Multichannel Frequency Comparator

VCH-315

User Guide

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1 Introduction

Program "Multichannel frequency comparator" (the Program) is designed to control the multichannel frequency comparator. The program provides processing and keeping of the measurement results of the phase difference, frequency difference and frequency instability.

Frequency comparator VCH-315 (the Comparator) is designed to measure the relative frequency difference and frequency signals instability of the time and frequency standards. It contains eight identical measuring channels and performs high precision phase and frequency comparison.

Key applications

- verification of metrological parameters of precision frequency signals sources;

- time and frequency etalon systems;

- computed control measustem;

- scientific research measurements.

Communication between the IBM / PC-type computer, on which the program is installed, and the comparator is performed via RS-232C interface, USB or LAN interface (Windows only).

Comparator supports only one connection via RS-232C interface, USB interface or LAN interface. Only one connection is available via LAN interface.

The program requires Windows XP, Vista, 7, 8, 10 or Linux operating system with kernel version 2.6.x or higher.

Implemented features:

• receiving measurement data from the comparator, automatically saving data in files;

• calculating statistical functions characterizing the frequency difference between two signals;

• displaying measurement results and calculated functions in the form of charts on windows interface;

• printing charts on a printer connected to the computer.

"Frequency comparator measurements processing program Analyser is included with the program. It has the following features:

• simultaneous processing of the data across multiple channels of the comparator, and the simultaneous processing of the data from several comparators (maximum number of concurrent entries - 32);

• processing of the previous measurements, and processing of the current measurement data with automatic update of charts and statistical characteristics;

• a wide range of computed parameters (mean relative frequency difference and frequency drift by least-squares method, standard deviation, Allan deviation, Hadamard deviation, maximum time interval error, time interval deviation, power spectral density of phase and frequency noise).

• calculation of the statistical characteristics with overlap method;

• elimination of frequency drift;

• the cross-correlation processing that allows to reduce the noise level contribution of the comparator in the measurement of the frequency instability (with appropriate measurement scheme);

• the cross-correlation processing that allows to evaluate the characteristics of the frequency instability not only for pairs of signals, but also for each signal individually by the method of three oscillators;

• comparing time-frequency measurements with the parameters (temperature, humidity, etc.) measurements;

This manual provides a summary of the basics of the Comparator, as well as the instructions on how to use and configure the Program.

2 The working principle of the Comparator

Comparator contains eight identical blocks of single-channel phase comparators for measuring sinusoidal signals, signal processor unit with RS-232C, USB and LAN interfaces, power supply unit.

Each single-channel comparator has one input for the measurement signal and a reference input and consists of two modules: the relative frequency difference multiplier providing multiplier $K=10^6$, and the time stamp counter with 10-nanosecond resolution.

Pulse signal F is taken from the output of the multiplier unit, its frequency (equal to about 1 Hz) carries information about the frequency difference between the compared signals $-f_y$ and f_x:

$$F_{yx}\,[\text{Hz}] = 1 + K \cdot (f_y - f_x)/f_x \ .\qquad\qquad (2.1.1)$$

K is the coefficient of frequency fluctuations multiplication, equal to 10^6.

B band of the fluctuation frequency transmittance is 3 Hz.

Pulse signals with frequency determined by (2.1.1) are fed to the input of the time stamp counter (TSC).

Signal t_{yx}, that carries information on the phase difference of signals f_y and f_x., is taken from the output of the TSC digitized with 10-nanosecond resolution. Diagram of processes in the TSC that explains the formation and usage of the digitized phase difference signal t_{yx}, is given in figure 2.1.
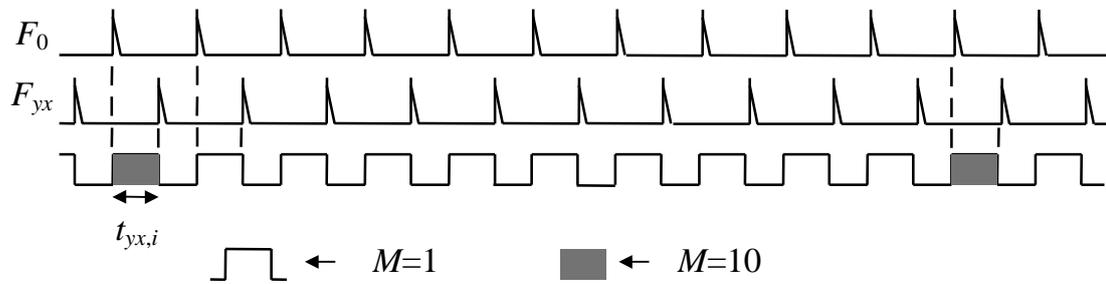
Figure 2.1 – Diagram of processes in the TSC explaining formation of the digitized phase difference signal t_{yx}

F_0 – reference signal 1 PPS, generated from the heterodyne signal, "bound" by the PLL to the reference signal X.

