by the measuring channels. In the general case, it is a closed loop or a sequence of blocks consisting of functional converters (analog, digital, combined). Their functionality, metrological parameters, mass and size indicators, energy consumption, cost, as well as the method of measurement used, ultimately determine the technical and economic characteristics of a particular type of equipment. The channel includes a test signal generator, a measuring circuit with a measuring object, a device for excretion and converting an informative signal, units for generating reference signals and for analog-digital conversion, devices for comparing signals and digital data processing and also the unit of measurement process control.

When using bridge methods, the separation errors in determining the components of the measured impedance are determined by the phase errors in the bridge branches which associated with the quadrature parasitic parameters of the reference measures, scale converters and connecting circuits. Calibration errors are determined by deviations of the actual values of the main parameter of the reference measures and other blocks from the nominal values, and also by relative value of their non-informative quadrature parameters, which in a wide range of frequencies can reach of large values.

In devices with direct immitance conversion, the information signal is divided into two components by quadrature synchronous detectors. The accuracy of this operation depends on the error of the phase relationships between the test signal and the reference signals of the detectors, as well as on the phase errors of the measuring circuit and the of device its output signal conversion. It is quite difficult to achieve a small level of these errors or to correct them by structural and algorithmic methods in a wide range of frequencies. The existing ways to reduce them significantly complicate the equipment and measurement algorithm. The operation of calibration modulo of the obtained impedance components is performed using an ADC with highly stable source of reference DC voltage and usually does not cause difficulties.

There are specialized chips currently on the market, which combine all the above blocks of the impedance-metric channel [11]. The separation of the quadrature components of the measuring signal is performed in them by means of the Fourier transform. On their basis, quite simple devices for various purposes can be created [12, 13], but their metrological capabilities are very limited.

Reducing of the phase errors in the measuring channel with ensuring acceptable technical and economic characteristics of the devices is the main task under expanding the range of operating frequencies of the immitance parameters meters and increasing their accuracy. This task is especially relevant for the development of new technologies in technical and biomedical fields. A promising way to solve it is to improve the methods of generating test and reference signals and optimize on this basis the methods of determining the parameters of impedance. The ideas of the necessary technical solutions were proposed several decades ago [14 - 17], but were not then implemented in practice due to insufficient development of the element base. In [14 - 16], the structures of AC bridges with signal frequency conversion in the bridge circuit were proposed. In these devices, the sinusoidal voltage generator of the bridge is replaced by a highly stable source of constant reference voltage, to which the branches of the bridge are connected: the object of measurement and reference measures. At the inputs of these branches are installed digital-to-analog converters (dividers) of DC voltage, and after them - digital-to-analog converters, which multiply the DC voltage by the codes of the values of the function $\sin 2\pi f_t t$; where f_t is the frequency of the test signal. These codes obtain using a clock counter with a decoder. Formed quasi-sinusoidal (stepped) voltages are applied to the measurement object and to the reference measures of resistance or capacitance. Their spectrum does not contain harmonics with frequencies below $(4n \pm 1)\ f_t$, where n is the number of steps in the 1/4 period of the quasi-sinusoid, when taking into account certain requirements for the selection and formation of the steps in approximating function [18, 19]. The values of n and f_t determine the required frequency f_c of the counter clocking: $f_c = 4nf_t$. Depending on the nature of the object of measurement and the problem to be solved, the value of n can vary from 1 to several tens.

In these works, it was proposed to use a ring Johnson's counter to generate the controlling code for digital-to-analog convertor (DAC). DAC of the generator is based on the principle of sequential addition and subtraction of n currents. Each of them is proportional to the height of one of the steps of the quasi-sinusoid. The currents are formed with use of precise resistors from the reference voltage. This allows you to significantly reduce the transients on the fronts of the steps, and thus expand the frequency range. Another advantage of this solution is the ability to obtain reference voltages for quadrature synchronous detectors directly from the logic signals of the ring counter, forming the test voltages. This allows achieving the minimum possible phase differences between these voltages. The structure and circuitry of the generator will be discussed in more detail below.

Structure and circuit solutions for construction of the broadband digital generators of test and reference signals

The general structure of the generator of test and reference signals, the simplified schemes of the ring counter with the decoder and of the digital-to-analog converter of the generator (COUNTER, DECODER, DAC accordingly) are presented on Fig. 1 a, b, c. Under the action of clocking pulses TI, at the outputs of the triggers of the counter (Q) are created voltages of the form "meander" with a frequency f_c, shifted by one clock. Fig. 1 d shows a timing diagram of obtaining from these voltages, using logic circuits overlap of their low levels, the logic signals D1 ... Dn/2 to control the keys of the driver DAC of quasi-sinusoidal voltage U_T, as well of the reference voltages for synchronous detector U_{IF} and U_{QF}, which are respectively in-phase and quadrature to U_T.

The peculiarity of this structure is that each of the steps is formed by a separate resistor of the DAC. The conductivities of these resistors are chosen in proportion to the heights of the respective steps, from which consist the each of ¼ periods U_T. Firstly, these resistors are been alternately connecting by high-speed switches to a positive reference voltage U_{ref}, and then in the reverse order are turned off. Thus a positive half-wave of a quasi-sinusoid is formed. A negative half-wave is formed similarly at a negative reference voltage $-U_{ref}$. The currents of the resistors are summed at the input of the operational amplifier, forming a quasi-sinusoidal voltage at its output. It is important that this method of its formation provides minimal switching interference and that the time of operation of the keys relative to TI is identical. Therefore, the undistorted shape of the output signal is maintained up to the maximum operating frequencies of the used element base (approximately 50 MHz). The total U_T delay relative to U_{IF} and U_{QF} is approximately 30 nsec. due to the operation time of the keys under the action of signals D1 ... Dn/2 and the inertia of the operational amplifier of the DAC. It is partially compensated by the same delay of operation under the action of U_{IF} and U_{QF} of similar keys of the synchronous detector.

