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INSTRUMENTATION FOR MEASURING THE PARAMETERS AND CHARACTERISTICS OF FOUR-POLES

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ABSTRACT

The paper presents the results of theoretical and experimental studies aimed at justifying the structure and parameters of an instrument for measuring the frequency response of four-poles, which provide measurement of a passband with minimum dynamic errors. As a result of the studies, the equation for measuring the four-pole frequency response passband, which relates the frequency change rate of the swept frequency generator to the number and frequency of counting and nonius pulses, was obtained. An example of the use of modern computer technologies for the implementation of the measuring instrument in the LabVIEW environment, which provides measurement of the frequency response passband of electoral systems with minimal dynamic errors, is presented. It is shown that the use of a virtual measuring instrument technology and interface with the four-pole under study by means of data acquisition board makes it possible to efficiently implement monitoring of technical condition according to the frequency response of electoral systems.

Keywords: frequency response, a dynamic error, the electoral system.

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1. INTRODUCTION

At the present time, instrumentation for monitoring frequency response (frequency response measuring instruments) is widely used to measure and monitor the parameters and characteristics of four-poles, which include radio engineering devices and radio engineering units.

Frequency response measuring instruments are necessary tools for research workers, designers of radio engineering devices and systems, are widely used in the production, operation and metrology maintenance of radio engineering devices and systems. For example, the quality of data transmission channels, as well as receiving radio devices, directly depend on the frequency response, which affects the quality of data transmission without loss and distortion, processing and detection of useful signals against a background of both natural and artificial interference.

The measurement of frequency response has a number of features, which include: measurements shall be made in a dynamic mode; characteristics, rather than values, shall be measured; the indicator shall display a dynamic characteristic, rather than a static one' measurements shall be performed in a wide frequency range and sweep band; both narrowband and broadband electoral systems of four-poles shall be measured.

1.1. Literature data analysis and target setting

One of the most common methods for measuring frequency response is to obtain an indicator of the frequency response of a certain electoral system. The frequency response of the electoral system is obtained by feeding an input signal and measuring the output signal. In this case, the output signal at the given input signal characterizes the frequency response of electoral systems [1, 2, 3].

The measurement of frequency response and the determination of the frequency selectivity parameters of measured radio engineering devices are fully considered in [1, 3]. However, they do not fully target the control and exclusion of dynamic errors in the measurement of frequency response, digital measurement of passband with the use of a nonius, normalization of the frequency response indicator observed on the screen. Due to [3], it is known that the cause of the dynamic error during measuring frequency response is the final rate of generator frequency change within the passband of the measured object.

The analysis showed that the existing methods and technical equipment for measuring the frequency response of radio engineering devices electoral systems are not effective enough in the context of both the presence of dynamic errors and the absence of passband digital measurement.

When solving the problem of reliable and accurate measurement of frequency response, it becomes possible to solve the problem of frequency response measurement and passband digital measurement using a nonius and with minimum dynamic errors.

1.2. Purposes and objectives of the study

The purpose of this study is to develop mathematical models, structure, hardware and software tools for measuring the frequency response based on the computer technology of virtual instruments of National Instruments (NI) company, to create procedures which provide frequency response measurement and passband digital measurement using a nonius and with minimum dynamic errors, to create a working model and to determine the scope of its application.

The objects of the study are the existing method and technical equipment for measuring the frequency response.

The scope of application is the frequency response measuring instrument can be used for adjustment, control and study of various radio engineering units and devices.

The scientific novelty is the development of mathematical models, as well as the structure of a frequency response measuring instrument, that provide frequency response measurement and passband digital measurement using a nonius and with minimum dynamic errors.

2. MATERIALS AND METHODS

Studies were carried out using mathematical and simulation modeling methods with the use of the NI LabVIEW 2012 programming environment and frequency response of real electoral systems of radio devices and units.

In order to carry out experimental studies, the following has been developed: a virtual instrument for frequency response measuring, the schematic structure of which is shown in Figure 1, time-based diagrams explaining the method for frequency response measuring in Figure 2, forms of frequency response in the presence of dynamic errors in Figure 3, time-based diagrams explaining the method for passband digital measurement and occurrence of a discreteness error in Figure 4, time-based diagrams explaining the method for reducing the discreteness error at the end of the count with the use of a nonius and eliminating the discreteness error at the beginning of the count in Figure 5, a functional diagram in Figure 6 and the layout of the measuring instrument front panel in Figure 7.