The comparator provides simultaneous measurements of phase differences between the different channels with an accuracy of less than 10 ms.

3 The computed functions

The program allows you to process measurement data in real time and calculate the following characteristics:

1) mean relative frequency difference (between the signals fed to the f_y (measured) and f_x (reference) inputs of each comparator channel);

2) standard deviation - root mean square deviation of the measured relative frequency value, calculated for the difference between the frequencies of the input signals in each channel of the comparator;

3) Allan deviation - root mean square relative two-sample deviation of the measured frequency value, calculated for the difference between the frequencies of the input signals in each channel of the comparator;

4) assessment of the current relative frequency difference using the Kalman filter.

Standard deviation and Allan deviation are calculated for the measurement time intervals (samplings): 1 s, 10 s, 100 s, 1000 s, 1 h, 10000 s, 1 day.

Standard deviation and Allan deviation are calculated on the entire range of observation time (for all samples from measurement start). In addition, Allan deviation values can also be calculated in observation time intervals T, fixed for each averaging interval τ_A (in the "sliding window" duration $T = N\ \tau_A$, see. Section 6.2).

3.1 Basic ratios

The source for all the calculated statistical functions are signals of the digitized phase difference t_{yx}, taken from the inputs of the "Time stamp counter" (TSC) blocks, see Section **Ошибка! Источник ссылки не найден.**.

Initially the phase difference of signal pairs is calculated (based on K - frequency fluctuations multiplier):

$$\Delta_{yx,i} = -\frac{1}{K} t_{yx,i} \; .$$

(3.1.1)

i – number of intermediate count. **The value $\Delta_{yx,i}$ should correspond to the difference between the phases of the signals f_y and f_x, and the measured value $t_{yx,i}$ corresponds to the difference between the phases of the signals f_x and f_y. Therefore it is a minus sign in the formula (3.1.1). The resulting value $\Delta_{yx,i}$ can have a constant offset relative to the actual phase difference between the signals f_y and f_x.**

Then the relative frequency difference calculated for the pairs of signals, measured on the interval $\tau_A = M$ seconds:

$$y_{yx,i}^{M} = \frac{1}{\tau_A}\left(\Delta_{yx,M(i+1)} - \Delta_{yx,Mi}\right).$$

(3.1.2)

Equation (3.1.2) is the starting point for the calculation of Standard deviation and Allan deviation (formulas (3.2.1) and (3.2.2)), and also used to calculate mean relative frequency difference. The upper index M is further omitted, since it is everywhere implied that the frequency error is measured on the interval M seconds.

The Program also calculates the current variations in the relative frequency difference:

$$\delta_{yx,i} = y_{yx,i+1} - y_{yx,i} \; ,$$

(3.1.3)

These variations are used to calculate Standard deviation and Allan deviation.

3.2   Statistical functions

The mean-square deviation of the measured value of the relative frequency (RMS) is calculated using (3.1.2):

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} \left(y_{yx,i} - y_{yx}^{N} \right)^2} \; .$$

(3.2.1)

N – the number of the frequency difference counts $y_{yx,i}$ for a certain averaging interval τ_A, y^N_{yx} – the average value of the relative frequency difference on averaging interval $N \cdot \tau_A$.

Root mean square relative two-sample deviation of the measured frequency value (Allan deviation) is calculated on base of (3.1.3):

$$\sigma_y = \sqrt{\frac{1}{2(N-1)} \sum_{i=1}^{N-1} \left(\delta_{yx,i} \right)^2} \; .$$

(3.2.2)

Mean relative frequency difference is calculated by using the equation (3.1.2), its value is displayed in the main window. In the calculation in (3.1.2) averaging interval coincides with the whole time of observation in the respective channel.

The program evaluates the current relative frequencies difference using the Kalman filter. This estimate, along with mean relative frequency difference estimate is displayed in the main window. The following process model allows to take into account the white noise frequency and frequency random walk:

$$\Delta_{i+1} = \Delta_i + y_i \tau + \xi_i,$$
$$y_{i+1} = y_i + \eta_i,$$
$$\left\langle \xi_i^2 \right\rangle = q_1 \tau, \quad \left\langle \eta_i^2 \right\rangle = q_2 \tau,$$

(3.2.3)

where Δ corresponds to the phase difference, y corresponds to the estimated frequency difference, ξ, η – white Gaussian noise, τ – interval between counts, equal to 1 s. Measurement model describes the measurement of the phase difference:

$$z_i = \Delta_i + v_i, \quad \langle v_i^2 \rangle = R, \tag{3.2.4}$$

where v_i – white Gaussian noise, z_i – measured phase difference.

