V R E M Y A – C H
Joint Stock Company

PHASE COMPARATOR-ANALYZERS

VCH-325, VCH-325A

Operational Manual

411146.041OM

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Contents

This Operating Manual (OM) is intended to study the device, its principle of operation, rules of operation and maintenance of the VCH-325 Phase Comparator-Analyzer (hereinafter referred to as device) and the VCH-325A Phase Comparator-Analyzer (hereinafter referred to as device with built–in reference generators).

This Operating Manual contains a description, technical specifications and information necessary for the intended use of the devices.

Operational documentation supplied with the device and the device with built-in reference generators:

– Phase Comparator-Analyser VCH-325, VCH-325A. Operational Manual 411146.041OM;

– Phase Comparator-Analyser. User Guide;

– Program for processing measurement data of frequency comparators Analyser. User guide.

The manufacturer is constantly working to improve the devices. In this regard, there may be schematic and structural changes (including in terms of the composition of the devices) that do not worsen their technical characteristics.

The external view of the phase comparator-analyzers VCH-325, VCH-325A is shown in the figure 1.1 a), b).

Figure 1.1 a) – The external view of the phase comparator-analyzer VCH-325A

Figure 1.1 b) – The external view of the phase comparator-analyzer VCH-325

1 List of abbreviations

ADC – analog-to-digital converter;

ADEV – Allan deviation;

DDS – direct digital synthesis;

DSP – digital signal processor;

FTP – file transfer protocol;

GUI – graphical user interface;

HDMI – high definition multimedia interface;

PC – personal computer;

PSD – power spectral density;

RFD – relative frequency difference;

LAN – local area network;

LCD – liquid crystal display;

VGA – video graphics array;

USB – universal serial bus.

2 Safety requirements

Carefully read the operating manual before working with the device and note the safety information.

The device must be grounded before use via protective conductor in the power cable and protective ground terminal marked ⏚ on the rear panel. To avoid the influence of static electricity all further connections must be made only with the grounded device.

ATTENTION! Grounding failure makes the device unsafe. Operation of the ungrounded device is prohibited.

Ensure that all cables are properly connected before turning on the device.

Operation of the device must comply with the electrical safety regulations in force at the operating facility.

The repair and operation of the device must be carried out by qualified personnel who have access to work with a voltage of up to 1000 V.

WARNING! Any blocks and parts replacement should only be performed when the device is de-energized and the power cord is disconnected!

3 Device description

3.1 Key applications

Phase comparator-analyzers VCH-325 and VCH-325A are designed to measure the phase and frequency relative difference and instability, as well the spectral power density of phase fluctuations of sinusoidal signals with frequencies from 1 to 100 MHz.

Phase comparator-analyzer VCH-325A has built-in generators of a highly stable sinusoidal signal with frequency ratings of 4.8 and 5.3 MHz to provide autonomous measurements.

Key applications:

- in the development, production and testing of frequency and time standards;
- in the field of ensuring the uniformity of measurements in order to determine the metrological parameters of frequency and time standards;
- in time and frequency reference systems;
- in scientific research;
- for measurements in time synchronization systems.

3.2 Operating conditions:

Normal operating conditions:

- air temperature: +20±5°C;
- relative humidity: from 30 % to 80 %;
- atmospheric pressure: from 84 kPa to 106 kPa (from 630 mm Hg to 795 mm Hg);
- power supply: (220 ± 4,4) V.

Working operating conditions (in use):

- air temperature: from +5 to +40°C;
- relative humidity: up to 90 % at air temperature +25°C;

– atmospheric pressure: from 70 kPa to 106.7 kPa (from 537 mm Hg to 800 mm Hg);

– power supply: (220 ± 22) V.

Utmost operating conditions:

– air temperature: from –50 °C to +55 °C;

– relative humidity: up to 95 %

The device retains its technical characteristics within the limits of norms after being in extreme climatic conditions, followed by exposure in normal (working) conditions for 24 hours.

3.3 Product specifications

3.3.1 The device has three sinusoidal signal inputs:

– tested signal input (device connector marked "⊖ **DUT**");

– two reference signal inputs (device connectors marked "⊖ **REF1**" and "⊖ **REF2**").

3.3.2 The device works with sinusoidal input signals with the following parameters:

– frequency range: from 1 to 100 MHz;

– RMS voltage value: from 0.6 to 1.2 V at (50±1) Ohm load.

It is allowed to connect sinusoidal signals with any frequency combinations within the range from 1 to 100 MHz to the signal inputs ports.

3.3.3 Phase comparator-analyzer VCH-325A generates output sinusoidal signals with the following parameters:

– nominal frequency: 4.8 and 5.3 MHz;

– relative frequency deviation from the nominal value: $\pm 1.0 \cdot 10^{-6}$;

– RMS voltage value: (1.0±0,2) V at (50±1) Ohm load.

The output sinusoidal signals are generated by built-in reference quartz oscillators and are used as reference signal sources when the device is operating in the "3 inputs" mode (see section 5.4.4 of this Operating Manual).

3.3.4 The device has two operating modes:

– "2 inputs" – measuring the characteristics of the frequency difference between two signals connected to the "⊖ **DUT**" and "⊖ **REF1**" ports, while the noise introduced by the device is reduced;

– "3 inputs" – measuring the characteristics of the frequency instability of three sinusoidal signals connected to the "⊖ **DUT**," "⊖ **REF1**" and "⊖ **REF2**" ports using the "three-cornered hat" method, which allows to determine the frequency instability of any pair and each individual input sinusoidal signal connected to the device's ports.

3.3.5 The device control, as well as measurement results processing, displaying and saving are carried out using a personal computer. The controlled parameters transmission and control commands receiving are carried out via the USB interface.

The personal computer used must meet the following requirements:

- processor – at least Intel Pentium-IV, 2 GHz or similar;
- RAM – at least 1 GB;
- USB port;
- a hard drive with at least 100 GB of free space;
- OS – Microsoft Windows 7, 8, 10.

3.3.6 The software implements the following functions:

- setting the operating mode and control parameters of the device;
- calculation of the relative frequency difference and the relative phase difference of sinusoidal input signals;
- calculation of statistical functions characterizing:

  a) frequency instability of pairs of sinusoidal input signals;

  b) frequency instability of each input sinusoidal signal (only in the “3 inputs” mode);

  c) power spectral density (PSD) of the phase noise of two pairs of input sinusoidal signals;

  d) power spectral density (PSD) of the phase noise of each of the input sinusoidal signals separately (only in the "3 inputs" mode);

- displaying measurement results (and calculated functions) in the form of tables and graphs on a personal computer screen;
- saving measurement results as files.

3.3.7 The bandwidth of the measuring channels when measuring frequency instability with respect to frequency fluctuations of the input sinusoidal signals can be selected from a range of 0.5; 1.5; 5; 50; 500 Hz (digitally generated).

Note: the bandwidth of measuring channels equal to 1.5 Hz in the program “Phase comparator-analyzer” is designated as the “3 Hz” band to maintain compliance with other comparators produced by JSC “VREMYA-CH” in terms of bandwidth. Explanations are provided in Appendix B of this Operating Manual.

3.3.8 The frequency range for analyzing the spectral power density of phase noise – from 0.1 Hz to 100 kHz.

3.3.9 The averaging time range corresponds to the values given in Table 3.1.

Table 3.1

Bandwidth, Hz	**Averaging time τ, s**
500	1 ms, 10 ms, 100 ms, 1 s; 10 s; 100 s; 1000 s, 1 hour, 1 day
50	10 ms, 100 ms, 1 s; 10 s; 100 s; 1000 s, 1 hour, 1 day
5	100 ms, 1 s; 10 s; 100 s; 1000 s, 1 hour, 1 day
0.5; 1.5	1 s; 10 s; 100 s; 1000 s, 1 hour, 1 day

3.3.10 The basic measurement error in terms of frequency instability (frequency instability introduced by the device – ADEV), with a zero frequency difference of the input signals, should not be more than the values given in Table 3.2.

Table 3.2

Avera-ging time, τ	**Band-width, Hz**	**Allan deviation**	
		“3 inputs” mode for input signal pair REF1-DUT (ADEV REF1-DUT), for input signal pair REF2-DUT (ADEV REF2-DUT)	**“2 inputs” mode for input signal pair REF1-DUT (ADEV REF1-DUT), “3 inputs” mode for input signal DUT, (ADEV DUT)**
0.01 s	50	$5.0{\times}10^{-12}$	$3.0{\times}10^{-13}$
0.1 s	5	$6.0{\times}10^{-13}$	$1.0{\times}10^{-13}$
1 s	0.5	$3.0{\times}10^{-14}$	$5.0{\times}10^{-15}$
10 s	1.5	$5.0{\times}10^{-15}$	$1.0{\times}10^{-15}$
100 s		$1.0{\times}10^{-15}$	$2.0{\times}10^{-16}$
1 hour		$2.0{\times}10^{-16}$	$1.0{\times}10^{-16}$
1 day		$5.0{\times}10^{-17}$	$5.0{\times}10^{-17}$

Note: the values of the basic measurement error specified in Table 3.2 are guaranteed:

– after warming up the device (the time of setting the operating mode) according to section 3.2.11 of this Operating Manual;

– when the ambient temperature changes by no more than ± 0.3 °C per hour (within the operating temperature range).

3.3.11 The device provides its specifications in working conditions after warm-up time:

– 1 hour when measuring of phase noise power spectral density and frequency instability for averaging time range from 0.01 s to 100 s inclusive;

– 4 hours when measuring of frequency instability for averaging times more 100 s.

Note: During the warm-up time, the input sinusoidal signals must be applied to the inputs of the device.

3.3.12 The basic measurement error in terms of phase noise (the power spectral density – PSD) at an input signal frequency of 5; 10; 100 MHz, depending on the frequency of analysis and operating mode, should not be more than the values given in Table 3.3.

Table 3.3

Frequency offset	**Power spectral density, dBc/Hz**					
	"3 inputs" mode for input signal pair REF1-DUT (PSD REF1-DUT), for input signal pair REF2-DUT (PSD REF2-DUT)			**"2 inputs" mode for input signal pair REF1-DUT (PSD REF1-DUT), "3 inputs" mode for input signal DUT, (PSD DUT)**		
	Frequency of input signals			**Frequency of input signals**		
	5 MHz	**10 MHz**	**100 MHz**	**5 MHz**	**10 MHz**	**100 MHz**
1 Hz	–130	–127	–107	–135	–130	–110
10 Hz	–143	–135	–115	–150	–145	–127
100 Hz	–145	–143	–127	–155	–153	–140
1 kHz	–146	–145	–133	–160	–158	–143
10 kHz	–147	–145	–135	–163	–160	–150
100 kHz	–148	–146	–140	–163	–160	–155

3.3.13 Power spectral density (PSD) of the built-in reference generators (only for the device with built-in reference generators) is not more than the values shown in the table 3.4.

Table 3.4

Frequency offset	**Power spectral density, dBc/Hz**	
	Reference generator 4.8 MHz	**Reference generator 5.3 MHz**
1 Hz	–113	–113
10 kHz	–156	–156

3.3.14 An additional measurement error - it is the amplitude of the parasitic phase modulation, in the presence of a frequency difference of the input signals, no more than 2.0×10^{-12} s.