The key point of the proposed method is to control the dynamic measurement error by modulating the frequency of the swept frequency generator by the triangular law – symmetric linear frequency modulation.

The schematic structure of the measuring instrument is shown in Figure 1. The measuring instrument includes: a generator of swept frequency – 1; a measured object – 2; a reference signal generator – 3; a divider – 4; an amplitude detector – 5; a scaling amplifier – 6; an automatic pass band measurement unit – 7; a decade counter – 8; a decoder – 9; an indicator – 10.

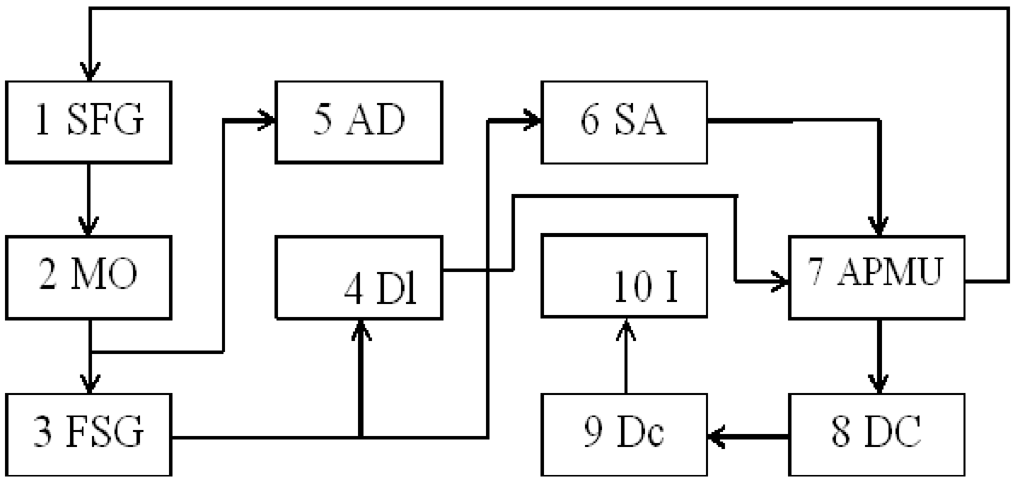

Figure 1 Schematic structure of the frequency response measuring instrument

The swept frequency generator generates a signal of constant amplitude, the frequency of which changes according to the triangular law, i.e. symmetric linear frequency modulation is used. There is a generator frequency deviation control.

The reference signal generator selects and stores the level of the input signal of the reference frequency with respect to which the frequency response is normalized.

The amplitude detector detects the envelope from the signal obtained at the measured object output, the shape of which is proportional to the input signal and characterizes the frequency response of the electoral system.

The divider carries out the normalization operation. The envelope at the divider output is proportional to the measured frequency response and is equal to the ratio of the signal at the amplitude detector output to the signal level at the reference frequency, coming from the reference signal generator output; it varies from 0 to 1 and does not depend on the amplitude of the signal at the amplitude detector output.

The scaling amplifier generates a signal level, in relation to which the passband of the measured object frequency response is measured.

The automatic passband measurement unit performs dynamic errors control and generates swept frequency generator frequency deviation control signal. When the frequency response of the measured object at a positive and negative frequency change rate of the swept frequency generator coincides, then this corresponds to the minimum dynamic errors. At this point in time, counting and nonius pulses are generated, the number of which is proportional to the measured passband.

The decade counters and decoders convert the unitary code to the binary-decimal one, which, in turn, is converted into code signals of the digital indicator used.