The filter parameters q_1, q_2, R are fixed at the moment, their values can be changed in the ini-file of the Program. Default values are $q_1 = 10^{-26}$, $q_2 = 0$, $R = 10^{-24}$.

According to (3.2.) And (3.2.) parameter vector, transition matrix and the measurement matrix have the form of:

$$X_i = \begin{pmatrix} \Delta_i \\ y_i \end{pmatrix}, \quad F = \begin{pmatrix} 1 & \tau \\ 0 & 1 \end{pmatrix}, \quad H = \begin{pmatrix} 1 & 0 \end{pmatrix}. \tag{3.2.5}$$

The covariance matrix of the process noise has the form of:

$$Q = \begin{pmatrix} q_1\tau + q_2\dfrac{\tau^3}{3} & q_2\dfrac{\tau^2}{2} \\ q_2\dfrac{\tau^2}{2} & q_2\tau \end{pmatrix}. \tag{3.2.6}$$

During initialization of the Kalman filter assessment of the state vector X- and estimation error matrix P- are given. After that filter algorithm starts. Filter coefficient is calculated:

$$K_i = P_i^- H_i^T \left[H_i P_i^- H_i^T + R \right]. \tag{3.2.7}$$

Then the filter state is specified:

$$\hat{X}_i^+ = \hat{X}_i^- + K_i \left[z_i - H\hat{X}_i^- \right]. \tag{3.2.8}$$

Error matrix is specified:

$$P_i^+ = [I - K_i H] P_i^- . \qquad (3.2.9)$$

Prediction for the next step is implemented:

$$\hat{X}_{i+1}^- = F(\tau) \hat{X}_i^+ \qquad (3.2.10)$$

$$P_{i+1}^- = F \, P_i^+ F^T + Q \qquad (3.2.11)$$

The procedure is repeated, starting with the calculation of the formula (3.2.7). The desired estimate of the relative frequency difference at the iteration i is the value y_i.

4 Installation

To use the Program you need at least Pentium-III with at least 512 MB RAM.

4.1 Installation in Windows

The program can work under Windows XP, Vista, 7, 8, 10. The software is installed from the CD (if CD is not included in the product package, ask the manufacturer the installation file). Usually the installation program starts automatically. If it does not, run setup.exe from the root directory of the CD-ROM manually. The installer will create a "Comparator" shortcut on the desktop and the corresponding item in the "Start" menu.

Installing the device via USB

Before using the USB interface of the comparator to the computer you need to install device driver that creates a virtual serial port when the comparator is connected via USB . To install the driver and create a virtual serial port connect the comparator to the computer USB port and turn it on. If the driver is already installed, the operating system will detect the new "USB Serial Port" device, assign it a number and display a message, such as "USB Serial Port (COM8)", "Your new hardware is installed and ready to use":

If there is no driver Windows will launch the New Hardware Found Wizard:

Decline connection to Windows Update, then click "Next" and select the setting "Install from a list or specific location".

As the directory containing the driver select the folder "Driver" on the CD-ROM with comparator software (Figure 4.4):

If the warning about software compatibility with the operating system "Windows XP" appears, click the Continue Anyway button.

After the driver installation, click "Finish" button.

After the installation of the driver the device availability message will appear on the screen.

In some cases, the New Hardware Found Wizard starts again. In this case, you need to go through the installation process again.

Installing the driver to connect the device via LAN interface

For remote control via LAN you need to install special software that comes on a disk. This software is also available at the following address: http://www.lantronix.com/device-networking/utilities-tools/com-port-redirector.html. To install run setup_cpr_x86x64cd_4.3.0.2.exe. After installation, run the "CPR Manager" program (see. Figure 4.1).
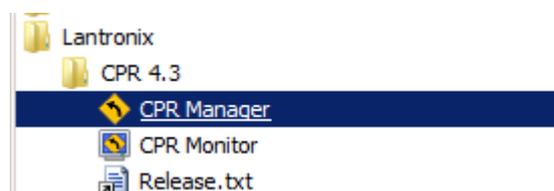