3.3.15 An additional measurement error- it is the temperature coefficient of phase change due to a phase shift with a change in ambient temperature, no more than $5{,}0 \cdot 10^{-12}$ c/°C.

3.3.16 The device provides continuous non-stop operation in working conditions with all specifications when powered by (220±22) V, (50±2) Hz AC.

3.3.17 Power consumption is no more than 60 V·A.

3.3.18 The weight of the device is no more than 12 kg, in a corrugated cardboard box – no more than 15 kg, in a packing and transport box - no more than 45 kg.

3.3.19 Dimensions: 184×449×337 mm.

3.3.20 Reliability indicators of the device:

3.3.20.1 The average time to failure is at least 10,000 hours.

3.3.20.2 Gamma-percentage resource, with a confidence probability of 0.95 – at least 10,000 hours.

3.3.20.3 The average recovery time is no more than 4 hours.

3.3.20.4 Gamma-percentage service life, with a confidence probability of 0.95 – at least 10 years.

3.3.20.5 Gamma-percentage retention period, with a confidence probability of 0.95:

- at least 10 years in heated storages;
- at least 3 years in unheated storages.

3.3.20.6 The probability of no hidden failures during the 24–month verification interval with an average utilization factor of 0.1 is at least 0.95.

3.4 Product composition

3.4.1 The composition of the phase comparator-analyzer VCH-325 is given in Table 3.5.

Table 3.5

№	Model and designation	Quantity	Note
1.	Phase comparator-analyzer VCH-325	1	
2.	Power connecting cord SCZ-1	1	
3.	RF interconnecting SMA/N cable 685661.033	3	0.2 m
4.	RF interconnecting SMA/N cable 685661.054	1	1.5 m
5.	High Power Combiner/Splitter ZA3CS-400-3W-S	1	
6.	Interface cable USB2.0 AM/BM-1,8M	1	
7.	Operational Manual 411146.041OM	1	
8.	Phase Comparator-Analyser. User Guide	1	
9.	Program for processing measurement data of frequency comparators Analyser. User guide.	1	
10.	"Phase Comparator-Analyser". Setup program	1	On USB flash drive

3.4.2 The composition of the phase comparator-analyzer VCH-325A is given in Table 3.6.

Table 3.6

№	Model and designation	Quantity	Note
1.	Phase comparator-analyzer VCH-325A	1	
2.	Power connecting cord SCZ-1	1	
3.	RF interconnecting SMA/N cable 685661.033	3	0.2 m
4.	RF interconnecting SMA/N cable 685661.054	1	1.5 m
5.	RF interconnecting N/N cable 685661.046	2	0.25 m
6.	High Power Combiner/Splitter ZA3CS-400-3W-S	1	
7.	Interface cable USB2.0 AM/BM-1,8M	1	
8.	Operational Manual 411146.041OM	1	
9.	Phase Comparator-Analyser. User Guide	1	
10.	Program for processing measurement data of frequency comparators Analyser. User guide.	1	
11.	"Phase Comparator-Analyser". Setup program	1	On USB flash drive

3.5 Basic configuration and operation

The operation of the device is based on the principles of digital signal processing and a modern high-tech element base that allows direct digital processing of input signals to calculate their characteristics without any transformations in analog circuits (except amplification).

Circuit diagram illustrating the operating principle of the device is shown in Figure 3.1. Phase comparator-analyzer VCH-325 has four identical measuring channels designed to calculate phase difference between two analyzed signals. In the measuring channel the input signals are digitized by two analog-to-digital (ADC) converters and fed to the inputs of a two-channel mixer. Then the digitized input signals are multiplied with π/2 (cos and sin) phase shifted quadrature LO signals, obtained by direct digital synthesis (DDS) that allows to synthesize signals with frequencies close to the frequencies of the input signals:

$$\begin{aligned} I\_F &= \cos\theta_{IN}\cos\theta_{DDS} = \frac{1}{2}\left[\cos(\theta_{IN}-\theta_{DDS})+\cos(\theta_{IN}+\theta_{DDS})\right], \\ Q\_F &= \cos\theta_{IN}\sin\theta_{DDS} = -\frac{1}{2}\left[\sin(\theta_{IN}-\theta_{DDS})-\sin(\theta_{IN}+\theta_{DDS})\right]. \end{aligned} \quad (3.1)$$

$\theta_{IN} = \omega_{IN}t+\varphi_{IN}$ – input signal phase, $\theta_{DDS} = \omega_{DDS}t+\varphi_{DDS}$ – synthesized signal phase.

After multiplying signal is filtered and decimated using a comb filter (CIC filter) and digital low-pass filters cascade with finite impulse response (FIR filters on the circuit). Comb filters allow to filter the signal in an extremely narrow band, which is convenient when decimating with a high coefficient (100 or more). This procedure leaves only the low-frequency components of the signals I_F and Q_F proportional to the cosine and sine of the phase difference of the input and synthesized signals, respectively. The received signals can be interpreted as the real and imaginary parts of the input signal. Then the phase difference is calculated by dividing I_F / Q_F and taking the arc tangent of the result, these functions are implemented in the FPGA.

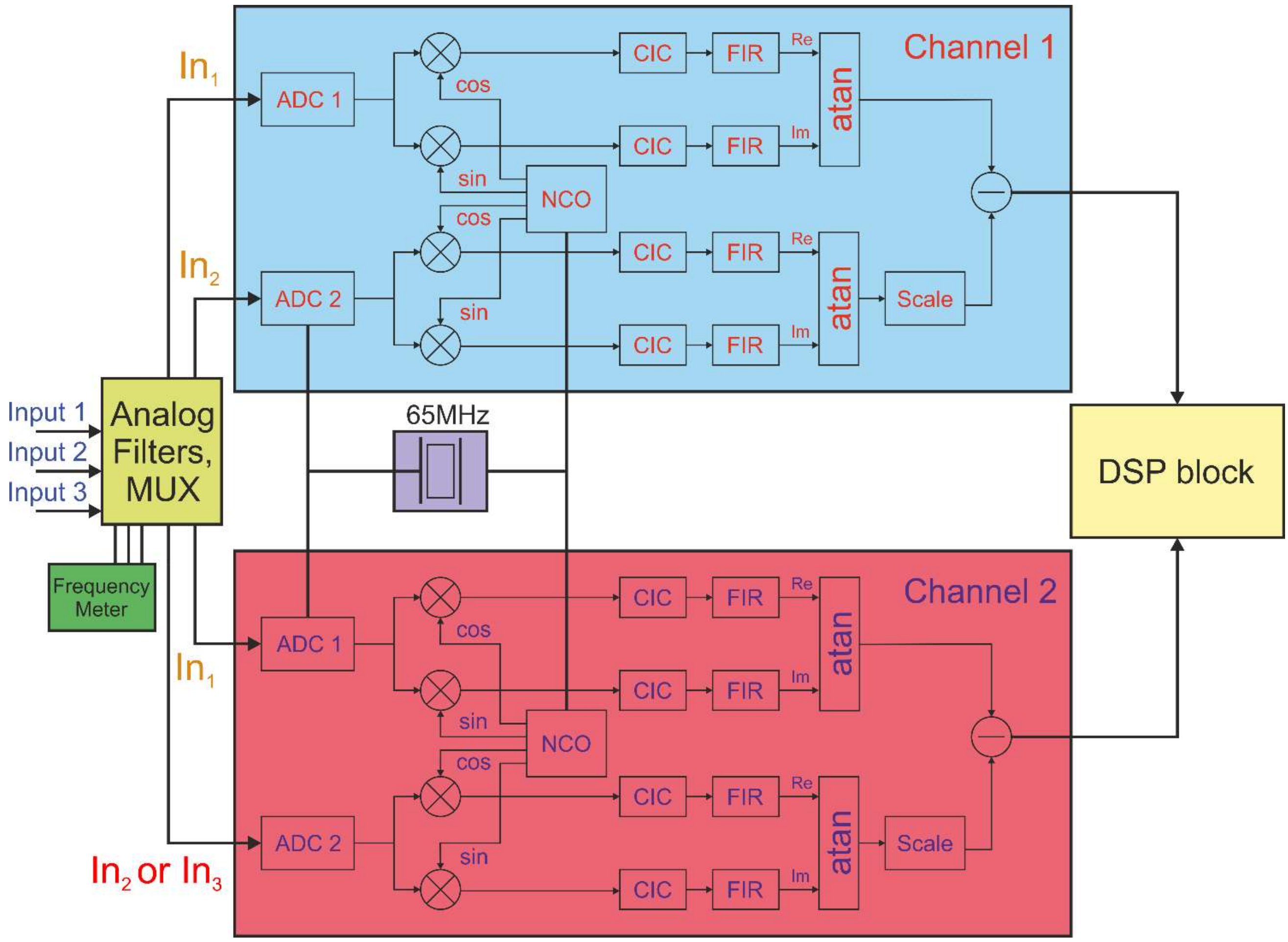

Figure 3.1. Block diagram of the signal processing path of the device

Direct digital synthesis (DDS) synthesizers are clocked by a quartz oscillator of the device that introduces noise into the measured phase difference. Two-input subtracters for samples from two ADC channels with common clock are used to suppress the additive noise. As a result, samples of the phase difference between two input signals are fed to the output of the measuring channel:

$$\varphi_{IN1,IN2} = (\theta_{IN1} - \theta_{DDS}) - (\theta_{IN2} - \theta_{DDS}) = \theta_{IN1} - \theta_{IN2}. \quad (3.2)$$

If input signals of the measuring channel have different frequencies it is necessary to scale one of the phase differences with a coefficient equal to the corresponding frequency ratio before subtraction.

In the obtained phase difference the noise of the clock generator is excluded, but the noise added by the analog-to-digital conversion remains.

The circuit (Fig. 3.1) allows to significantly reduce the influence of ADC noise on the results of measurements due to the duplication of measuring channels and use of cross-correlation processing of phase differences samples obtained in two parallel measuring channels. Measuring channels use different ADC chips, so the noise they contribute can be considered largely uncorrelated. In this case, cross-correlation processing allows to reduce the level of noise introduced by analog-to-digital converters by about 15 dB.

Phase difference samples are processed by the digital signal processor and the built-in microcomputer (the DSP block in Fig. 3.1) that calculate the relative frequency difference, ADEV, spectral density of the phase noise and perform cross-correlation signal processing.

3.6 The use of built-in reference generators

The device uses the method of three generators, which allows to increase the accuracy of measurements of input signals by eliminating instability $\sigma^2_{fc}/2$, where σ^2_{fc} – estimation of the Allan variation caused by a systematic error (offset) introduced by the comparator measuring channel (the σ^2_{fc} value can be measured in the mode when the same highly stable signal is connected to all inputs of the comparator). A four-channel circuit with dual processing of sin and cos signals reduces the measurement error introduced by comparators for the measured signal connected simultaneously to both processing channels – this is reference signal DUT.