The method for measuring the frequency response of the measured objects (four-poles) is shown in Figure 2. The duration of rectangular pulses of single amplitude Δt_1 and Δt_2 (diagram 3 in Figure 2) is directly proportional to the frequency response passband of the measured object (electoral system) and inversely proportional to the frequency change rate of the swept frequency generator, with a positive and negative frequency change rate, respectively (diagram 1 in Figure 2), and is determined by the formula:

$$\Delta t_1 = \Delta t_2 = \Delta t = \frac{\Delta F}{V_{\text{swfreqgen}}} = \frac{\Delta F}{\Delta f_{\text{sweep}}} T_p , \quad (1)$$

Where, $V_{\text{swfreqgen}} = \frac{\Delta f_{sweep}}{T_p}$ – is the frequency change rate of the swept frequency generator;

ΔF – is the passband of the measured object frequency response ;

Δf_{sweep} – is the sweep band of the swept frequency generator;

T_p – is the sweep period equal to the half of the triangular shape voltage period.

The sweep band of the swept frequency generator and the sweep period are shown in diagrams 1 and 2 in Figure 2. Since the swept frequency generator frequency and the sweep voltage are changed in accordance with the triangular law, the beam draws two frequency response characteristics on the indicator screen: one at the frequency increase, the other at the frequency decrease. The result of the dynamic errors in measurements is that two frequency response characteristics are observed on the indicator screen, which will be asymmetrically displaced in opposite directions with respect to the static frequency response characteristic (diagram 1 in Figure 2).

The process of frequency response measurement dynamic error control in the first and second halves of the measurement cycle is as follows [4, 5]. In the first half of the measurement cycle, when the frequency change rate of the swept frequency generator is positive, the time interval between the decrease in the single amplitude signal Δt_1 and the reference pulse is measured. The position of the reference pulse corresponds to the maximum amplitude of triangular shape modulating voltage. In the second half of the measurement cycle, when the frequency change rate of the swept frequency generator is negative, the time interval between the reference pulse and the front of the single amplitude signal Δt_2 is measured.

In the presence of dynamic errors, the time intervals between the decrease in the single amplitude signal Δt_1 and the reference pulse and between the reference pulse and the front of the single amplitude signal Δt_2 will not be equal to each other; hence, the number of counting pulses will be different.

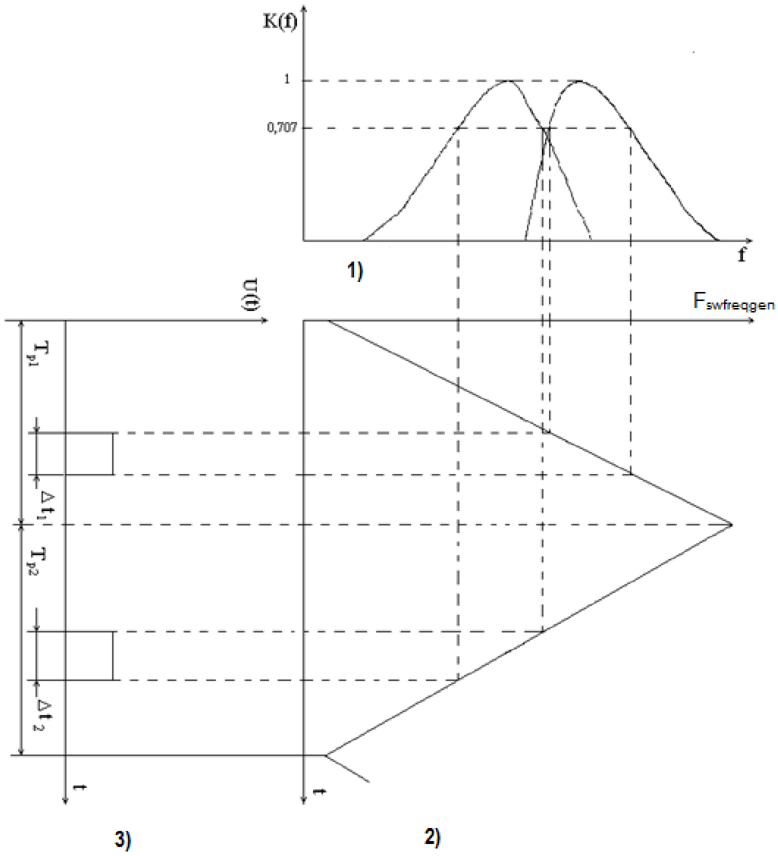

Figure 2 Time-based diagrams explaining the method for frequency response measuring

The duration of the time intervals in the first and second halves of the measurement cycle is proportional to the number of counting pulses following with a repetition cycle T_{count}.