Another part of the delay can be compensated by the correction of the operational amplifier. This is the base of possibility obtaining very small both amplitude and phase errors of the through characteristic of the transformation of the measuring channel as a whole in a very wide range of frequencies.

Development of principles of construction of digital generators of test signals and impedancemetric channels on their basis

Functional digital generators with integral multiplying DACs are currently widely used for various purposes, including and in impedance measuring equipment [6, 7, 20 - 22]. The other approach to their realization described above has an important advantage: it allows, in addition to the test quasi-sinusoidal signal, to obtain more accurate reference signals for synchronous detectors - rectangular (meander) or quasi-sinusoidal in the form of control voltages (of codes). This provides the possibility of obtaining in-phase and quadra-

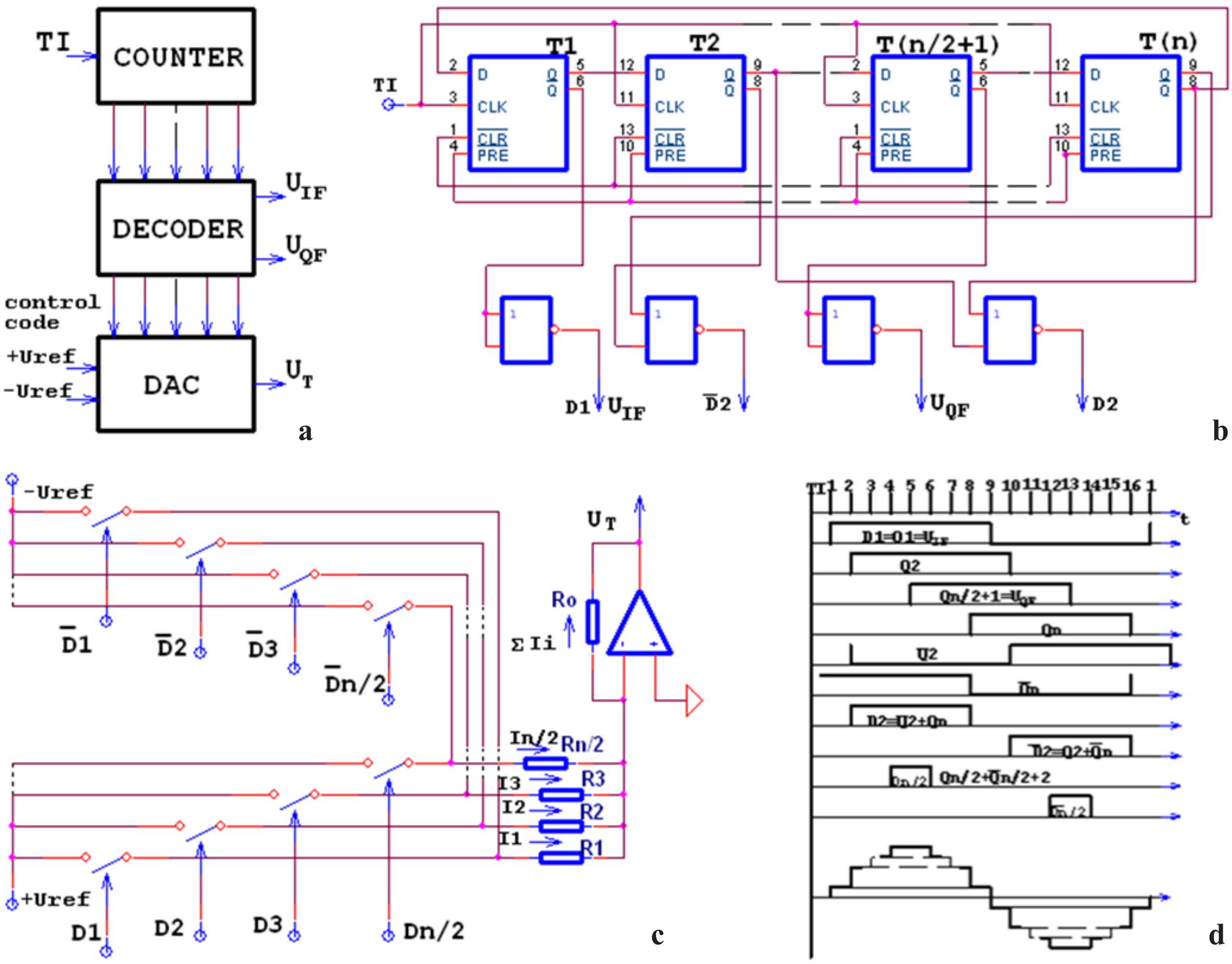

Figure 1. General structure of the generator of test and reference signals (Fig. 1a), simplified scheme of the ring counter with a decoder (Fig. 1b), digital-to-analog converter of the generator (Fig. 1c), diagram of formation the control signals for DAC's keys and reference voltages of a synchronous detector

ture signals, or one having a different phase, with high discreteness in time and with a very stable in time binding to the test signal.