Spectrum measurement can take place at frequencies in the range of 1-100 MHz. The spectral power density of the phase noise of the measured signals (PSD) is calculated by the periodogram method with weighing of the values in the Hann window. First, the PSD of frequency noise is calculated in each decade window using the FFT (D = 2^k), then the values are averaged:

$$S_{\mathrm{DUT}}(f) = 2{,}5 \cdot 2 \cdot \left(\frac{1}{P}\right) \sum_{p=0}^{p-1} \frac{1}{DT} \left| T \sum_{m=0}^{D-1} x^p[m] e^{-j2\pi f mT} \right|^2 \tag{3.3}$$

The PSD of the phase difference of the input signals at a certain frequency f_0 is calculated by the formula:

$$S_{\varphi}(f) = 4\pi^2 f_0^2 S_{\mathrm{DUT}}(f) \tag{3.4}$$

In the “2 inputs” mode, the PSD is always calculated by the cross-correlation method, meaning the samples in the spectral range calculated for each of the channels are multiplied and as a result, the spectral characteristic of the REF1-DUT signal pair is displayed on the screen.

At the same time, scaling to the DUT input takes place according to the formula:

$$20\, lg \left(\frac{F_{inf}(x)}{F_{ref}(y)} \right), \tag{3.5}$$

where F_{inf} (x) – the frequency of the signal applied to the DUT input and F_{ref} (y) – the frequency of the signal applied to the REF1 input when switching on the mode of two generators.

Moreover, it is required that the reduced noise of the reference signal to the measured output should be at least three times better than the noise of the measured signal for measurement reliability.

The operation of the device using built-in reference generators is based on the use of two independent reference generators, followed by the calculation of the cross-variation for the measured signal. The signals of these generators are uncorrelated as well as the noise of the comparators REF1-DUT and REF2-DUT. The measurement scheme is shown in Figure 3.2. Generators must have a frequency difference of at least 100 kHz (100 kHz is the maximum frequency of analysis in S_{DUT}). This makes it possible to exclude the occurrence of parasitic components in the measured spectrum.

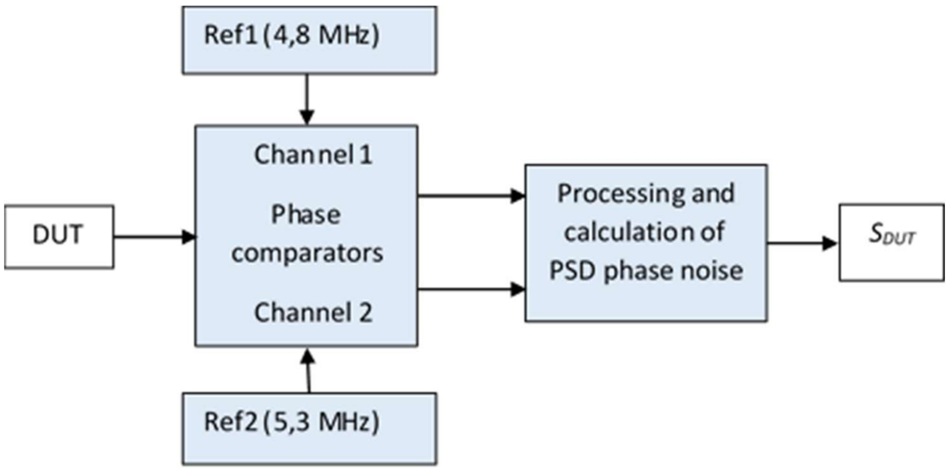

Figure 3.2. S_{DUT} measurement scheme in the mode of 2 reference generators

Here DUT is the measured signal, REF1 and REF2 are the signals of the built–in reference generators, S_{DUT} – PSD of the phase noise of the measured signal with the introduced errors.

The noise of the reference generators and phase comparators is uncorrelated, so their contribution to the total measurement error will decrease proportionally to $1/\sqrt{N}$, where N is the number of averaging of the measurement results.

Table 3.7 shows an example of reducing the noise level relative to the number of averaging of measurement results.

Table 3.7

The number of averages	10	100	1000	10000
Noise reduction, dB	–5	–10	–15	–20

4 Preparing the device for use

4.1 Operational limitations

4.1.1 It is recommended to install the device in a closed, thermostatically controlled room with limited access to personnel.

ATTENTION! Do not place the device near any engines, generators, transformers, or other equipment that can produce magnetic fields and acoustic vibrations. Placement near such equipment may impair the operation of the device.

4.1.2 The power supply of the device is a voltage (220±22) V, (50±2) Hz AC.

4.1.3 Operating conditions:

– operating temperature range: from +5 °C to +40 °C;

– relative humidity: not more than 90 %;

– the change in air temperature is not more than ± 0.3 ° C per hour when measuring frequency instability for measurement time intervals of 1 hour, 1 day.

4.1.4 Transportation conditions:

– air temperature: from –50 °C to +55 °C;

– relative humidity: not more than 90 % at +25 °C;

4.1.5 The device provides its technical characteristics in working conditions after warm-up time equal to:

– 1 hour, when measuring of phase noise spectral density and frequency instability characteristics for averaging time range from 10 ms to 100 s inclusive;

– 4 hours, when measuring of frequency instability characteristics for averaging times more 100 s.

NOTE: during the warm-up time, input sinusoidal signals must be applied to the

4.2 Installation procedure

4.2.1 Safety measures

When working with the device, follow the safety measures described in section 2 of this Operating Manual.

4.2.2 Device inspection rules

4.2.2.1 Unpack the device following the section 4.2 of this Operating Manual.

4.2.2.2 Check the completeness of the device.

4.2.2.3 Perform a visual inspection of the device following the section 4.2.2 of this Operating Manual.

4.2.3 Requirements for the device placement

4.2.3.1 The device placement must be selected taking into account the dimensions of the device 184×449×337 mm and free air convection through the ventilation openings of its body, as well as taking into account the requirements of section 4.1.1 of this Operating Manual.

4.3 Preparation for work

4.3.1 Perform a visual inspection of the device following the section 4.2.2 of this Operating Manual.

4.3.2 An AC network with a rated voltage of 220 V, 50 Hz must be connected to the workplace.

4.3.3 During operation, the ventilation openings on the device body must not be blocked by foreign objects.

4.3.4 Please read section 2 of this Operating Manual before turning on the device.

4.4 Software installation procedure

4.4.1 The procedure for installing the software on a computer is specified in section 4 of “Phase Comparator-Analyser. User Guide.”

4.4.2 Before starting to work with the device, you need to install a device driver that creates a virtual serial port when the Device is connected via USB (if none has been performed) of a personal computer following the instructions of the “Phase Comparator-Analyser. User Guide.”

5 Operating procedure

5.1 Location of controls and device connections

5.1.1 The controls and connectors of the device with built-in reference generators are shown in Figure 5.1. A description of the controls and connectors of the device with integrated reference generators is given in Table 5.1.

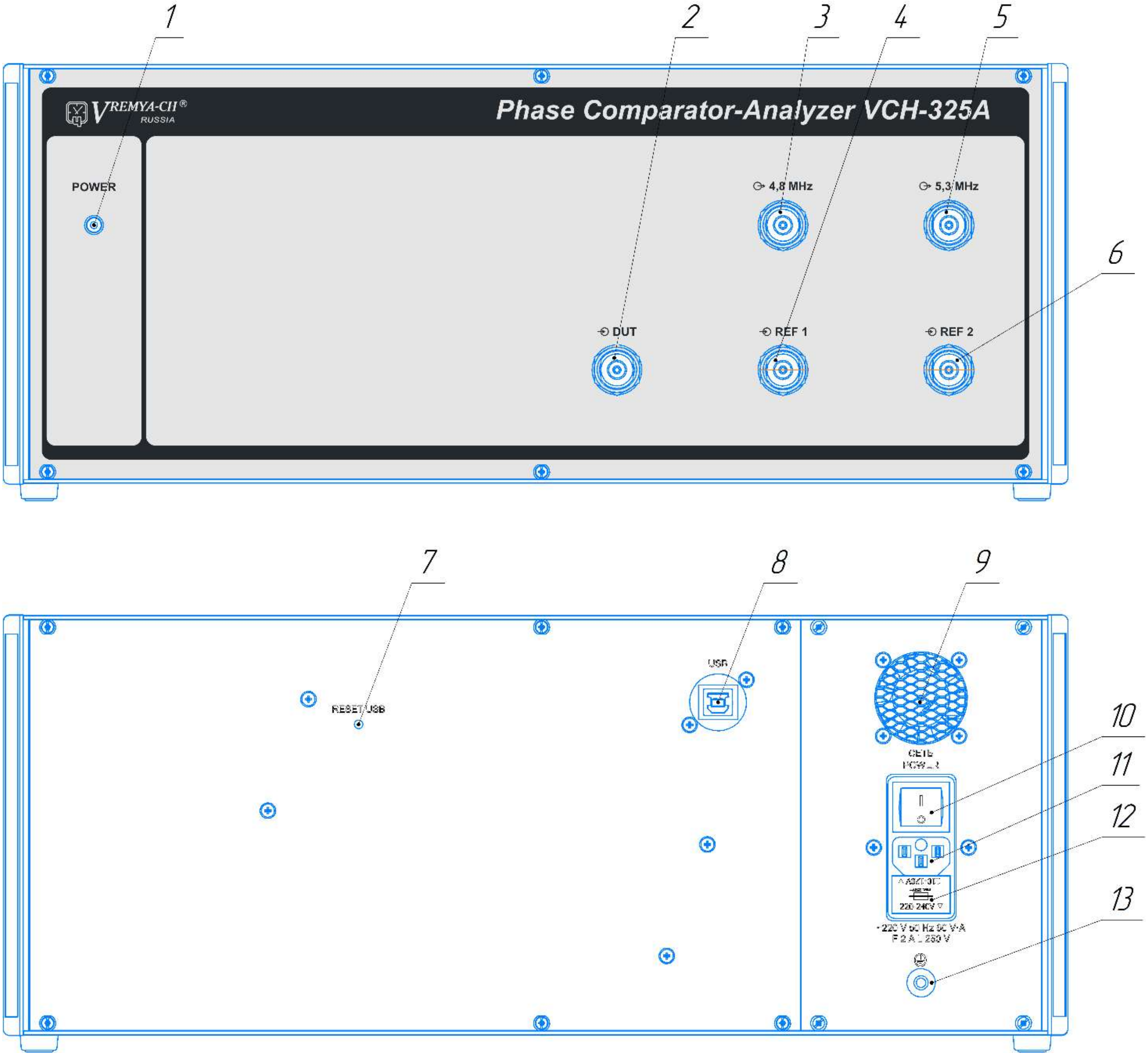

Figure 5.1 – The location of the controls and connectors of the phase comparator-analyzer with built-in reference generators VCH-325A

Table 5.1

Position (Fig.5.1)	**Designation**	**Destination**
1	**POWER**	Device system on and off indicator
2	**⊸ DUT**	Tested signal input
3	**⊸ 4.8 MHz**	Output of the reference oscillator 4.8 MHz
4	**⊸ REF1**	Reference signal input 1
5	**⊸ 5.3 MHz**	Output of the reference oscillator 5.3 MHz
6	**⊸ REF2**	Reference signal input 2
7	**RESET USB**	Restarting the USB hub
8	**USB**	Connector tor an external computer
9		Cooling fan safety net
10	**220 V 50 Hz 60 V·A**	Toggle switch for switching on the AC supply network with a voltage of 220 V
11		Fuse holders (integrated into the filter of the AC supply network)
12		Connector tor an AC power supply network with a voltage of 220 V
13	⏚	Protective grounding terminal

5.1.2 The controls and connectors of the device are shown in Figure 5.2. The description of the controls and connectors of the device is given in Table 5.2.