In order to measure the frequency response and passband of the measured object, it is necessary to set the frequency change rate (deviation) of the swept frequency generator so that only one frequency response characteristic of the measured object is observed on the indicator screen, both at positive and negative frequency change rates. This corresponds to the minimum dynamic errors, i.e. it should be considered that dynamic distortions are insignificant or equal to zero. The process of deviation in the shape of frequency response in the presence of a dynamic error is shown in Figure 3.

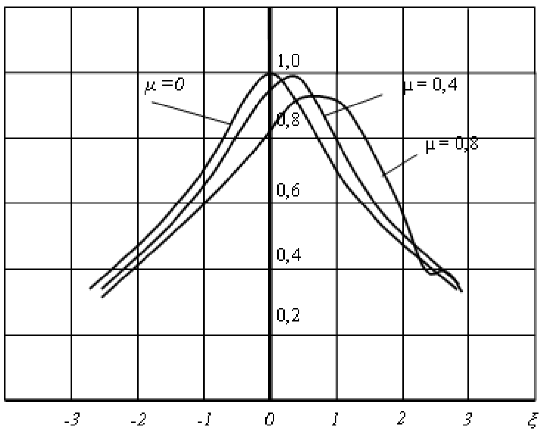

Figure 3 Shapes of frequency response in the presence of a dynamic error

Dynamic errors lead to a decrease in the maximum of the frequency response, distortion (deformation), frequency axial displacement and an increase in the passband.

Time-based diagrams explaining the method for digital measurement of the passband and occurrence of a discreteness error are shown in Fig. 4. The process of the frequency response passband digital measurement is performed after the dynamic errors are minimal or insignificant. The condition of insignificant dynamic errors is the equality of the single amplitude rectangular pulses duration $\Delta t_1=\Delta t_2=\Delta t$. In case this equation is satisfied, the automatic passband measurement unit generates a signal to generate counting pulses. The total number of counting pulses when measuring the single amplitude rectangular pulses duration Δt is determined by the formula:

$$N_x = F_{\text{count}} \cdot \Delta t = F_{\text{count}} \cdot \frac{\Delta F}{V_{\text{swfreqgen}}} = F_{count} \cdot \frac{\Delta F}{\Delta f_{sweep}} \cdot T_p. \quad (2)$$

Accordingly, the result of measuring the frequency response passband is determined by the formula:

$$\Delta F = \frac{N_x \cdot \Delta f_{sweep}}{F_{count} \cdot Tp} = \frac{N_x}{F_{count}} \cdot V_{\text{swfreqgen}} = N_x \cdot T_{\text{count}} \cdot V_{\text{swfreqgen}} \quad (3)$$

The accuracy of frequency response passband measuring is determined by the discreteness error, which depends on the counting pulses repetition cycle T_{count}.