The presence of such voltages allows us to successfully solve the problem of accurately dividing the measuring signal into informative quadrature components in a wide frequency range, with reaching the simplicity of the measuring channel and the high measurement speed.

Another advantage of this approach to the construction of the quasi-sinusoidal voltage generator is the ability to combine several such devices to obtain two (or more) signals with a calibrated phase difference and the ability of precisely discrete control that difference. On the basis of such multiphase generators can be implemented bridge impedance meters with balancing of the bridge circuit by adjusting the phase and voltage amplitude in the branches of the bridge, which has only one reference measure [14, 15, 20, 23].

The peculiarity of this solution is that the phase balancing is performed in digital form by a discrete change of the delay between the cycles of clocking of the counters of digital generators. This is realized by means of additional counters with adjustable initial installation, which form time shifts of clocking and synchronizing pulses of these generators [23]. The installation errors of the phase difference of the output signals of the multiphase generator are determined by the difference of the parasitic delays of the digital signals in identical channels of their formation and do not exceed a few nanoseconds. The time offset errors of the test signal relative to the reference signals may be significantly greater due to delays in the digital-to-analog converter, but they are stable and can be compensated.

The use of a multiphase test signal generator can significantly to improve the metrological characteristics of both bridge measuring devices and channels with direct conversion through the use of the previously proposed phase adjustment of the reference voltage of the synchronous detector [17]. Consider the scheme of such a channel, shown in Fig. 2.

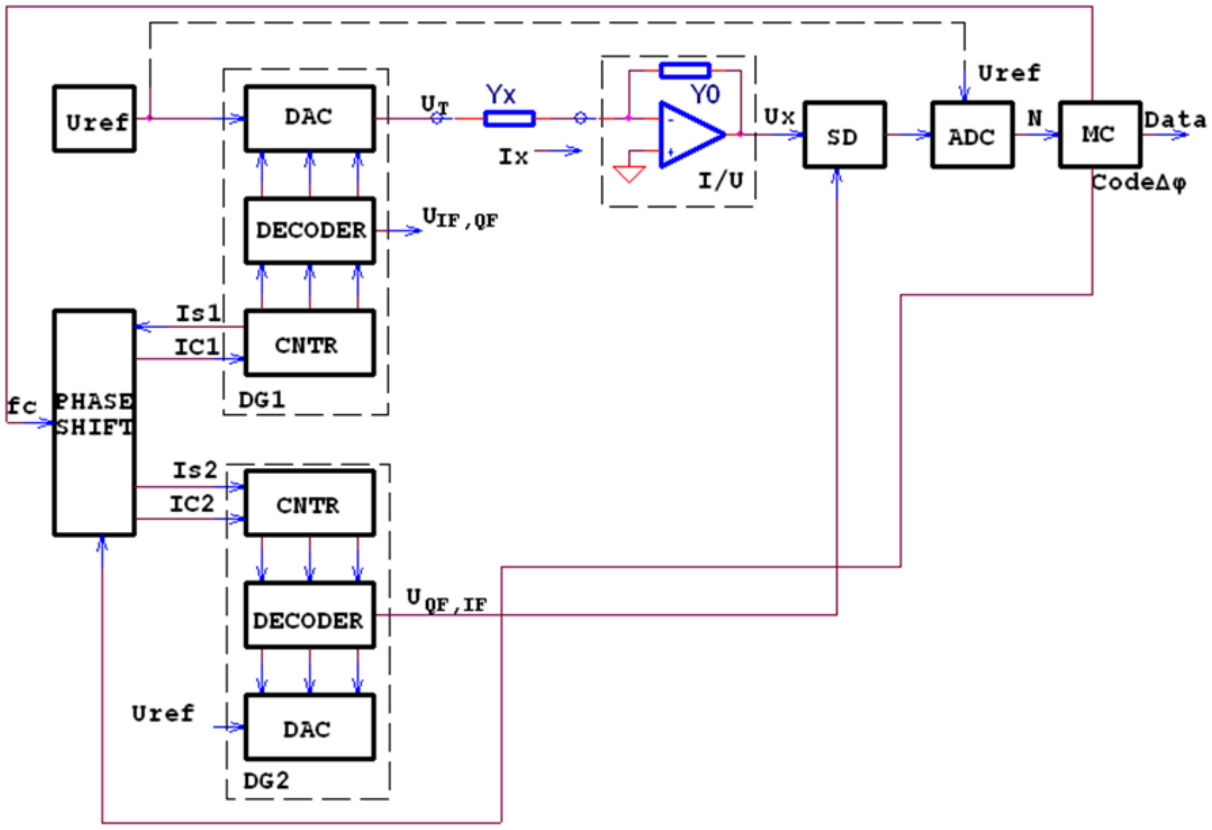

Figure 2. The scheme of the converter of an immitans parameters with phase adjustment of the reference voltage of a synchronous detector

The device contains: a source of reference voltage U_{ref}; identical digital generators DG1, 2 quasi-sinusoidal test signals U_t, the amplitude of which is determined by the voltage U_{ref}; the converter I/U of current I_x through the object of measurement Y_x in normalized relatively to U_t information signal U_x; synchronous SD detector and analog-to-digital converter ADC, which provide selection and conversion into digital code N of the information signal component that coincides in phase with the reference signal of the synchronous detector. The output reference signal $U_{IF,\ QF}$ (in-phase or quadrature) of the generator DG2 is used as such reference signal. Clocking of digital generators and synchronization of their output signals phases is carried out by clocking pulses Ic1,2 and synchronization pulses Is1,2, which are obtained from the clock sequence fc of the microcontroller MC using the delay generator PS. The circuitry of this device is discussed below. The MC processes the results of the transformation N to obtain ready-made measurement data, and also controls the measurement process, in particular generates delay codes Δφ of the signals of the generator DG2. The normalization of the measurement results Y_x (to obtain the value of the modulo of measured parameter) is performed relative to the value of the reference measure Y_o taking into account the values of reference voltages in DAC of the generators and in ADC, as well as by accurately forming of the delay Δφ of the test signal voltage Ut (to obtain the value of the phase angle).