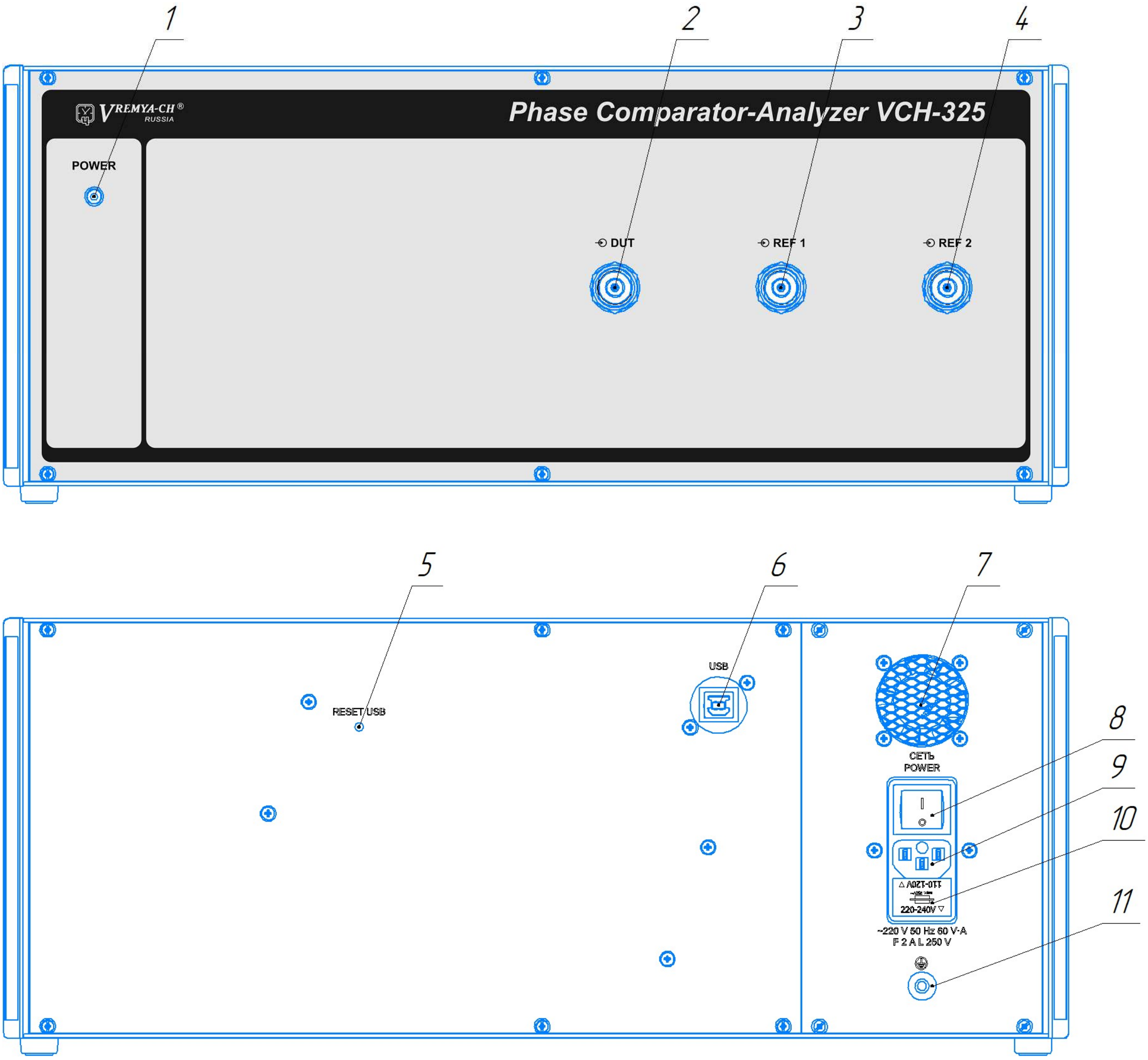

Figure 5.2 – The location of the controls and connectors of the phase comparator-analyzer VCH-325

Table 5.2

Position (Fig.5.2)	Designation	Destination
1	**POWER**	Device system on and off indicator
2	**⊸ DUT**	Tested signal input
3	**⊸ REF1**	Reference signal input 1
4	**⊸ REF2**	Reference signal input 2
5	**RESET USB**	Restarting the USB hub
6	**USB**	Connector for to an external computer
7		Cooling fan safety net
8	**220 V 50 Hz 60 V·A**	Toggle switch for switching on the AC supply network with a voltage of 220 V
9		Fuse holders (integrated into the filter of the AC supply network)
10		Connector for an AC power supply network with a voltage of 220 V
11	⏚	Protective grounding terminal

5.2 Preparation for measurement

5.2.1 Carefully read this Operating Manual and examine of the location of the controls and connections (Figures 5.1 and 5.2) and their purpose (Tables 5.1 and 5.2).

5.2.2 Ensure the device is properly grounded. Protective grounding is carried out through the protective wire of the network cable and the grounding contact of the plug of the power cord or through the protective grounding clamp. Connect the ground wire to the ground terminal before the other connections. The fasteners of the grounding terminal ⏚ and the conductors must be securely fixed.

5.2.3 Install the necessary software on your computer following the instructions in section 4.5 of this Operating Manual.

5.2.4 Connect the computer to the device by connecting the USB connector of the device to one of the USB ports of the computer using a USB interface cable.

5.2.5 Connect the power connecting cord SCZ-1 (supplied with the device) to "**220 V 50 Hz 60 V·A**" device connector.

5.2.6 Turn on the power supply of the device from the AC mains by turning "**220 V 50 Hz 60 V·A**" device switch to position "**I**" (on).

5.3 Description of the measurement process

5.3.1 Connect the needed signals according to the selected operating mode (see section 5.4 of this Operating Manual).

5.3.2 The connection is made by coaxial cables with a wave resistance of 50 Ohm and connectors of type N.

5.3.3 The device will be ready for operation with a guaranteed value of the basic measurement error in terms of frequency instability and phase noise specified in Tables 3.2-3.4 of this Operating Manual after the expiration of the operating mode setting time.

5.3.4 The configuration of the measuring device is carried out according to the instructions set out in “Phase Comparator-Analyser. User Guide.”

5.3.5 The frequency instability characteristics of the measured sinusoidal signals can be viewed during the measurement process or after the end of the measurement, following the instructions of the “Phase Comparator-Analyser. User Guide” and user guide for program for processing measurement data of frequency comparators Analyser.

5.4 Operating modes of the device and measurement error

5.4.1 “2 inputs” mode

In this mode, one of the sinusoidal input signals is connected to the “⊸ **DUT**” port and another is connected to the “⊸ **REF1”** port (Figure 5.3).

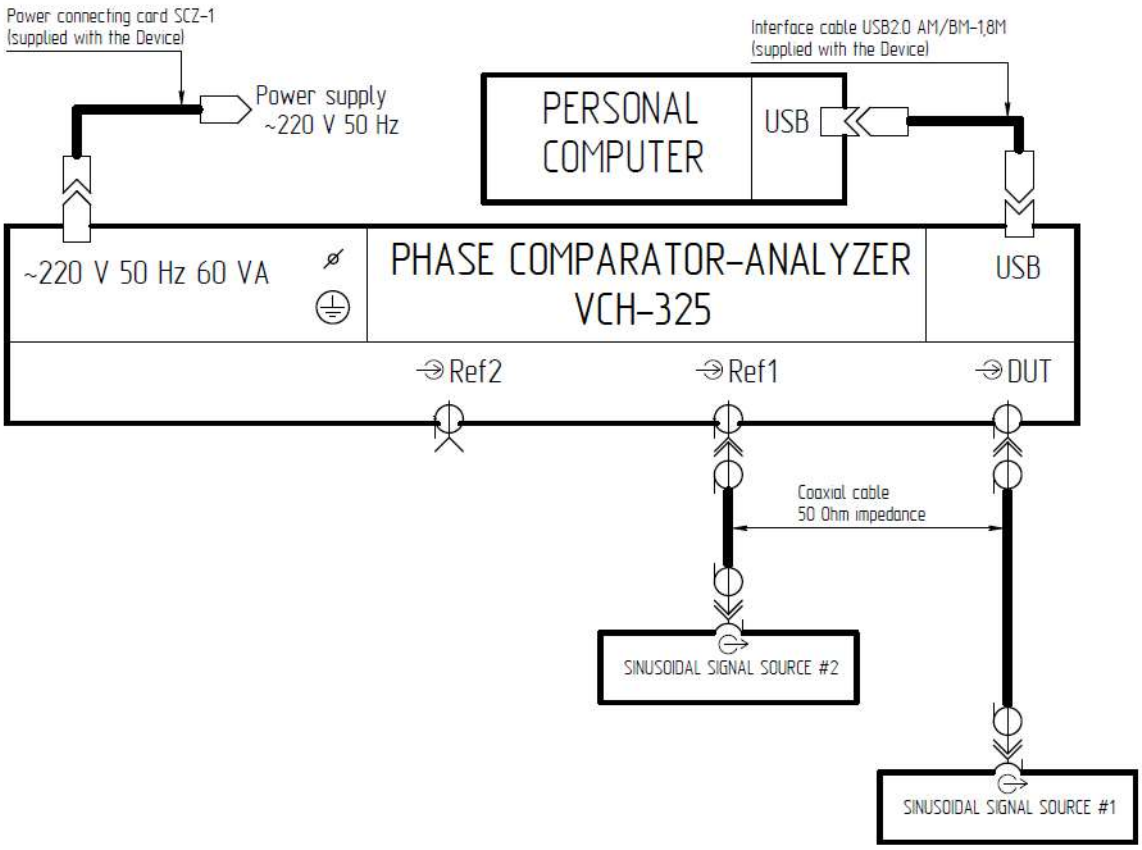

Figure 5.3 – “2 inputs” mode configuration

The input signal (DUT) connected to the “⊸ **DUT**” connector, inside the device is connected in parallel to the inputs of two identical measuring channels. The signal connected to the “⊸ **REF1**” connector, inside the device is connected in parallel to other inputs of the same two identical measuring channels (see Figure 3.1, Input 1 and Input 2). As a result, simultaneous measurement of the same value is performed (total frequency instability or total PSD of signals sent to the inputs of “⊸ **DUT**” and “⊸ **REF1**”) on two channels of the device, due to cross-correlation processing, the measurement error introduced by the measuring channels is reduced (see the basic measurement error of the device, section 3.2.10 – Table 3.2).

Appendix A (section A.2) shows an example of the functions measured in this mode and their mathematical expectations.

5.4.2 “3 inputs” mode

In this mode, the characteristics of the frequency instability are calculated using cross-correlation processing by the “three-cornered hat” method. For this method three different signals with similar frequency instability characteristics must be connected to the Device inputs. **If less than three signals are connected to the device, this mode is not available!** The input signal (DUT) connected to the “⊖ **DUT**” connector, inside the device is connected in parallel to the inputs of two identical measuring channels. Reference signal 1 (REF1) is connected to the input of one measuring channel and reference signal 2 (REF2) is connected to the input of another measuring channel.