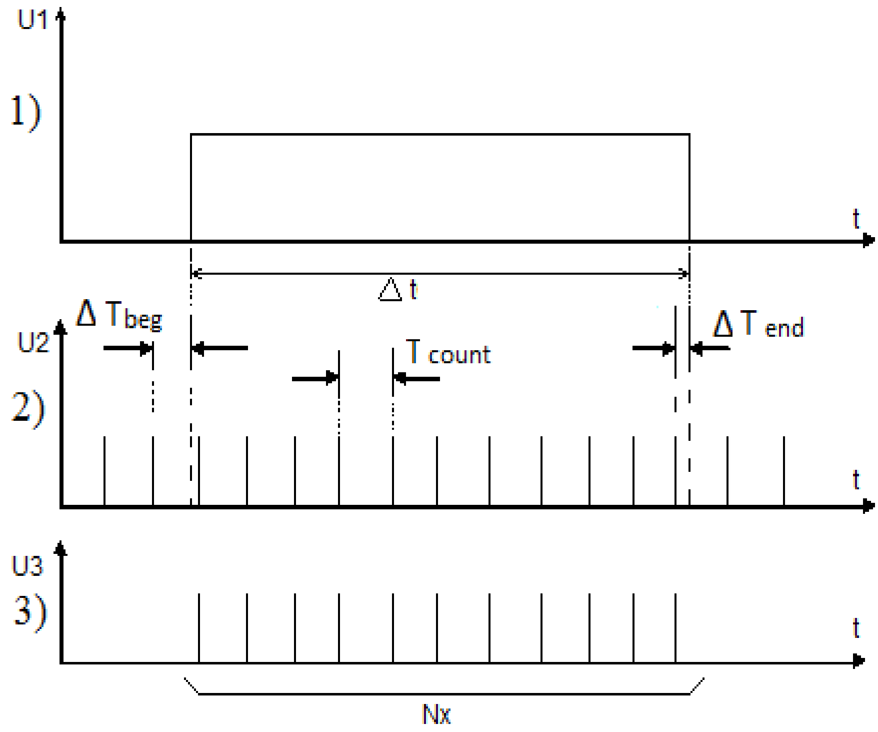

Figure 4 Time-based diagrams explaining the method for digital measurement of the passband and occurrence of a discreteness error

In order to improve the accuracy of frequency response passband measuring, it is necessary to reduce the discreteness error. Time-based diagrams explaining the method for reducing the discreteness error with the use of a nonius are shown in Figure 5.

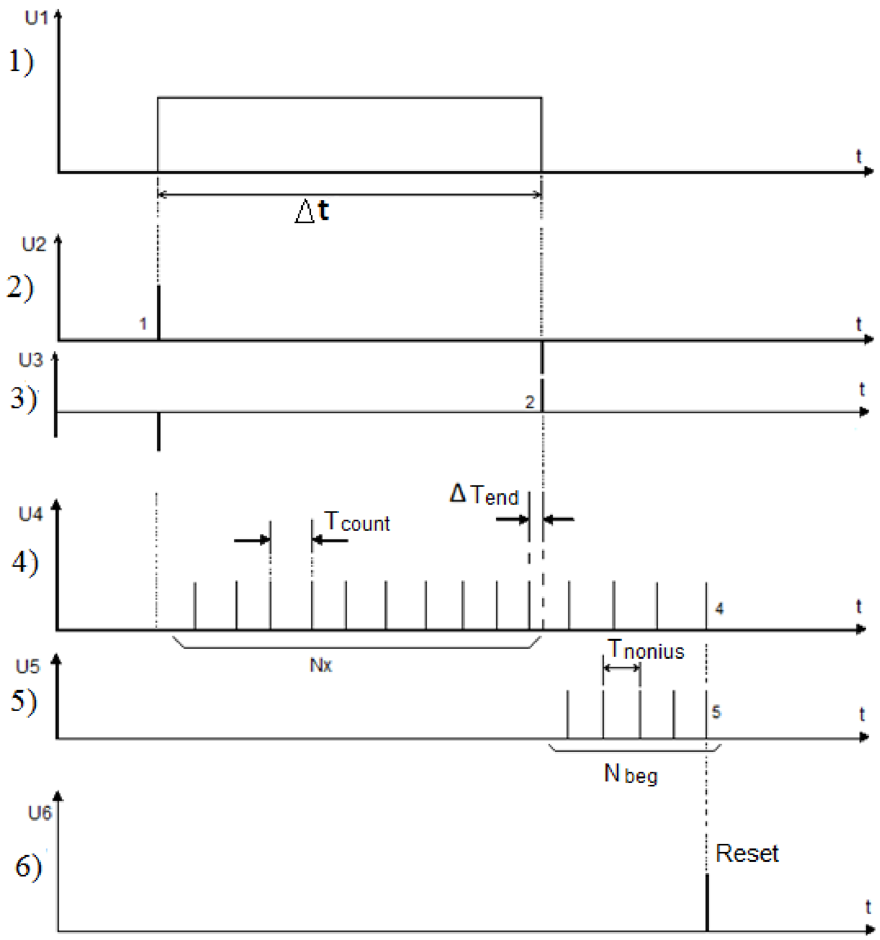

Figure 5 Time-based diagrams explaining the method for reducing the discreteness error with the use of a nonius