Figure 4.1 – Location of the "CPR Manager" shortcut in the "All Programs" menu in Windows 7
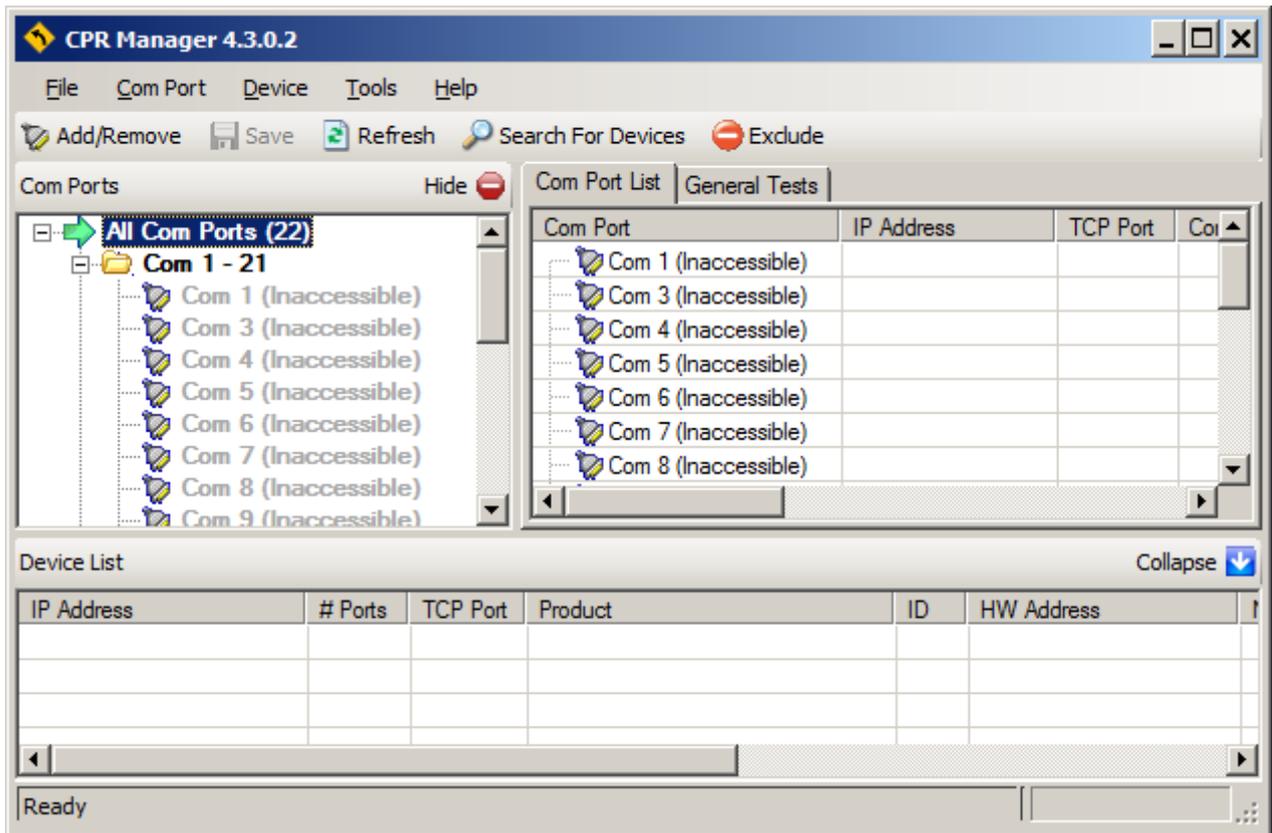
Figure 4.2 – "CPR Manager" main window

List of the COM-ports will be displayed. If all of them are marked as unavailable (Inaccessible) click the "Add/Remove" and select an available number for the virtual COM-port (Figure 4.3). After that the new COM-port appears in the list labeled "New" (Figure 4.4).

Click "Search For Device", after some time the list of available devices will appear in the bottom of the table window (Figure 4.4). Select the device with MAC-address (HW Address) that matches the MAC-address of the device. Double-click the left mouse button on the required row of the table. IP-address of the device will be copied to the table in the Settings tab for the new (selected) COM-port (Figure 4.4).