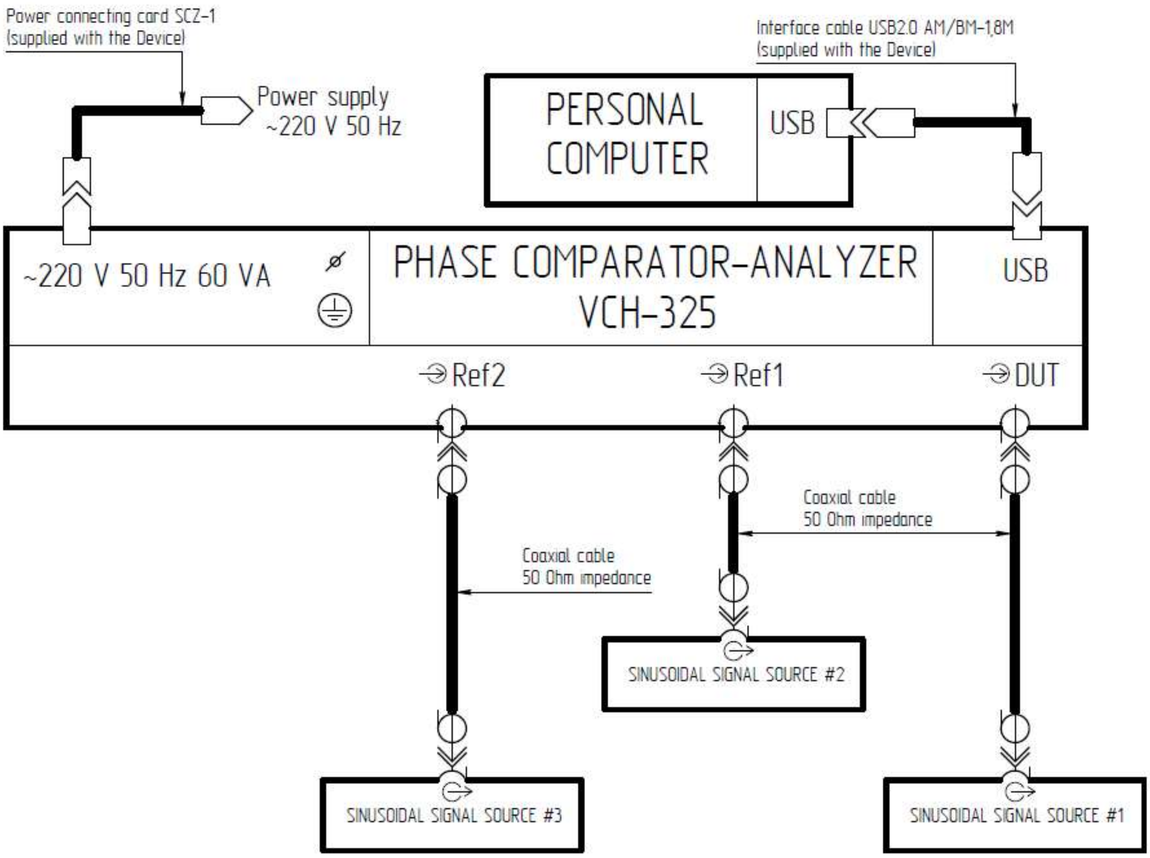

Figure 5.4 – “3 inputs” mode configuration.

It is the most advanced mode, when we use for instability measuring three oscillators and two identical measuring channels. One can see three main advantages of this mode:

- simultaneous frequency instability measuring of three oscillator's;
- calculation frequency instability of each individual oscillator;
- reduced systematic error due to frequency instability of reference signal and measuring channels.

In terms of measuring spectral characteristics, after the end of the measurements, estimates (graphs) of the PSD phase noise are obtained for a pair of signals supplied to the inputs of DUT and REF1 and for a pair of signals supplied to the inputs of REF1 and REF2, as well as the PSD for the DUT input signal, calculated by the cross-correlation method (see the basic measurement error of the device in terms of phase noise, section 3.2.12, Table 3.3). Appendix A (section A.3) shows an example of the functions measured in this mode and their mathematical expectations.

5.4.3 The measurement mode of ADEV of the signal frequency and PSD of the phase noise introduced by the device.

This mode corresponds to the method when the same signal connected to the connectors "⊖ **DUT**", "⊖ **REF1**", "⊖ **REF2**" of the device is involved in the measurements for both measuring channels, see figure 5.5.

After the end of the measurements, estimates of frequency instability and PSD are obtained, introduced by each of the measuring channels, and in addition, correlation estimates of frequency instability and PSD of the two channels.

Appendix A (section A.4) shows an example of the functions measured in this mode and their mathematical expectations.

Thus, this measurement mode allows to determine the main measurement error of the device in terms of frequency instability – frequency instability introduced by the device, ADEV (see section 3.2.10 of this Operating Manual) and in terms of phase noise – the level of intrinsic phase noise, PSD (see section 3.2.12 of this Manual operation).

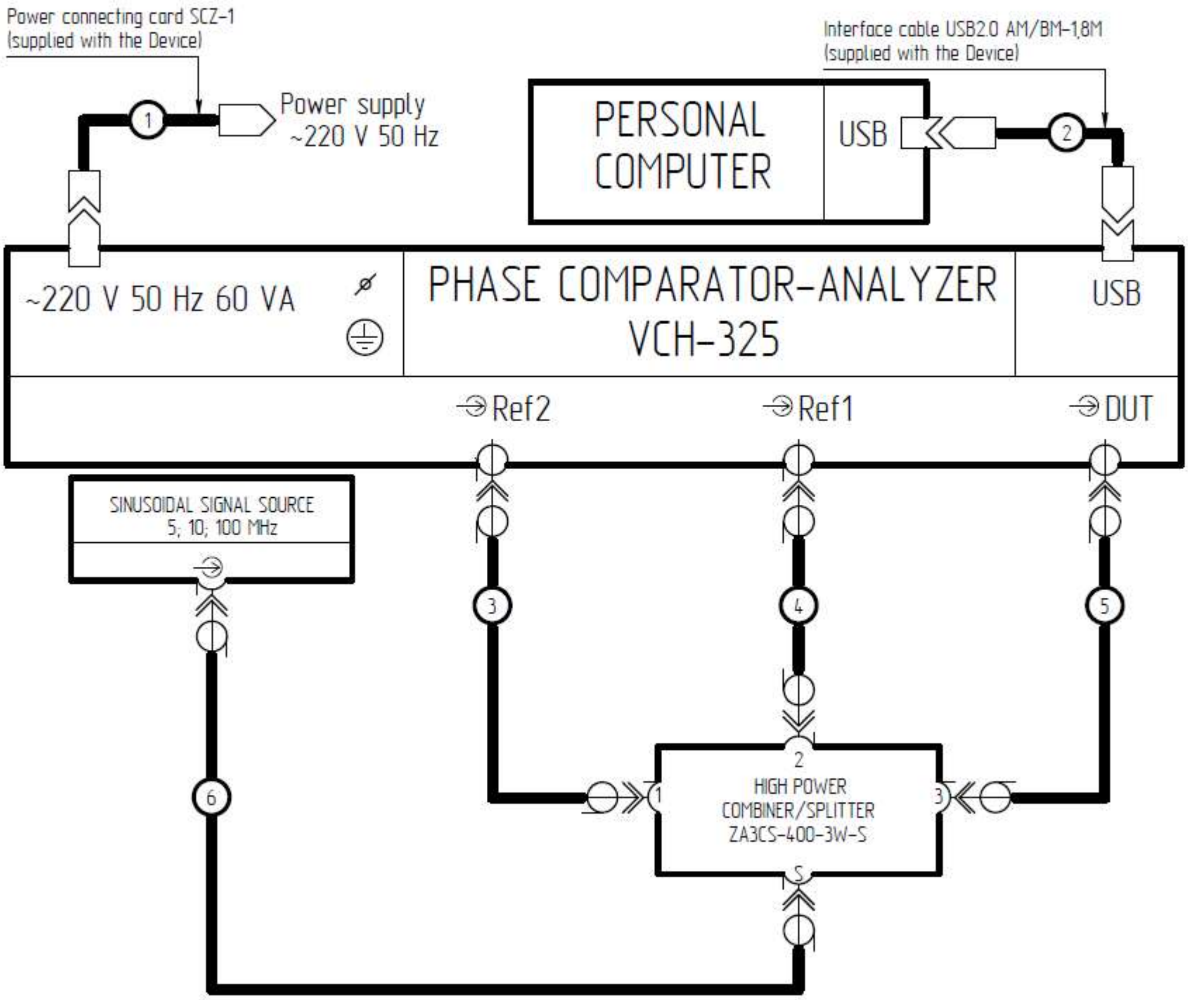

Figure 5.5 – Connection diagram of the device in the measurement mode of frequency instability and PSD introduced by measuring channels

Table 5.4

Cable number	Designation	Note
1	Power connecting cord SCZ-1	Included in the device package
2	Interface cable USB2.0 AM/BM-1,8M	Included in the device package
3, 4, 5	RF interconnecting SMA/N cable 685661.033	Included in the device package
6	RF interconnecting SMA/N cable 685661.054	Included in the device package

The cables used in the measuring circuit according to Figure 5.5 are indicated in Table 5.4.

5.4.4 Measurements relative to the built-in reference generators by the phase comparator-analyzer VCH-325A.

5.4.4.1 Measurements with respect to the built-in reference generators are carried out in accordance with the connection diagram Figure 5.6. Moreover, the input "-⊙ **REF1**" and input "-⊙ **REF2**" are supplied with signals from the outputs "⊖**4,8 MHz**" and "⊖**5,3 MHz**" of the front panel of the device with built-in reference generators with RF connecting cables 685661.046 included in the package of the device with built-in reference generators. The input "-⊙ **DUT"** of the device with built-in reference generators is supplied with the measured signal.

The cables used in the measuring circuit according to Figure 5.6 are shown in Table 5.5

After the measurements are completed, estimates of the instability of the frequency and PSD of the signal supplied to the "-⊙ **DUT**" input of the device with built-in reference generators are obtained.