Diagram 2 in Figure 5 shows two pulses; the first is a reference pulse and the second is an interval pulse, which correspond to the beginning and end of the measured interval Δt, diagram 1 in Figure 5. The reference pulse coincides with the first counting pulse (diagram 3 and 4 in Figure 5). Since the beginning of the count coincides with the reference pulse (diagrams 1, 2, 3, and 4 in Figure 5), so at the count beginning the discreteness error Δt_{begin}, which lies in the range (0, $-T_{count}$), is excluded (Figure 4). The interval pulse (diagram 3 in Figure 5) fixes an integer N_x of pulses. The duration of the Δt interval is directly proportional to the frequency response passband of the measured object and inversely proportional to the frequency change rate of the swept frequency generator. The value of the measured interval Δt will be determined by the expression

$$\Delta t = N_x \cdot T_{count} + \Delta t_{end} \tag{4}$$

At the end of the pulse count, the discreteness error Δt_{end} lies in the range (0, $+T_{count}$).

In order to reduce the discreteness error Δt_{end}, the interval pulse (diagram 3 in Figure 5) starts the nonius pulse generator and the nonius pulse counting begins (diagram 5 in Figure 5). The repetition cycle of the nonius pulses T_{nonius} is selected by the relation

$$T_{nonius} = \frac{k-1}{k} \cdot T_{count}, \tag{5}$$

Where, T_{count} is the repetition cycle of the counting pulses;

k = 10 or 100.

After some time, there will be a coincidence of nonius and counting pulses, and the "reset" pulse (diagram 6 in Fig. 5) fixes the number of pulses N_{nonius} (diagram 5 in Figure 5). If we know N_{nonius}, the discreteness error Δt_{end} is determined by the relation

$$\Delta t_{\text{end}} = N_{\text{nonius}} \cdot T_{\text{count}} - N_{\text{nonius}} \cdot T_{\text{nonius}} = N_{\text{nonius}} \cdot T_{\text{count}} - N_{\text{nonius}} \cdot T_{\text{count}} \frac{k-1}{k} = \frac{N_{\text{nonius}} \cdot T_{\text{count}}}{k} \quad (6)$$

Therefore, the discreteness error Δt_{end} decreases by *k* times, and the discreteness error at the beginning of the count $\Delta t_{beg} = 0$.

At the same time, N_x is fixed with the indicator digital counting device in the highest digits, and N_{nonius} is fixed in the lower ones.

The total number of nonius pulses is

$$N_{\text{nonius}} = \frac{\Delta t_{\text{end}} \cdot k}{T_{\text{count}}} = \frac{\Delta t_{\text{end}} \cdot (k-1)}{T_{\text{nonius}}} = \Delta t_{\text{end}} \cdot k \cdot F_{\text{count}} = \Delta t_{\text{end}} \cdot (k-1) \cdot F_{\text{nonius}} \quad (7)$$

Therefore,

$$\Delta t = N_x \cdot T_{\text{count}} + \Delta t_{end} = N_x \cdot T_{\text{count}} + \frac{N_{\text{nonius}} \cdot T_{\text{count}}}{k} = T_{\text{count}} (N_x + \frac{N_{\text{beg}}}{k}) = \frac{\Delta F}{\Delta f_{sweep}} \cdot T_p \quad (8)$$

Accordingly, the result of measuring the passband measured by the frequency response is determined by

$$\Delta F = \frac{T_{\text{crep}} (N_x + \frac{N_{\text{nonius}}}{k}) \cdot \Delta f_{sweep}}{T_p} = \frac{(N_x + \frac{N_{\text{nonius}}}{k})}{F_{count}} \cdot V_{\text{swfreqgen}} \quad (9)$$

The reliability of frequency response measurement depends on the frequency change rate of the swept frequency generator and the passband of the measured object (four-pole) and is determined by:

$$\mu = \frac{\Delta F_{sweep}}{T_p \cdot \Delta F^2} = \frac{V_{\text{swfreqgen}}}{\Delta F^2} \quad (10)$$

The above expression characterizes the dynamic errors. An increase in the parameter μ leads to the fact that the frequency response of the measured object, both in parameters and in form, differs from its static characteristic on the indicator screen.