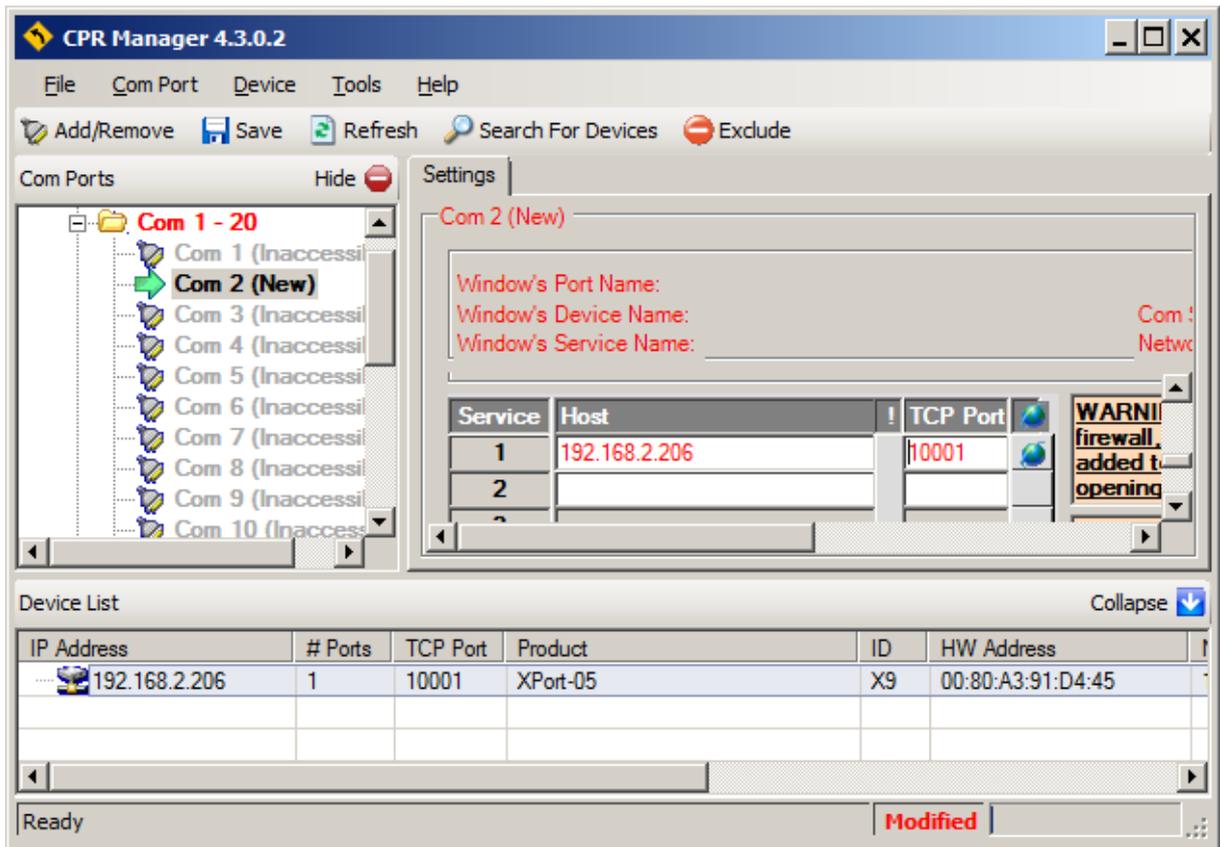Click "Save". The device is ready for use via LAN interface.

To ensure the successful setting up of the virtual COM-port you can use the Windows Device Manager, it will show created port, for example: Lantronix CPR Port (COM2), in "Ports (COM & LPT)" tab.

Figure 4.3 – Virtual COM-port selection window (COM2 is selected)

Figure 4.4 – Selecting device from the list by its MAC-address (only one device shown here)

4.2 Installation in Linux

To use the Program in Linux copy VCH315 directory from the CD included in the product package to the local computer's disk (or unzip the file with this directory when downloading programs from the site). If CD is not included in the product package, ask the manufacturer the installation file. To start the Program run from the command line file "start.sh" from VCH315 directory as follows:

./start.sh

The Program requires root access because it works with computer ports.

FTDI-driver for virtual COM-port VCP is needed to work with a comparator via USB.

Most Linux distributions with kernel version 2.6 and above have this driver, so no setup is required. Otherwise, the driver is available for download on the web-address: http://www.ftdichip.com/Drivers/VCP.htm.

For RS-232 interface connection it is recommended to use the computer COM-port integrated on the motherboard, or use a special USB-RS232 adapter from FTDI company. Otherwise operation via COM-port to Linux is not guaranteed.

5 Connecting the Comparator and starting to work with the Program

If the comparator is connected via RS-232 interface, then before connecting the device to the computer it is recommended to turn off the device. If a USB interface is used, the comparator can be connected in the ON state.

After connecting the device to a computer, you can turn the device on. When you first connect the device via USB, you may need to install a driver (see Section 4).

After program started the main window and the window "Auto Connect ..." showing the process of connecting with the device (see Figure 5.1) will appear. The "Auto connect ..." window is displayed and the ports analysis process and device connection begin at startup if you select the "Analyse ports at every program start" item in the "Auto connect ..." or in the "Connecting to the device" (menu item "Options> Connection ", refer to Section 6.2).

The program automatically searches for COM or USB ports on the computer with connected comparators. If no comparator is not found, the program displays a message asking you to retry the connection.