In the channel under consideration, the key synchronous detector operates with a rectangular reference signal (meander) received from the CNTR counter through a decoder. Other DG2 nodes can be used for synchronous detection by processing of the information signal with weight coefficients, which provides better suppression of its harmonics and increase the accuracy of measurements. It should be emphasized that the reference voltages for digital generators and ADC are obtained from one high-stable source. Therefore, such a measuring channel can be considered as a bridge device with frequency conversion in the branch of the measuring object. The DC voltage U_{ref} is converted in this branch into a test signal Ut with a frequency f_t by the DAC multiplier in DG1. Then, the obtained measuring signal Ux is converted into a pulsating DC voltage by multiplying on a reference signal with a synchronous detector. This signal converts in the charge of the integrating capacity of ADC. The branch of the reference measure operates on direct current and contains only the measure (divider) of the reference voltage in the ADC where it is compared with the detected signal.

The algorithm for performing measurements is based on the following operations. In the initial state, the phase of the reference voltage $U_{IF,\ QF}$ for the synchronous detector is set in quadrature to the phase of the test signal U_T of DG1 (if a resistor is used as a reference measure Y_o). If Y_x is the active conductivity with a small phase angle, the result of the ADC transformation will be close to zero. In this case, FS changes the phase $U_{IF,\ QF}$ of DG2 to in-fase with U_t, and the result of the conversion in ADC will become correspond to the modulus of Y_x. If Y_x is a reactive conductivity of high-quality , then the zero result of the conversion in ADC will be obtained under in-phase or anti-phase reference signal $U_{IF,\ Q}$F relative to U_t (depending on the nature of the reactivity Yx). The modulus of its value will be obtained under quadrature $U_{IF,\ QF}$ relative U_t.

When measuring the parameters Y_x of a complex nature, the phase shift 90° between U_x and $U_{IF,\ QF}$ of DG2 is achieved in the first stage by adjusting the phase shift delay Δφ of the signal $U_{IF,\ QF}$ in one or the other direction. After reaching of the code N value close to zero, the change of the phase of a reference signal SD on 90° could be made and Y_x modulo will be determined. This can be realized by phase adjustment by the PS unit or with switching the reference voltages IF - QF. The phase angle Y_x, the tangent of its phase angle or loss angle, as well as its other parameters are calculated by the microcontroller according to the obtained values of the amplitude and phase delay, taking into account the clock frequency f_c and, accordingly, f_t.

At high frequencies of the test signal, the discreteness of the phase shift control between the signals DG1 and DG2 may be insufficient to obtain the required resolution of the object's phase angle measurement. In this case, additional bits of the code of this angle can be obtained by using the results of measuring the residual value of the quadrature component U_x after balancing the measuring circuit by phase in the first stage of measurement.

The circuit of the impedance parameter meter discussed above implements a combined measurement method that combines the principle of the impedance parameters direct conversion into digital codes and the phase angle balancing method. In this scheme the phase shift of the signal in the object of measurement is compensated by the phase shift of the synchronous detector's reference signal. This significantly reduces the errors from the non-informative influence of the measurement object's quadrature parameter under direct transducing its main parameter. At the same time, the modular errors (from the instability of the test signal level, the transmission ratio of the measuring circuits and the amplification path of the information signal) remain unchanged and limit the achievable accuracy of the instruments. This is especially actual for high-precision and high-sensitivity measurements under large background values of a parameter that is homogeneous with the informative. In these cases use the bridge methods of measurement with full compensation (balancing) of the measuring circuit output signal at the operating point of the conversion characteristic. When working with impedance-type sensors, such balancing usually occurs for the conventional zero value of their informative parameter, and its small changes under the influence of measured parameter are measured by the method of direct conversion of the output signal of the bridge. However, to achieve high measurement accuracy in a wide range of frequencies (above 10 - 20 kHz and below 100 Hz) in existing AC bridges with two balancing circuits - on the active and reactive parameters of the object impedance, difficult due to an increase in both amplitude and phase errors of in the reference branches of the bridge circuit. Therefore, when broadband impedance meters are needed, it is often found that the technical and economic performance of existing devices is unsatisfactory.

Previous studies [20 - 22], including of the authors [15, 23] have shown the prospects for solving this problem using two-channel (two-phase) the test signal digital generators, which allow to perform fully balance the AC bridge with a single reference measure for the any impedance. It is possible use reference measure, which has the best characteristics in the required frequency range: of capacitance or active resistance. Obtaining the required phase of the signal, that balances the bridge circuit, is achieved by adjusting the phase difference between the test voltages applied to the object of measurement and to the reference measure. Based on the above circuit solutions, a fairly simple and technological device for implementing this method was developed.