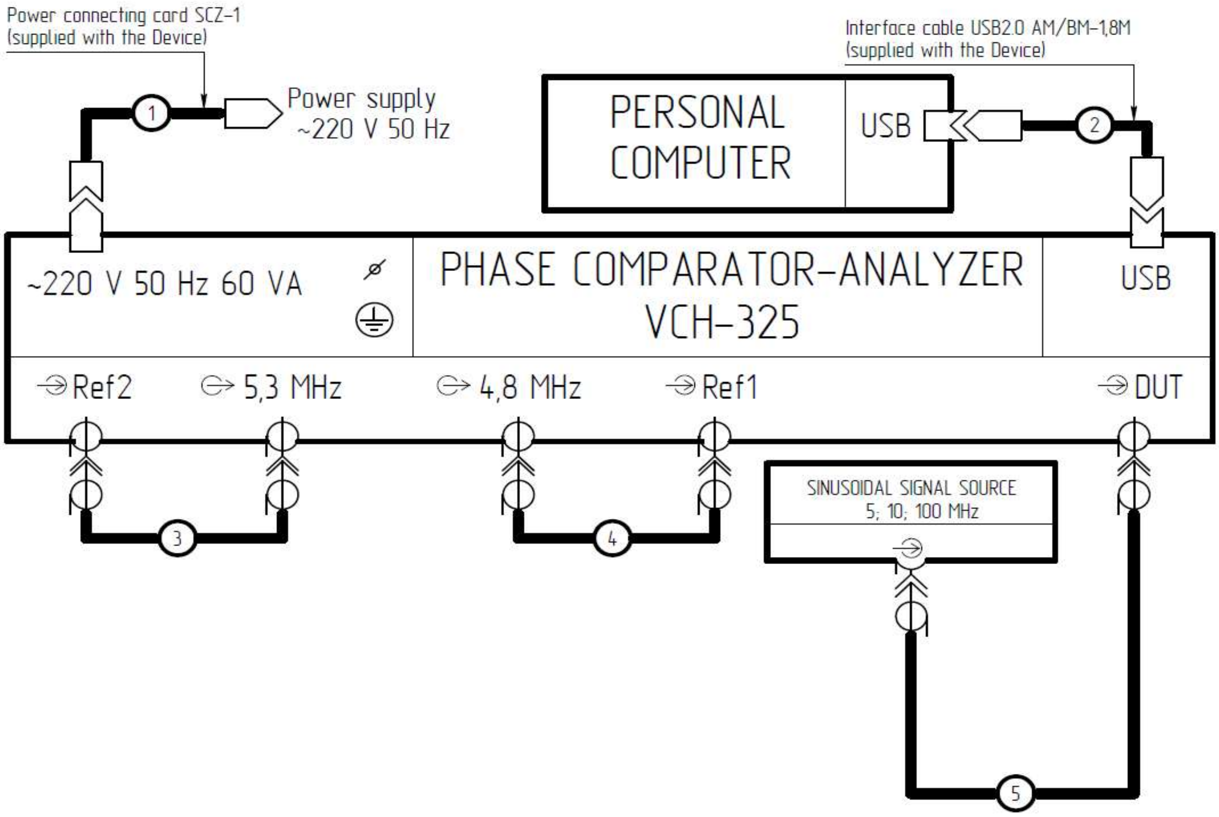

Figure 5.6 – Connection diagram of the device in the measurement mode relative to the built-in reference generators

Appendix A (section A.2) shows an example of the functions measured in this mode and their mathematical expectations.

Table 5.5

Cable number	Designation	Note
1	Power connecting cord SCZ-1	Included in the device package
2	Interface cable USB2.0 AM/BM-1,8M	Included in the device package
3, 4	RF interconnecting N/N cable 685661.046	Included in the device package
5	RF interconnecting SMA/N cable 685661.033	Included in the device package

5.4.5 The components of the measurement error

5.4.5.1 The main error is in terms of frequency instability introduced due to frequency fluctuations in the signal conversion circuit. With respect to the estimation of the measured frequency difference, this leads to a random error with a zero mean (the estimate is unbiased), and in relation to the estimation of frequency instability, this results in a bias towards large values. As an estimate of this error, the ADEV is used. This value is measured when the same signal is applied to all three outputs of the device (the frequency difference is zero) and the ADEV function is calculated. Its permissible values are given in section 3.2.10 of this Operating Manual.

5.4.5.2 The main measurement error in terms of phase noise appears in the form of its own phase noise. In relation to the estimation of the spectral power density of phase noise, this results in a bias towards higher values. The level of intrinsic phase noise (PSD) is chosen as an estimate of this error. This value is measured when the same signal is applied to all three outputs of the device (the frequency difference is zero) and the PSD function is calculated. Its permissible values are given in section 3.2.12 of this Operating Manual.

5.4.5.3 An additional error due to parasitic phase modulation in the presence of a frequency difference of the input signals is Δf. After conversion, the device has parasitic modulation with frequencies that are multiples of the difference in input frequencies – Δf.

When measuring instability, a characteristic feature of such frequency modulation is an increased spread of the measured values of the frequency difference and a significant increase in estimates of frequency instability at certain values of the measurement time intervals – τ.

When measuring phase noise, a characteristic feature of such modulation is a significant increase in the estimates of PSD in the area of the frequency difference of the analyzed signals.

To reduce this component of the error, the measurement of frequency instability and PSD should be carried out at the lowest possible value Δf.

5.4.5.4 Error due to a finite number of measurements – N. This only applies to frequency instability. The estimate of this error is the square root of the relative variance of the instability measurement results at a given value of N. It can be represented with a sufficient degree of accuracy by the expression $1/\sqrt{N}$.

5.4.5.5 Additional error due to changes in ambient temperature. Changes in ambient temperature cause additional phase shifts in the signal conversion path.

The slow and smooth drift of the ambient temperature leads to an additional measurement error of the difference and frequency instability for measurement time intervals of more than 100 s. Rapid, short-term changes in ambient temperature can lead to additional measurement error of frequency instability in the range of measurement time intervals from 1 to 10 seconds.

When measuring phase noise, a change in ambient temperature leads to an increase in the estimate of the PSD of phase noise in the low-frequency region of the analysis on the left side of the PSD graph.

All characteristics are guaranteed in the device at a rate of change of ambient temperature of no more than 0.3 ° C / hour.

6 Verification of the device

6.1 Introduction

This procedure is used to verify the basic measurement errors:

– frequency instability noise floor (the Allan deviation – ADEV) for averaging times 0.01 s, 0.1 s, 1 s, 10 s, 100 s;

– phase noise floor L(f), (the Power spectral density – PSD), for the input sinusoidal signal frequency 5 or 10 MHz (by user's choice).

6.2 Service Equipment Required

Equipment required for the verification procedure is listed in Table 8.

Any equipment that satisfies the critical specification listed in the table 8 may be substituted for the recommended models.

Table 8 – Equipment required for the verification procedure

Instrument (Quantity)	Required Characteristics	Model
Sinusoidal signal sourse (1 piece)	- Outputs - number of ports: 2 - frequency: 5 MHz, 10 MHz - amplitude: (1.0±0.2) Vrms - load impedance: 50 Ohm - phase noise spectral density: not more –140 dBc/Hz - stability, two-samples Allan variance for averaging time 1 s: not more 5.0×10^{-11}	——
Three way reactive power divider (1 piece)	Connectors: SMA jack (4 pieces). Impedance: 50 Ohm. Frequency range: 5 to 10 MHz.	High Power Combiner/Splitter ZA3CS-400-3W-S (supplied with the device)

Instrument (Quantity)	Required Characteristics	Model
Special cables (3 pieces)	Coaxial cable, length: 0.2 to 0.5 meters Connectors: SMA cable plug, N cable plug. Impedance: 50 Ohm.	RF interconnecting SMA/N cable 685661.033 (supplied with the device)
Special cable (1 piece)	Coaxial cable, length: 1.5 to 3.0 meters Connectors: SMA cable plug, N cable plug. Impedance: 50 Ohm.	RF interconnecting SMA/N cable 685661.054 (supplied with the device)

6.3 Environmental Control

6.3.1 The quality of the measurements made by the device is highly influenced by environmental conditions.

6.3.2 The device and all test equipment used during this verification procedure shall be shielded from air drafts. Also, the device and all test equipment used during this verification procedure shall be isolated from all sources of shock and vibration.

6.3.3 Verification procedure operating conditions:

– Ambient temperature range: +5 °C to +40 °C;
– Ambient temperature change: no more than 1 °C/hour;
– Relative humidity: 30 % to 80 %;
– Atmospheric pressure: 70 kPa – 106,7 kPa (537 mm Hg to 800 mm Hg);
– Power supply: (220±22) V, (50±2) Hz AC.

6.4 Test A. The frequency instability noise floor checking

6.4.1 Make preparation for measurement according section 5.2

6.4.2 For the frequency instability noise floor checking use the configuration shown in Figure 28.

The frequency of sinusoidal signal sourse may be 5 MHz, 10 MHz or 100 MHz by user's choice.

Use RF interconnecting SMA/N cables 685661.033 and the device connectors "⊸ **DUT**", "⊸ **REF1**", "⊸ **REF2**".

6.4.3 Set "3 inputs" mode and run measurement by pressing the **"START"** button in the program menu.

6.4.4 Allow the device to collect data until the data collection period is in the range 150 to 200 minutes.

CAUTION! Bumping or moving cables or the device or the signal source will invalidate the following tests.

6.4.5 Finish measurement by pressing the **"STOP"** button in the program menu.

6.4.6 Click on the "ADEV" tab to go to the ADEV table with calculated ADEV values for a pair of REF1-DUT and REF2-DUT signals (ADEV REF1-DUT, ADEV REF2-DUT).

Click on the tab "50Hz" in the program menu on the left.

Record the calculated ADEV values for pair of signals REF1-DUT and REF2-DUT (ADEV REF1-DUT, ADEV REF2-DUT) at tau 0.01 s, 0.1 s to the device checking report (the Table – Test A. The frequency instability noise floor checking).

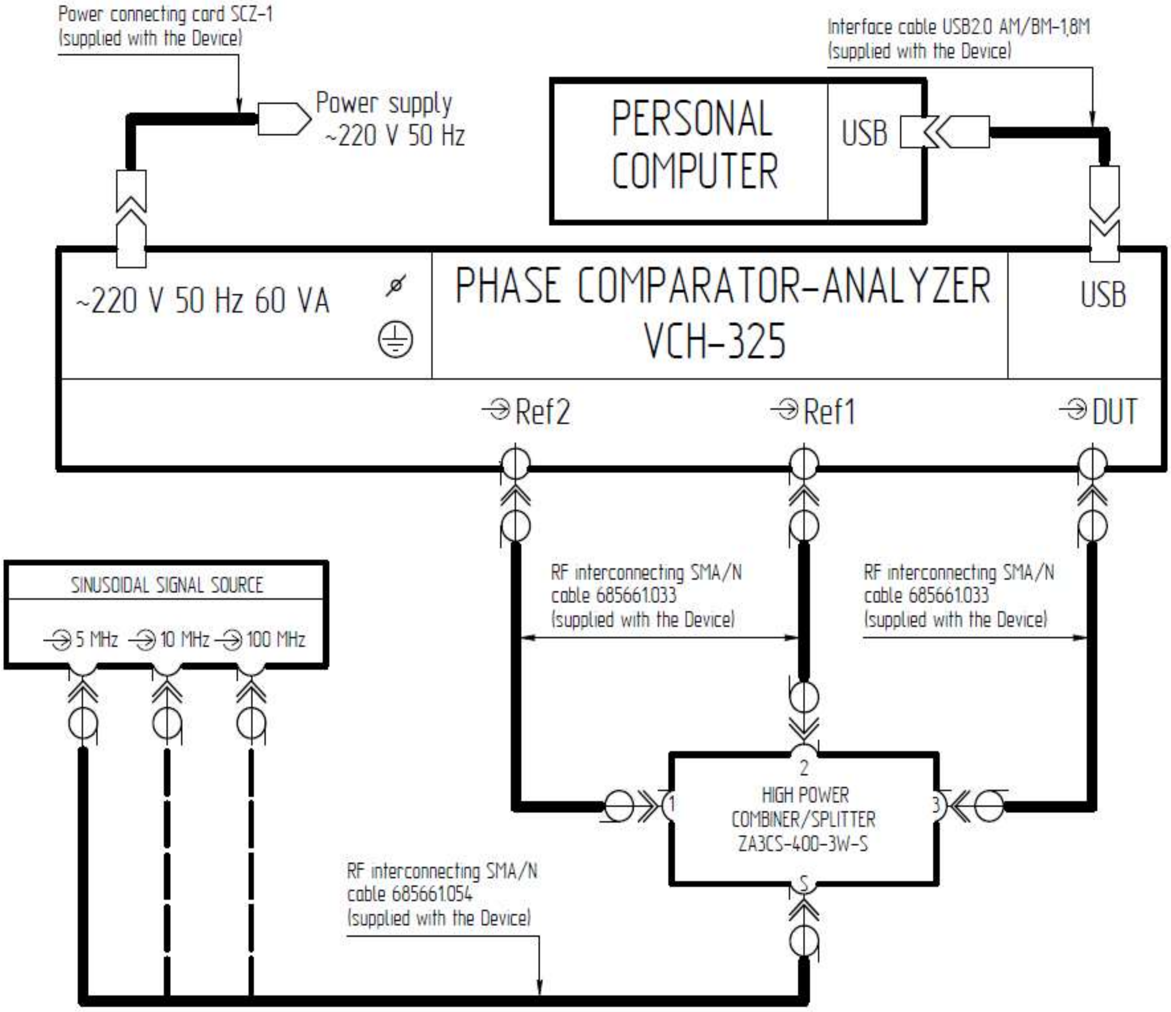

Figure 28. Noise floor checking configuration

6.4.7 Click on the "Cross ADEV" tab to go to the ADEV table with the calculated ADEV values for individual signal DUT (ADEV DUT).