If "Analyse ports at every program start" is not checked, then when you run the Program it will attempt to connect using COM-port number from the previous program run, the number is stored in the ini-file in the Program directory.
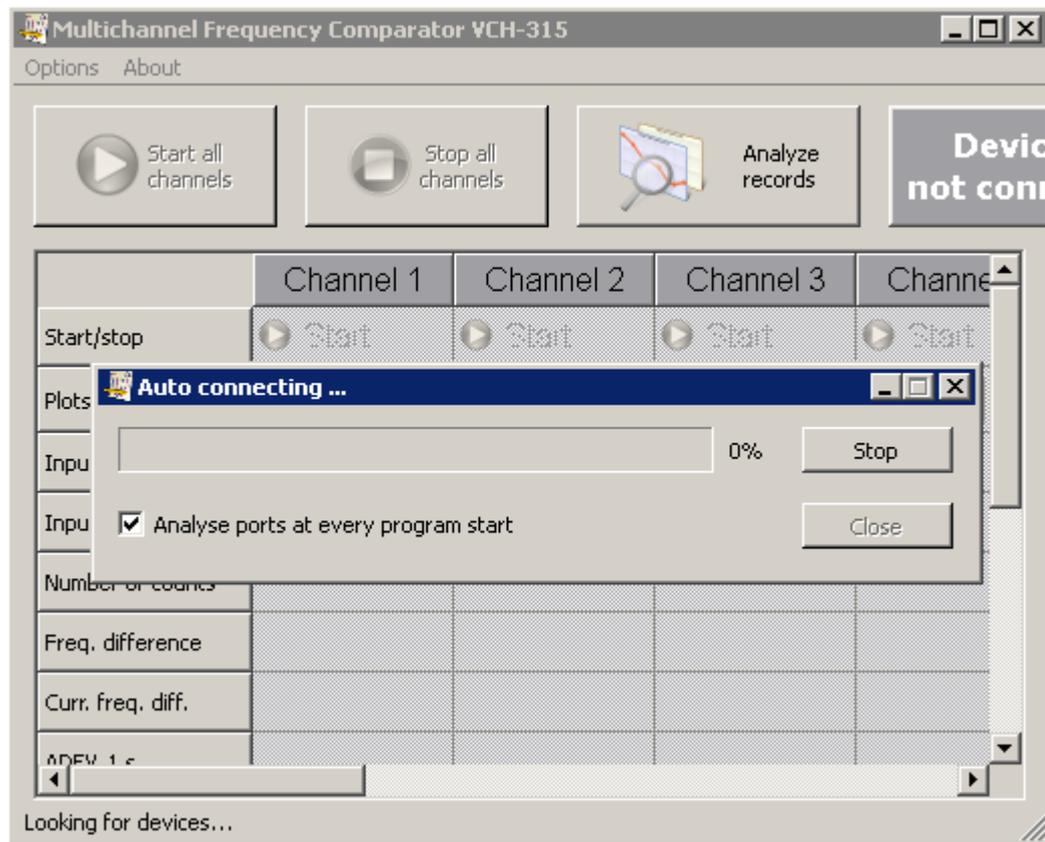
Figure 5.1 – Main window at startup

Name of the main program window contains the name of the comparator and its code (VCH-315).

You can turn on the Comparator after the launch of the Program.

If the program was able to detect connected Comparator, message "Connecting the comparator" (see Figure 5.1) is displayed in the status bar.

If communication with the comparator was successful status bar will show message containing the connection port number, for example: "The comparator is connected (COM1)". The field in the upper right corner of the main window changes colour to green, the label changes to "The comparator is connected". The comparator channels that contain measured and reference signals are marked green in the table in the main window, the corresponding table columns become active (Figure 5.2).
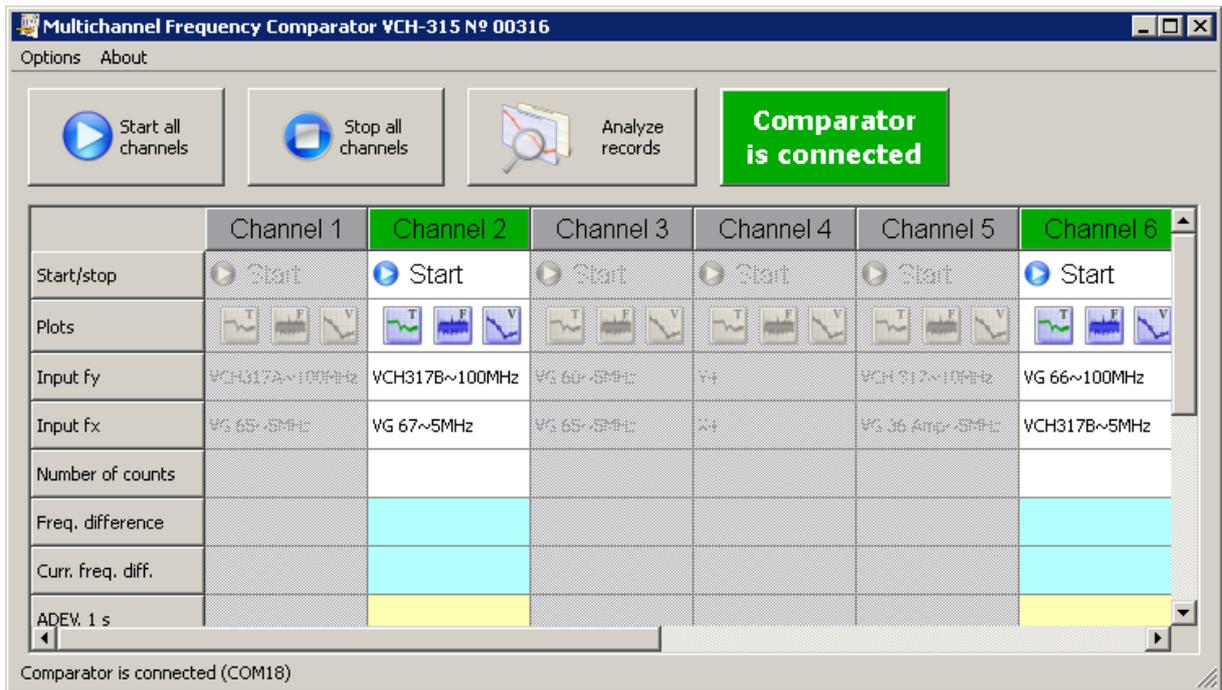
Figure 5.2 – Main window after connection is established