The diagram of formation the two coherent test signals and their corresponding reference signals with precise discrete adjustment of the phase difference between them shown on Fig. 3. In the development performed by the authors, the discreteness of the quasi-sinusoid was 32 steps per period. Circuits of signal generators ("Digital generator" 1 and 2) differ in this case. In the decoder of one of them (master) there are two schemes of formation of sync pulses: the scheme of internal synchronization of the ring counter (loop end) at the end of a cycle and for synchronization of the external device with a phase shift corresponding to a phase of an output signal 90o (mid cycle). This pulse is fed to the clocks generation unit (clock sequencer), which forms the clock sequences CI1 for the master counter, and time-shifted relative to it sequences CI2 for the slave counter. The mutual shift of these sequences is precisely regulated by the 4-bit delay counter FD2 according to the "delay codes" 2, set by the microcontroller MPC of the device. To increase the discreteness of the phase control, the MPC generates pulses TI0 with a frequency 16 times higher than the frequency of DG's counters clocking (to clocking the master generator, they are divided 16 times by a similar counter FD1). Therefore, this discreteness is 1/16 of the duration of one step. If the ratio of the frequency TI0 and the test signal U_t allows, the number of bit FD1, 2 can be much higher, and the discreteness of the phase shift control is correspondingly higher. The same counter FD3 serves for less discrete control (signal Res) of the synchronization moment of the initial state of the slave generator relative to the internal synchronization of the master generator. This delay is ± 8 intervals of clock pulses CI (of durations of one step of the quasi-sinusoid) and is

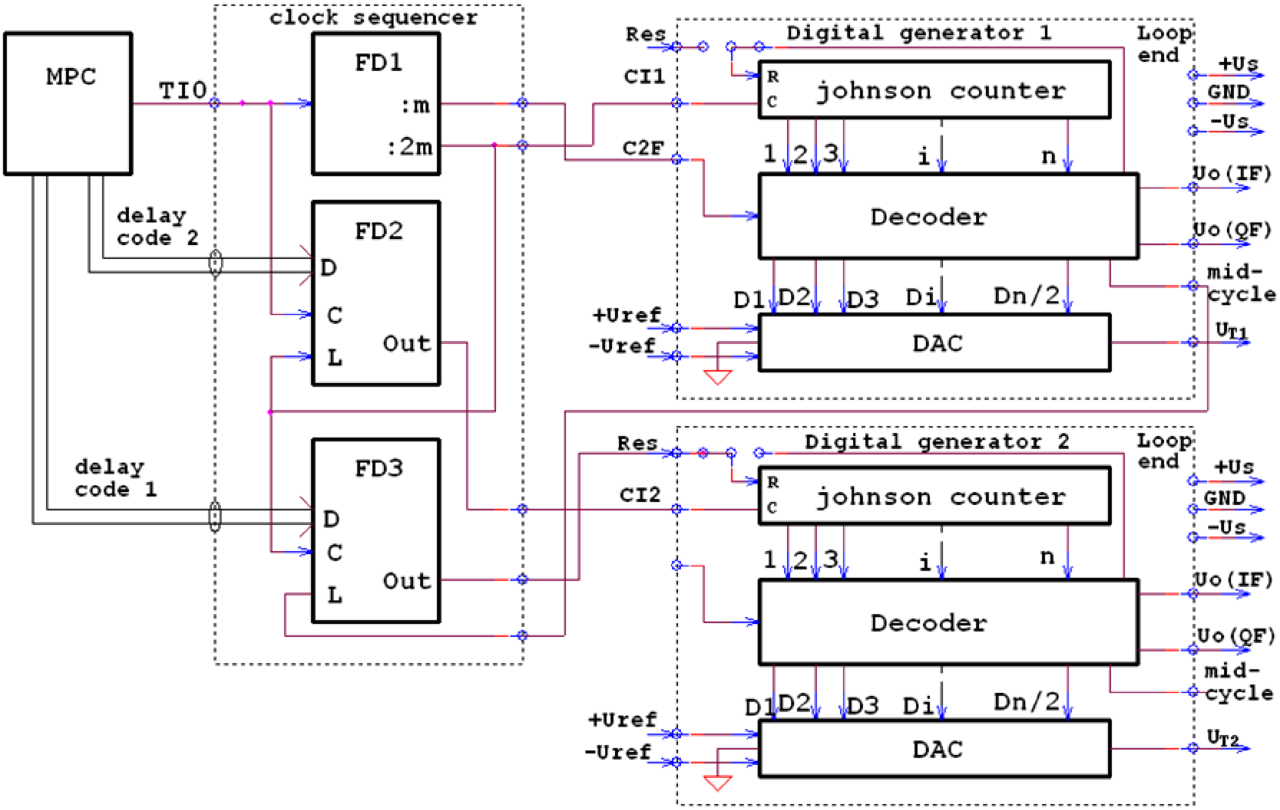

Figure 3. The scheme of formation of two sets of test and reference signals with precise regulation of their phase difference

regulated with the delay counter FD3 using delay code 1. This allows you to adjust the phase ratio of the output signals of the generators within 0° … +180°. If in the decoder of the leading generator to form one more sync pulse (for a phase – 90°) adjustment of phase shift of test signals becomes also possible within (0° ... – 180°).