The accuracy of the passband measurement and the measured frequency response is determined by the discreteness error, which is equal to the least significant digit value and depends on the frequency (repetition cycle) of nonius pulses and the duration of the single amplitude rectangular pulse.

In the quasistatic mode of the measuring instrument operation, the frequency change rate (deviation) of the swept frequency generator is set so that only one frequency response characteristic is observed on the indicator screen, both at positive and negative frequency change rates of the swept frequency generator. The combination of frequency responses corresponds to the minimum dynamic errors and the greatest reliability of the measurement.

Based on the proposed measurement method and mathematical models, a virtual frequency response measuring instrument [6, 7] was developed in the LabVIEW environment. Its functional scheme is shown in Figure 6, and the layout of the front panel is shown in Figure 7.

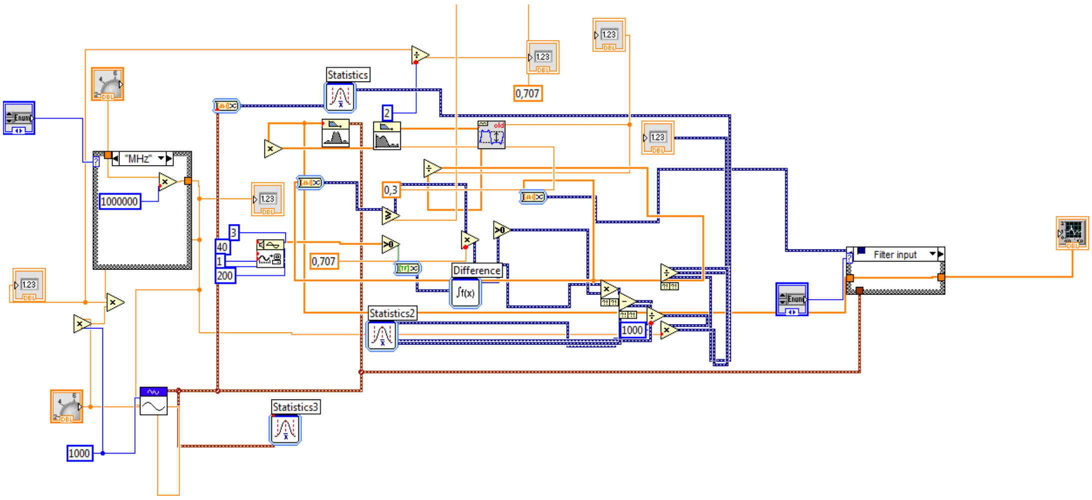

Figure 6 Virtual frequency response measuring instrument. Functional scheme

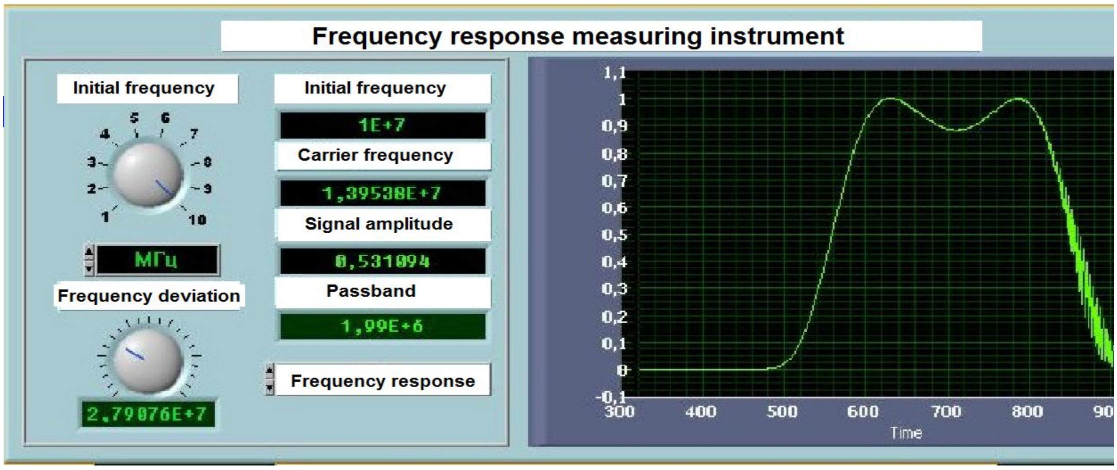

Figure 7 Virtual frequency response measuring instrument. Fragment of the virtual measuring instrument front panel