Record the calculated ADEV values for individual signal DUT (ADEV DUT) at tau 0.01 s, 0.1 s to the device checking report (the Table – Test A. The frequency instability noise floor checking).

6.4.8 Click on the "ADEV" tab to go to the ADEV table with the calculated ADEV values for pair of signals REF1-DUT and REF2-DUT (ADEV REF1-DUT, ADEV REF2-DUT).

Click on the tab "0.5 Hz" in the program menu on the left.

Record the calculated ADEV values for pair of signals REF1-DUT and REF2-DUT (ADEV REF1-DUT, ADEV REF2-DUT) at tau 1 s, 10 s, 100 s to the device verification report (the Table – Test A. The frequency instability noise floor checking).

6.4.9 Click on the "ADEV" tab to go to the ADEV table with the calculated ADEV values for individual signal DUT (ADEV DUT).

Record the calculated ADEV values for individual signal DUT (ADEV DUT) at tau 1 s, 10 s, 100 s to Device checking report (the Table – Test A. The frequency instability noise floor checking).

6.4.10 Verify that the calculated ADEV values for pair of signals REF1-DUT, REF2-DUT (ADEV REF1-DUT, ADEV REF2-DUT) and for individual signal DUT (ADEV DUT) at tau 0.01 s, 0.1 s, 1 s, 10 s, 100 s are less than the value in the table 2 at each specified averaging time.

6.5 Test B. The phase noise floor checking

6.5.1 This checking uses the data just collected during the frequency instability noise floor checking.

6.5.2 Click on the “Spectra” tab to go to the PSD graphs calculated for pair of signals REF1-DUT and REF2-DUT (PSD REF1-DUT, PSD REF2-DUT), DUT (PSD DUT).

Record the PSD values for pair of signals REF1-DUT and REF2-DUT (PSD REF1-DUT, PSD REF2-DUT) at frequency offset 1 Hz, 10 Hz, 100 Hz, 1 kHz, 10 kHz, 100 kHz to the device checking report (the Table – Test B. The phase noise floor checking).

Record the PSD values for individual signal DUT (PSD DUT) at frequency offset 1 Hz, 10 Hz, 100 Hz, 1 kHz, 10 kHz, 100 kHz to the device checking report (the Table – Test B. The phase noise floor checking).

6.5.3 Verify that the calculated PSD values for pair of signals REF1-DUT and REF2-DUT (PSD REF1-DUT, PSD REF2-DUT) and for individual signal DUT (PSD DUT) are less than the value in the table 3 at each specified frequency offset and frequency of the input sinusoidal signal.

6.6 Device verification report

Below is a possible form of the device verification report.

Table A records the calculated ADEV values obtained in the execution of section 6.4.

Table B records the calculated PSD values obtained in the execution of section 6.5.

Device verification report

Date ________________________________

Model Type ________________________________

Serial Number ________________________________

Table A – Test A. The frequency instability noise floor checking

Averaging time, tau	**Allan deviation**		
	ADEV REF1-DUT	**ADEV REF2-DUT**	**ADEV DUT**
0. 01 s			
0.1 s			
1 s			
10 s			
100 s			

Table B – Test B. The phase noise floor checking

Frequency offset	**Power spectral density, dBc/Hz**		
	PSD REF1-DUT	**PSD REF2-DUT**	**PSD DUT**
1 Hz			
10 Hz			
100 Hz			
1 kHz			
10 kHz			
100 kHz			

7 Technical maintenance

7.1 Safety measures

7.1.1 When carrying out maintenance work on the device, the safety measures listed in section 2 of this manual must be observed.

7.1.2 The types of technical condition and maintenance control, as well as the frequency and work performed during their implementation, are determined by this Manual.

7.2 Control inspection

7.2.1 Control inspection of the device during operation is the main type of the device technical condition monitoring.

7.2.2 Control inspection is carried out by the person operating the device when preparing the device for its intended use.

Control inspection of the device includes:

– external inspection to check the absence of mechanical damage, reliability of fastening of controls and connections, integrity of insulation and paint coatings, serviceability of RF connection cables and power cable;

– checking the cleanliness of the connectors of the device for connecting the input sinusoidal signals marked “–⊙ **DUT**”, “–⊙ **REF1**”, “–⊙ **REF2**”;

– checking the cleanliness of the connectors “⊖→**4,8 MHz**” and “⊖→**5,3 MHz**” of the phase comparator-analyzer VCH-325A with built-in reference generators;

– checking the cleanliness of the cable connectors and the power divider included in the delivery package of the device;

– checking the status of the labels.

7.3 Maintenance

7.3.1 Maintenance includes the following types:

– daily maintenance;

– maintenance No. 1;
– maintenance No. 2.

7.3.2 Daily maintenance is carried out when preparing the device for its intended use, combined with a control inspection and includes:

– elimination of deficiencies identified during the inspection;
– removal of dust and moisture from external surfaces.

Daily maintenance is carried out by the personnel operating the device, without opening it.

7.3.3 Maintenance No. 1 is carried out before preparing the device for use and when placing the device in short-term storage.

Maintenance No. 1 includes:

– elimination of deficiencies identified during the inspection;
– removal of dust and moisture from external surfaces;
– other operations specified in the operational documentation;
– checking the condition and completeness of the device;
– verification of the correctness of maintenance of operational documentation;
– elimination of the shortcomings identified in the Maintenance No. 1 process.

Maintenance No. 1 is carried out by the personnel operating the device, without opening it.

7.3.4 Maintenance No. 2 is carried out with the frequency of verification of the device and is combined with it, as well as when placed for long-term (more than two years) storage and includes:

– Maintenance No. 1 operations;
– verification to ensure the required metrological characteristics;
– preservation of the device (performed when placing the device for long-term storage).

Maintenance No. 2 is carried out by the person operating the device, with the exception of verification, which is performed by the forces and means of metrological services.

7.3.5 Before starting to perform various types of maintenance, operational documentation should be prepared and rectified ethyl alcohol and bleached cotton fabric should be obtained for the connector cleaning operation.

8 Repair

If the device does not comply with the technical data or for other reasons that make it impossible to continue using it, the device must be repaired.

The repair of the device and its components requires complex special equipment and therefore can only be carried out by the manufacturer.

9 Transportation and storage

9.1 Transportation

9.1.1 The device allows transportation in closed vehicles of any kind in a package under extreme conditions of transportation for electronic measuring devices.

9.1.2 The climatic conditions of transportation must not exceed the specified limit conditions:

– ambient temperature from minus 50 °C to plus 55 °C;

– relative humidity of 95% at a temperature of plus 25 °C.

9.1.3 When transported by plane, the device must be placed in a heated, sealed compartment.

9.1.4 After staying in extreme conditions, the exposure time in normal (working) conditions is at least 24 hours. In case the device stays in conditions of temperature below zero, in order to prevent the formation of condensation inside the device, the device should be kept in a warm room, without violating the integrity of the package, for at least 24 hours.

9.1.5 During transportation, protection against atmospheric precipitation and dust must be provided.

9.1.6 Holds of ships, car bodies used to transport the device should not have traces of cement, coal, chemicals, etc.

9.1.7 Before commissioning, the device should be stored in a warehouse in the packaging of the manufacturer at ambient temperatures from 0 °C to plus 40 °C and relative humidity of the ambient air up to 80% at a temperature of plus 35 °C.

9.1.8 The device should be stored without packaging at ambient temperatures from plus 10 °C to plus 35 °C and relative humidity of the ambient air up to 80% at a temperature of plus 25 °C.

9.1.9 When the device is placed in storage, the device is repackaged. The repackaging operations are specified in clause 4.2.3 of this Operating Manual.

9.1.10 Upon receipt of the device for storage (removal of the device from storage), it is necessary to make a note in the form on the date of installation of the device for storage (removal from storage) in the “Storage” section.

9.1.11 The storage room of the device must be free of dust, acid and alkali vapors and other harmful impurities that cause corrosion.

9.1.12 No special measures are required to ensure the required storage duration.

10 Disposal

A device that has fallen into disrepair does not pose an environmental hazard when disposed of. The device is disposed of in accordance with the procedure established by the consumer.

Appendix A

Examples of calculation functions of various modes of operation of the device

A.1 Designations and abbreviations

A.1.1 This Appendix shows examples of measured functions and their mathematical expectations for the operating modes of the device specified in section 5.4.

To simplify the writing of calculated functions, the following symbols of the input sinusoidal signals of the device are used in paragraphs A.1 and A.2:

– the signal connected to the DUT input (connector marked "⇾ **DUT**") is designated as X;

– the signal connected to the REF1 input (connector marked "⇾ **REF1**") is designated as Y_1;

– the signal connected to the REF2 input (connector marked "⇾ **REF2**") is designated as Y_2;

A.1.2 To simplify the writing of calculated functions in the tables of Appendix A, the following abbreviations are used:

1) RFD – relative frequency difference

RFD $\{XY_1\}$, RFD $\{XY_2\}$, RFD $\{Y_1Y_2\}$ – RFD for the corresponding pairs of signals X, Y_1, Y_2.

2) ADEV – Allan deviation

– ADEV $\{XY_1\}$, ADEV $\{XY_2\}$, ADEV $\{Y_1Y_2\}$ – ADEV for the corresponding pairs of signals X, Y_1, Y_2.

– ADEV $\{X\}$, ADEV $\{Y_1\}$, ADEV $\{Y_2\}$ – ADEV for the corresponding individual signals X, Y_1, Y_2.