If multiple comparators are connected, toy need to choose the comparator from the list in the "Options" menu under "Connection" item (see Section 6.2). Next time you start the Program connection is established with the comparator selected earlier.

6 Interface

Program interface is standard for Windows applications (Figure 6.1). Appearance of the program may differ from shown in this manual depending on the user's individual settings. The main element of the Program window is a table containing information on the signal in each channel, the number of counts obtained, the average relative frequency difference, assessment of the current relative frequency difference, value of the frequency instability (standard deviation or Allan deviation). You can choose between showing either standard deviation or Allan deviation in the table and graphs performed in "Setting calculations" item in "Options" menu (see Section 6.2).
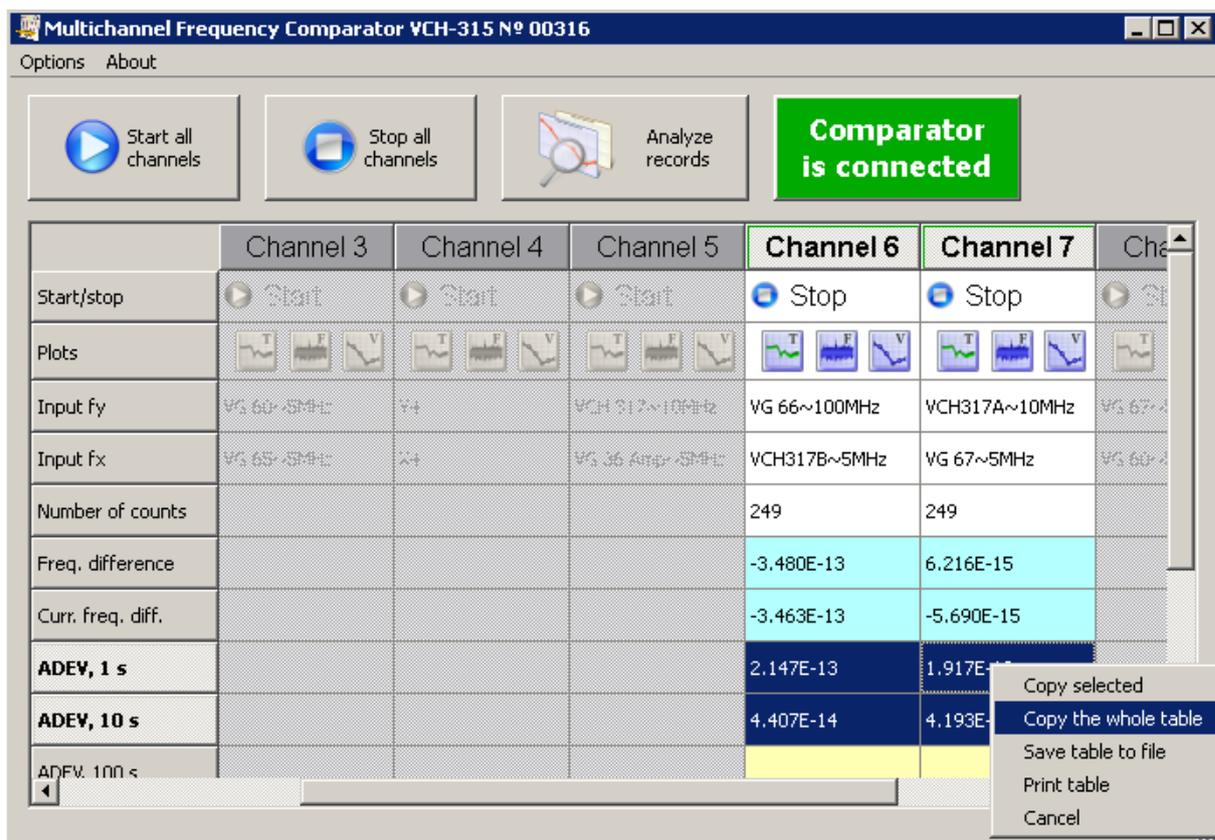

Figure 6.1 – Main Window

To start or stop measurements in the required channel click on the corresponding field in the "Start/Stop" row. If you want to start or stop measurements simultaneously

on all channels that contain signals use the buttons: "Start all channels", "Stop all channels." When you try to stop the measurement in one or all channels window appears, asking whether this operation should continue.