3. RESULTS

Experimental studies were performed using the NI LabVIEW 2012 programming environment and verified by half-sized modeling on a personal computer using the frequency characteristics of real electoral systems of radio devices (four-pole). The four-pole passband, the sweep band (frequency deviation) of the swept frequency generator, the sweep period and frequency change rate of the swept frequency generator, and the repetition cycle of counting and nonius pulses are given in the table 1.

Table 1 The four-pole passband, the sweep band (frequency deviation) of the swept frequency generator, the sweep period and frequency change rate of the swept frequency generator, and the repetition cycle of counting and nonius pulses

ΔF_{sweep}, kHz	1,000	1,000
ΔF , kHz	100	500
T_{sweep}, ms	50	100
$V_{swfreqgen}$, kHz/	$20 \cdot 10^3$	$10 \cdot 10^3$

T_{coun}, μs	1	10	1	10
T_{nonius}, μs	0.9	9	0.9	9
N	5,009	509	50,009	5,009
δ_d	$2\cdot10^{-4}$	$2\cdot10^{-3}$	$2\cdot10^{-5}$	$2\cdot10^{-4}$
μ	$1\cdot10^{-3}$		$4\cdot10^{-5}$	
ξ	$1.27\cdot10^{-3}$		$5.08\cdot10^{-5}$	

Note: Calculation is carried out according to the formulas:

1. The total number of counting and nonius pulses $N=N_x+N_{beg}$ (N_x by formula (2), and N_{nonius} by formula (7), provided that $\Delta t_{end}=T_{count}$.
2. The relative discreteness error $\delta_d=1/N$.
3. The dynamic errors indicator μ by formula (10).
4. The shift of the maximum of the frequency response $\xi=1,27\cdot\mu$.

4. DISCUSSION

The analysis of the experimental studies of the virtual instrument for frequency response measuring and the results given in the table shows that the accuracy of frequency response measurement and electoral systems passband measurement depends on the frequency change rate of the swept frequency generator, the passband of electoral systems, as well as the frequency of counting and nonius pulses. The studies have shown that the dynamic error increases with an increase in the frequency change rate of the swept frequency generator and a decrease in the passband of four-poles (electoral systems).

The main advantages of the measuring instrument, which implements the proposed method of frequency response measurement:

1. The dynamic error is controlled due to the use of symmetrical linear frequency modulation of the swept frequency generator. Based on the results of the control, the frequency deviations, and, consequently, the frequency change rate of the swept frequency generator, at which the dynamic error can be neglected, are changed.
2. The digital measurement of the frequency response passband is performed automatically at the time when the frequency change rate of the swept frequency generator has such a value that the dynamic error can be neglected. In this case, the error in frequency response shape representation caused by the fact that the indicator beam is not stable over the sweep width does not affect the accuracy of the passband measurement.
3. The frequency response of the measured object is normalized on the indicator screen, and its vertical dimensions do not depend on the signal amplitude at the output of the swept frequency generator and the transmission frequency coefficient of the measured object.

5. CONCLUSION

The proposed method, the developed mathematical model, the structure and the virtual frequency response measuring instrument allow controlling the dynamic error and excluding or reducing it to the values at which it does not affect the accuracy of frequency response and passband measurement.

The effect of the transmission frequency coefficient of the measured object (four-pole) on the vertical dimensions of the image on the indicator screen is excluded. The error in frequency response shape representation on the screen does not affect the accuracy of the passband measurement.

It is shown that the developed measuring instrument provides an increased accuracy and reliability of the frequency response and passband measurement, and a small dynamic error caused by the finite frequency change rate of the swept frequency generator.

In the known frequency response measuring instruments, the specified error is not controlled, and with the increase in the frequency change rate, it will be increased.

The developed frequency response measuring instrument is designed to be used in automated systems for monitoring the parameters and characteristics of radio-electronic systems.

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