The diagram of a measuring channel based on a bridge circuit, with balancing the modulus and phase of the output signal is shown on Fig. 4. It differs from the scheme in fig. 2 by the presence in the measuring circuit of the second branch, which includes DG2 and the reference measure Y0. The reference resistor (R1) is installed in the feedback circuit of the current/voltage converter I/U at the output of the bridge circuit, and determines the transmission coefficient of the bridge imbalance signal. The characteristics of I/U converter in this case gives little effect on the metrological parameters of the measuring channel. In the high-frequency or low-frequency sections of a wide range of frequencies, these parameters can be optimized by the appropriate choice of the kind of the measure Y0 (capacitance or active conductivity, respectively), which provides a significant increase in measurement accuracy. The second difference is the ability to control the amplitude of the test voltage at the output of DG2 using the regulator of its reference voltages U_B and $–U_B$. It includes a balancing DAC of the bridge (DAC_B) , a current-voltage converter (I/U) and an inverter (INV).

The measurement process consists of two stages. Initially, as in the above-mentioned channel with direct impedance conversion, the phase shift of the current in the object of measurement is compensated by the phase shift of the synchronous detector's reference voltage at zero values of the reference voltages U_B and $–U_B$. In the second stage, the voltage at the output of DG2 increases until the equilibrium of the bridge circuit is reached. If the measure Y_0 is a resistor, the phase of this voltage must be opposite to the current phase of the object being measured. If Y_0 is a capacitor, this phase must be delayed by 90°. As mentioned above, additional data bits can be de-

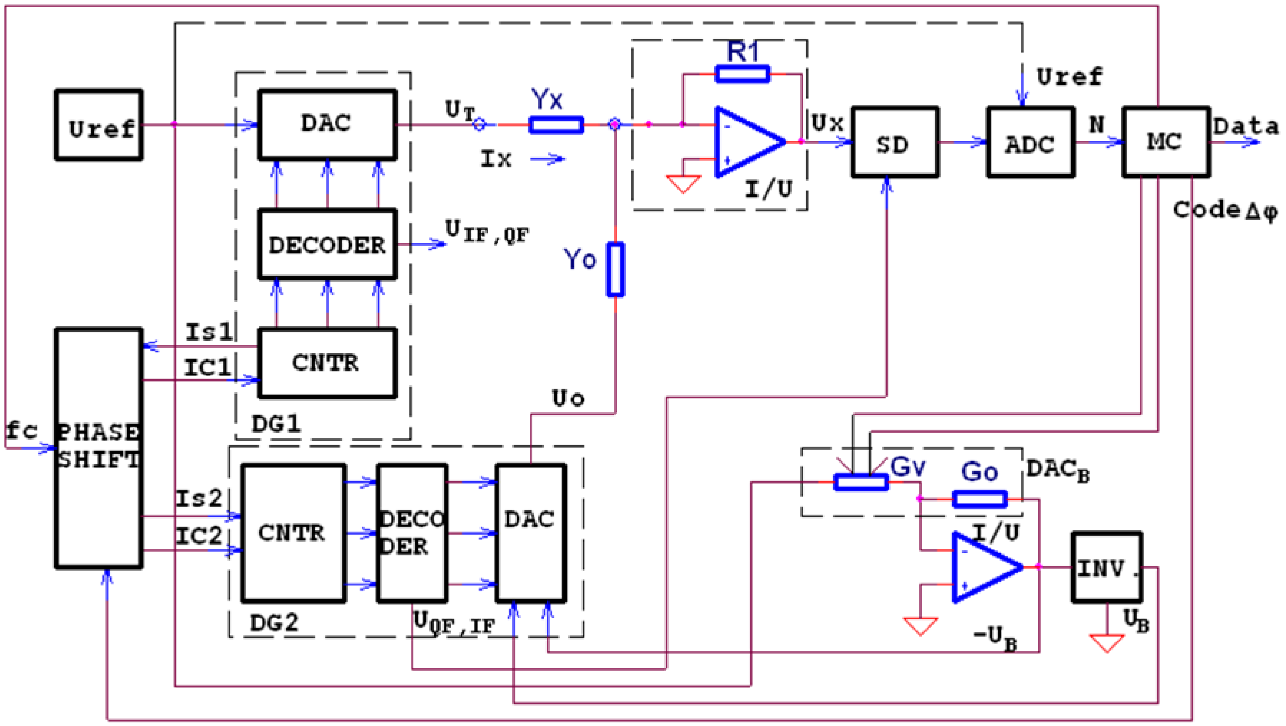

Figure 4. The scheme of the measuring channel based on the bridge circuit with balancing the module and phase of the output signal

termined by converting the residual imbalance signal into the ADC in the case of insufficient discreteness of the result codes obtained by the performed bridge balancing.

Based on the results of the development, prototypes of basic measuring modules with single-phase and two-phase test signal generators were made. Their description and results of metrological research will be presented in the continuation of this article.

Conclusions

1. Phase errors of separation of immitances into active and reactive components are the main problem for obtaining high accuracy of their measurements in a wide range of frequencies. Traditional principles of construction of impedance-metric means do not provide achievement of an acceptable ratio of metrological and technical and economic characteristics of devices.

2. A promising way to reduce the phase errors of immitance parameters meters in a wide range of frequencies is the use of digital generators of quasi-sinusoidal test signals based on Johnson's ring counter and DAC with sequential summation and subtraction of currents forming the quasi-sinusoidal stair-step voltage. This provides minimal switching interference and time differences of the signal's components from which the quasi-sinusoidal test voltage and in-phase and quadrature voltages to control key synchronous detectors are synthesized.

3. The proposed schemes of immitance parameters meters based on the developed digital generators and on the bridge circuit balanced by module and phase, and also the circuit of combined type with partial balancing and direct conversion of the output signal, provide simplicity and manufacturability of devices and low phase errors.