A.1.3 To simplify the writing in the tables of the text of Appendix A, the following designations are used:

1) $y_x^N, y_{y1}^N, y_{y2}^N$ – averaged over the entire observation time interval ($N\cdot\tau$), the relative deviation of the frequency of signals X, Y_1, Y_2 from the nominal frequency;

2) y_{c1}^N, y_{c2}^N – the relative deviation of the average frequency difference introduced by the measuring channel CHANNEL 1, CHANNEL 2;

3) $\sigma_x, \sigma_{y1}, \sigma_{y2}, \sigma_{c1}, \sigma_{c2}$ – ADEV for signals DUT, REF1, REF2 and measuring channels CHANNEL 1, CHANNEL 2 respectively.

A.2 “2 inputs” mode

Calculation functions and their mathematical expectations are given in Table A.1.

To simplify the writing of the calculated functions in Table A.1, the following conventions are used for the input sinusoidal signals of the device:

– the signal connected to the DUT input (connector marked “⊸ **DUT**”) is designated as X;

– the signal connected to the REF1 input (connector marked “⊸ **REF1**”) is designated as Y_1;

Table A.1 – Calculation functions for two-channel measurements in the “2 inputs” mode

Pos. number	Calculated function	Mathematical expectation	Note
1	RFD {XY_1}	$y_x^N - y_{y1}^N + y_{c1}^N$	Measured by CHANNEL 1
2	RFD {XY_1}	$y_x^N - y_{y1}^N + y_{c2}^N$	Measured by CHANNEL 2
3	ADEV{XY_1}	$\sqrt{\sigma_x^2 + \sigma_{y1}^2 + \sigma_{c1}^2}$	Measured by CHANNEL 1
4	ADEV {XY_1}	$\sqrt{\sigma_x^2 + \sigma_{y1}^2 + \sigma_{c2}^2}$	Measured by CHANNEL 2
5	ADEV{XY_1}	$\sqrt{\sigma_x^2 + \sigma_{y1}^2}$	Calculation by the cross-correlation method between measurements CHANNEL 1 и CHANNEL 2
6	ADEV{XY_1- XY_1}	$\sqrt{\sigma_{c1}^2 + \sigma_{c2}^2}$	Total instability of CHANNEL 1 and CHANNEL 2

Functions with pos. numbers 3 and 4 – table A.1 are the values of the ADEV{XY_1}, directly measured by the device and containing a systematic error due to the reference signal (the signal connected to the input of REF1) and measuring channels (CHANNEL 1 or CHANNEL 2, respectively).

The function with pos. number 5, table A.1 is the value of the ADEV{XY_1}, calculated by the cross-correlation method and giving an estimate of the total frequency instability without bias due to the noise of the measuring channels.

At the same time, an estimate of the frequency instability introduced by the measuring channels can be obtained at the same observation time interval (function with pos. number 6, table A.1).

It should be remembered that the values of mathematical expectations are obtained assuming the simultaneity of measurements in channels and the uncorrelation of all noise of the measured signals and parasitic interference.

A.3 “3 inputs” mode

Calculation functions and their mathematical expectations are given in Table A.2.

To simplify the writing of the calculated functions in Table A.2, the following conventions are used for the input sinusoidal signals of the device:

– the signal connected to the DUT input (connector marked “⊸ **DUT**”) is designated as X;

– the signal connected to the REF1 input (connector marked “⊸ **REF1**”) is designated as Y_1;

– the signal connected to the REF2 input (connector marked “⊸ **REF2**”) is designated as Y_2;

Table A.2 – Calculation functions for two-channel measurements in the “3 inputs” mode

Pos. number	Calculated function	Mathematical expectation	Note
1	RFD {XY_1}	$y_x^N - y_{y1}^N + y_{c1}^N$	Measured by CHANNEL 1
2	RFD {XY_2}	$y_x^N - y_{y2}^N + y_{c2}^N$	Measured by CHANNEL 2
3	RFD {Y_1Y_2}	$y_{y1}^N - y_{y2}^N + y_{c1}^N - y_{c2}^N$	
4	ADEV{XY_1}	$\sqrt{\sigma_x^2 + \sigma_{y1}^2 + \sigma_{c1}^2}$	Measured by CHANNEL 1
5	ADEV{XY_2}	$\sqrt{\sigma_x^2 + \sigma_{y2}^2 + \sigma_{c2}^2}$	Measured by CHANNEL 2
6	ADEV{Y_1Y_2}	$\sqrt{\sigma_{y1}^2 + \sigma_{y2}^2 + \sigma_{c1}^2 + \sigma_{c2}^2}$	
7	ADEV{Y_1}	$\sqrt{\sigma_{y1}^2 + \sigma_{c1}^2}$	Calculation by the cross-correlation method
8	ADEV{Y_2}	$\sqrt{\sigma_{y2}^2 + \sigma_{c2}^2}$	Calculation by the cross-correlation method
9	ADEV{X}	$\sqrt{\sigma_x^2}$	Calculation by the cross-correlation method

The function with pos. number 4, table A.2 is the value of the ADEV{XY_1}, directly measured by the device and containing a systematic error due to the reference signal (the signal connected to the input of REF1) and the measuring channel (CHANNEL 1) of the device.

The function with pos. number 5, table A.2 is the value of the ADEV{XY_2}, directly measured by the device and containing a systematic error due to the reference signal (the signal connected to the input of the REF2) and the measuring channel (CHANNEL 2) of the device.

The instability characteristics introduced by the measuring channels CHANNEL 1, CHANNEL 2 – y_{c1}^N, σ_{c1}, y_{c2}^N, σ_{c2} are measured according to the same program when the same signal is applied to all three inputs of the device.

If we are interested in the frequency instability of the signals Y_1, Y_2 (supplied to the inputs REF1 and REF2), then the first and third terms of the expressions of the mathematical expectation for the function with pos. numbers 4 and 5 of Table A.2 represent a systematic measurement error (shift) due to the signal connected to the input of the DUT and measuring channels (CHANNEL 1 or CHANNEL 2, respectively).

The functions with pos. numbers 7 and 8, table A.2 are the values of ADEV{Y_1}, ADEV{Y_2} calculated for individual signals, the systematic error of which is determined only by the instability introduced by the measuring channels of the device (CHANNEL 1 or CHANNEL 2, respectively).

The function with pos. number 9, table A.2 is the calculated value of the ADEV{X} for a single signal, which does not have a systematic error.

Only the signal DUT connected to the DUT input of the device can be measured without systematic error (function with pos. number 9 – ADEV{X}).

A.4 Frequency instability (introduced by measuring channels) measurement mode

Calculation functions and their mathematical expectations are given in Table A.3.

To simplify the writing of the calculated functions in Table A.3, the signal connected to the inputs of the DUT, REF1 and REF2 of the device is designated as Y_1.

Table A.3 – Calculation functions for measuring frequency instability introduced by measuring channels

Pos. number	Calculated function	Mathematical expectation	Note
1	RFD {Y_1 Y_1}	0	Measured by CHANNEL 1
2	RFD {Y_1 Y_1}	0	Measured by CHANNEL 2
3	ADEV{Y_1 Y_1}	$\sqrt{\sigma_{c1}^2}$	Measured by CHANNEL 1
4	ADEV {Y_1 Y_1}	$\sqrt{\sigma_{c2}^2}$	Measured by CHANNEL 2
5	ADEV{Y_1 Y_1}	0	Calculation by the cross-correlation method between measurements CHANNEL 1 и CHANNEL 2

The function with pos. number 5 of Table A.3 is the value of the ADEV{Y_1 Y_1}, calculated by the cross-correlation method and giving an estimate of the frequency instability introduced by the measuring channels in the “3 inputs” mode when measuring the DUT signal. This value meets the requirements for the basic measurement error in terms of frequency instability (see section 3.3.10 of this Operating Manual).

Appendix B

Explanation of the bandwidth of the measuring channels of the device

The spectrum of a carrier frequency signal consists of both negative and positive frequencies. This sometimes leads to ambiguity, because sometimes it is said only about the positive half of the spectrum and an expression such as

$$B=2W \tag{B.1}$$

where B – total bandwidth (i.e. the maximum bandwidth of a carrier-modulated RF signal and the minimum bandwidth of a physical channel with bandwidth); W – the positive part of the total bandwidth.

Below, in the text of this Appendix, explanations are provided about the correspondence of the bandwidth indicated in the program “Phase comparator-analyser” as “3 Hz,” to the real bandwidth of 1.5 Hz.

The designation of the bandwidth as “3 Hz” is related to the following reasoning:

“The frequency response of the comparator, taking into account analog filtering and digital averaging with respect to frequency fluctuations, is calculated using the formula (B.1).

$$W^2(f)=\frac{f_h^2}{f^2+f_h^2}\frac{Sin^2(L\pi fT)}{(L\pi fT)^2} \tag{B.2}$$

where f_h = B/2=5 Hz, B – the bandwidth of the measuring channels determined by a bandpass filter with a bandwidth equal to 10 Hz; *L* – the number of samples (samples of measurement channel data) over which averaging is performed during the formation of digital bandwidth.

Graphs of the frequency response of the comparator for these cases are shown in Figure B.1.

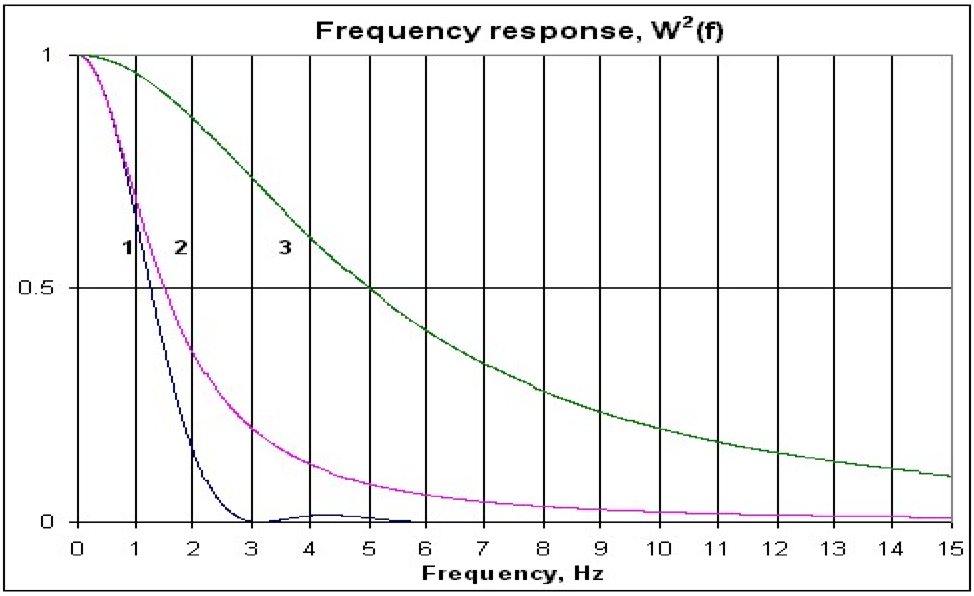

Figure B.1 The frequency response of the device, where:

1 – the real frequency response of the comparator B = 3 Hz (with averaging);

2 – frequency response of a first-order analog filter with a 3 Hz band;

3 – frequency response of the comparator at B = 10 Hz."

In the Program "Phase comparator-analyser," the adjustable comparator bands are designated as low–pass filter bands (W is the positive part of the total bandwidth): 0.5; 5; 50 and 500 Hz, and the comparator band 1.5 Hz is designated as the full band B "3 Hz" to maintain continuity with previous models of devices.