References

[1]. Kibble P. B. Rayner G. H. Coaxsial Alternative Current Bridges // Briston; Pdam Hilder Ltd. 203 p. (1984).

[2]. Karandeev K. B. Mostovye metody izmerenij // Gostehizdat USSR, (1952).

[3]. Grinevich F. B. Avtomaticheskie mosty peremennogo toka // Novosibirsk: Izd. SO AN SSSR, 215 s. (1964).

[4]. Novik A. I. Sistemy uravnoveshivaniya

precizionnyh bystrodejstvuyushih odno-parametrovyh mostov peremennogo toka // Tehnichna elektrodinamika. 1997. №5. S. 65 – 69.

[5]. F. B. Grinevich, M. N. Surdu Vysokotochnye variacionnye izmeritelnye sistemy peremennogo toka // Kiev: Naukova dumka, 192 s. (1989)

[6]. M. M. Surdu, Z. Ya. Monastirskij Variacijni metodi pidvishennya tochnosti vimiryuvachiv imitansu // K.: In-t elektrodinamiki NAN Ukrayini, 385 s. (2015).

[7]. M. Surdu Variational Calibration, Published in the book: «Metrology» Edited by: Anil Akdogan. Chapter 3. IntechOpen 01. 08. 2018.

[8]. Pohodilo Ye. V., Homa V. V. Vimiryuvachi CLR z peretvorennyam «imitans — napruga» // Lviv: Lvivska politehnika, 292 s. (2011).

[9]. A. D. Vasilenko, V. G. Melnik, A. I. Novik, L. N. Semenycheva Povyshenie razreshayushej sposobnosti immitansometricheskih kanalov // Tehnichna elektrodinamika. 2013. № 1. S. 70 – 81.

[10]. Labuzov A. E., Lameko A. L., Surdu M. N. Precizionnye izmeriteli impedansa (RLC-metry: Sostoyanie rynka i tendencii razvitiya). // Rezhim dostupu: http://www.promix.com.ua/public/RLC.pdf.

[11]. AD5933 Obzor. Osobennosti i preimushestva. Rezhim dostupu: https://www.analog.com/ru/products/ad5933.html.

[12]. Hoya J., Lentka Gr. Portal analyzer for impedance spectroscopy. X1X IMEKO World Congress. September 6-11, 2009, Lisabon, Portugal. P. P. 497-502. Режим доступу: https://pdfs.semanticscholar.org/0027/a81d802a3fd565d69c7239710d105c6a34ea.pdf?_ga=2.153056890.2112044939.1588864114-1395720667.1588864114.

[13]. Hoya J., Lentka Gr Interface circuit for impedance Sensors using two specialized Single-chip Microsystems Sensors and Actuators A Physical, 2010, 163, 1, p. 191-197.

[14]. Melnik V. G. Nizkochastotnye cifrovye ekstremalnye mosty peremennogo toka izmeritelnye cepi i algoritmy uravnoveshivaniya. Avtoreferat dissertacii na soiskanie uchenoj stepeni kandidata tehnicheskih nauk AN USSR // Institut elektrodinamiki, Kiev, 1988, 20 s.

[15]. A. S. 1524005 (SSSR) Avtomaticheskij most peremennogo toka. Kromplyas B. A., Melnik V. G. Surdu M. N., Skripchenko I. A. // Institut elektrodinamiki AN USSR. Zayavka №4387628. 03.03.1989.

[16]. A. S. 1265624 (SSSR) Avtomaticheskij cifrovoj most peremennogo toka Grinevich F. B., Novik A. I., Melnik V. G., Ornatskij O. A., Surdu M. N., Skripchenko I. A. // Institut elektrodinamiki AN USSR. Zayavka №3824063, 13.12.1984. Zaregistrirovano v Gosreestre izobretenij SSSR 22.06.1986.

[17]. A. S. 853560. Avtomaticheskij most peremennogo toka. Surdu M. N., OrnatskijO. A., Melnik V. G // Institut elektrodinamiki AN USSR. Zayavka №2847759, 30.11.1979. Zaregistrirovano v Gosreestre izobretenij SSSR 07.04.1981.

[18]. Surdu M. N., Melnik V. G., Ornatskij O. A. K vyboru metodiki rascheta parametrov kvazisinusoidalnogo napryazheniya. // V kn.: “Tehnika elektricheskih izmerenij”, “Naukova dumka”, Kiev, 1979. s. 41-48.

[19]. Surdu M. N., Melnik V. G., Ornatskij O. A. Pogreshnosti formirovaniya kvazisinusoidalnogo napryazheniya cifrovogo generatora // V kn.: “Tehnika elektricheskih izmerenij”, “Naukova dumka”, Kiev, 1979, s. 13-19.

[20]. M. N. Surdu, D. M. Surdu. AC bridges with phase controlled dividers – theory and experimental results (Mosty peremennogo toka s fazovym upravleniem – teoriya i rezultaty eksperimenta) // Ukrayinskij metrologichnij zhurnal. 2015. № 3. s. 16 – 24.

[21]. Surdu M. N., Lameko A, L, , Surdu D. M. Kursin S. H Avtomaticheskaya precizionnaya sistema dlya metrologicheskogo obespecheniya izmerenij parametrov impedansa // Ch. 1 Principy dejstviya., Izmeritelnaya Tehnika., 2012, №7, str. 51-57.

[22]. M. Surdu, A. Lameko, D. Surdu, S. Kursin, M. Mukharovsky, A. Akhmadov, S. Shevkun Accurate universal set of automatic comparators for impedance parametersunits reproduction and transfer // XVIII IMEKO TC4 Symposium and IX Semetro, Natal, (2011).

[23]. Melnik V. G., Slickij A. V., Vasilenko A. D. Kvaziuravnoveshennyj konduktometricheskij most dlya biosensornoj sistemy s balansirovkoj po modulyu i faze. // “Sensorna elektronika ta mikrosistemni tehnologiyi”, 2016. – T. 13, №3. - s. 91-100.

Стаття надійшла до редакції 10.05.2020 р.

UDC 621.317
DOI: https://doi.org/10.18524/1815-7459.2020.2.205825

IMPROVEMENT GENERATING OF THE TEST SIGNALS FOR DETERMINATION OF THE IMPEDANCE PARAMETERS IN WIDE FREQUENCY RANGE

V. G. Melnyk[1]*, P. I. Borschov*[1]*, V. K. Beliaev*[2]*, O. D. Vasylenko*[1]*, O. L. Lameko*[1]*, O. V. Slitskiy*[1]

[1]Institute of electrodynamic National Academy of Sciences of Ukraine, 56 Pr. Peremohy, 03057, Kyiv – 57. E-mail: melnik@ied.org.ua
[2]National University of Life and Environmental Sciences of Ukraine, Heroyiv Oborony st., 15, Kyiv, 03041, Ukraine

Summary

A brief analysis is given of modern methods for measuring impedance parameters and sources of error, limiting their accuracy in a wide range of frequencies and the possibilities of their use in newest, in particular sensor, technologies on technical and economic characteristics. An effective way to solve the main problem - a significant increase in the errors of the separation of the informative signal into the an active Re and a reactive Im components with increasing frequency due to insufficient accuracy of the test's and reference's signals phase ratio is substantiated. New principles of construction of the digital generators of test and reference signals by synthesis of quasi-sinusoidal voltage by means of Johnson's ring counters and the digital-to-analog converters with sequential summation and subtraction of currents that forms stair-step voltage are considered detail. This, as well as the simplicity and identity of the structures of the formation of the test and reference signals, provide minimal switching interference and time inconsistencies of the test voltage with in-phase and quadrature voltages to control key synchronous detectors. The construction of a simple two-phase digital generator of test and reference signals with precise control of the phase difference in the two channels of voltage generation is considered. The schemes of impedance parameter meters based on the developed digital generators are proposed: with a bridge circuit balanced by module and phase, and a combined type with partial balancing and direct conversion of the output signal, which provide simplicity and manufacturability of devices and low phase error. Based on the results of the development, prototypes of basic measuring modules with single-phase and two-phase test signal generators were made. Their description and results of metrological research will be presented in the continuation of this article.

Keywords: impedance, measurement, phase error, test signal, reference signal

УДК 621.317
DOI: https://doi.org/10.18524/1815-7459.2020.2.205825

УДОСКОНАЛЕННЯ ГЕНЕРУВАННЯ ТЕСТОВИХ СИГНАЛІВ ДЛЯ ВИЗНАЧЕННЯ ПАРАМЕТРІВ ІМПЕДАНСУ В ШИРОКОМУ ДІАПАЗОНІ ЧАСТОТ

В. Г. Мельник[1], П. І. Борщов[1], В. К. Бєляєв[2], О. Д. Василенко[1], О. Л. Ламеко[1], О. В. Сліцький[1]

[1] Інститут електродинаміки НАН України пр. Перемоги 56, м. Київ-57, 03057, Україна. E-mail: melnik@ied.org.ua
[2] Національний університет біоресурсів та природокористування України,
Вул. Героїв Оборони, 15, Київ, 03041, Україна.

Реферат

Дано короткий аналіз сучасних методів вимірювання параметрів імпедансу і джерел похибок, що обмежують їх точність в широкому діапазоні частот, та можливості їх використання в новітніх, зокрема сенсорних, технологіях за техніко-економічними характеристиками. Обґрунтовано ефективний шлях вирішення основної проблеми – значного збільшення похибок розділення інформативного сигналу на активну Re та реактивну Im складові при підвищенні частоти через недостатню точність співвідношення фаз тестових та опорних сигналів. Детально розглянуто нові принципи побудови цифрових генераторів тестових та опорних сигналів шляхом синтезу квазісинусоїдальної напруги за допомогою кільцевих лічильників за кодом Джонсона та цифро-аналогового перетворювача з послідовним підсумовуванням і відніманням струмів, що формують сходинки квазісинусоїди. Це, а також простота та ідентичність структур формування сходинок тестових і опорних сигналів, забезпечують мінімальні комутаційні завади та часові неузгодженості тестової напруги з синфазною і квадратурною до неї напругами для управління ключовими синхронними детекторами. Розглянуто побудову простого двофазного цифрового генератора тестових та опорних сигналів з точним регулюванням різниці фаз в двох каналах формування напруги. Запропоновані схеми вимірювачів параметрів імпедансу на основі розроблених цифрових генераторів: з мостовим колом, що урівноважується за модулем та фазою, і комбінованого типу з частковим урівноваженням та прямим перетворенням вихідного сигналу, які забезпечують простоту і технологічність приладів при низьких фазових похибках. За результатами проведених розробок були виготовлені прототипи базових вимірювальних модулів з однофазним та двофазним генераторами тестових сигналів. Їх опис та результати метрологічних досліджень будуть представлені в продовженні даної статті.

Ключові слова: імпеданс, вимірювання, фазова похибка, тестовий сигнал, опорний сигнал