When you click "Analyse records" program starts the time-frequency measurement data processing that allows you to analyse both the current measurement data and previous data. Entries for channels that are measured at the current time are automatically downloaded in the window. This entries are automatically updated.

The program allows you to specify names for the reference and measured signals of each channel in the appropriate fields in the "reference signal" and "measured signal" rows. The names of the signals must be assigned before the measurements start, after that editing fields of the table with the names of the signals will not be possible. The names of the signals will be displayed when working with the entries in the time-frequency measurements data processing program.

The text of the entire table or only the selection can be copied to the clipboard, saved to a file or printed out. To do this, press the right mouse button on the table field and select the requiered option in the pop-up menu (see Figure 6.1).

If the device containes one or more temperature sensors, additional channels for measuring temperature, highlighted in orange, are available in the table of the main window (see Figure 6.2).
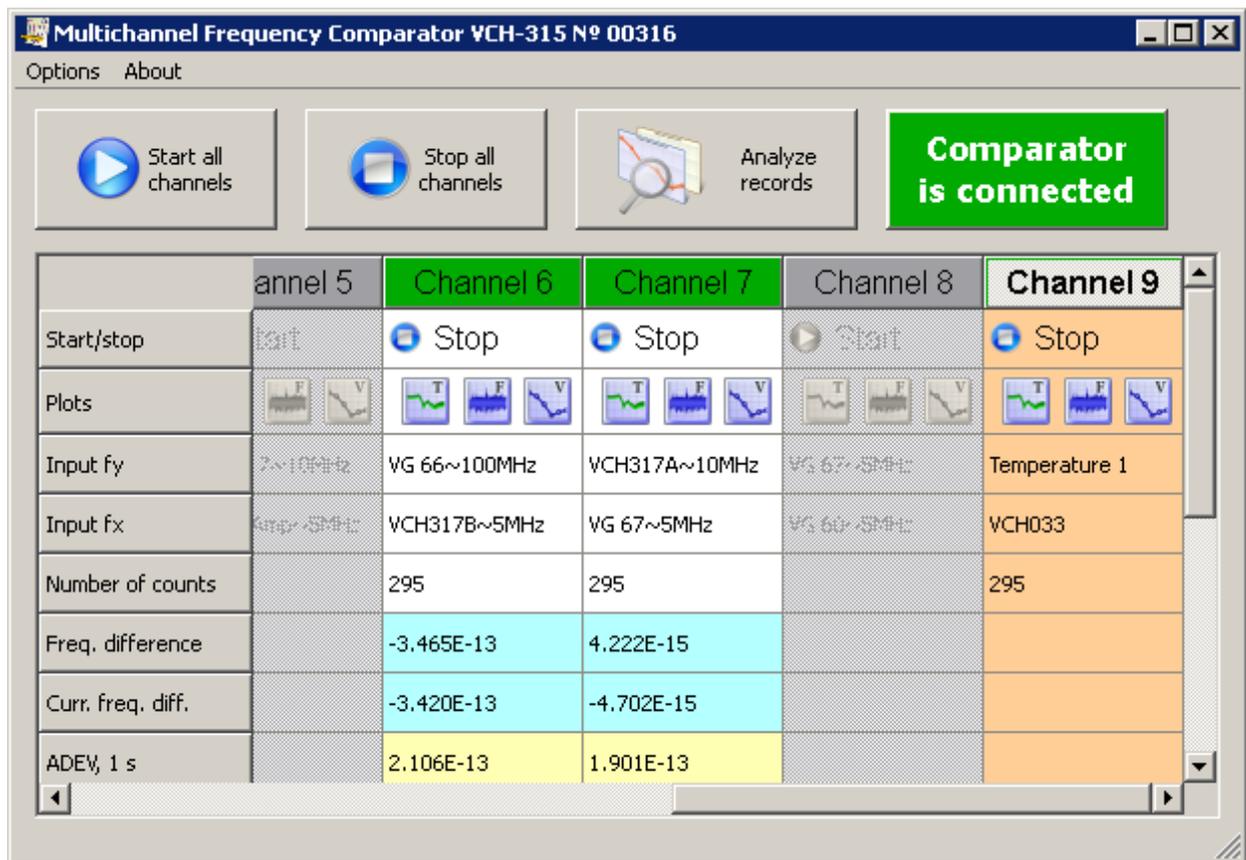
Figure 6.2 – Main window. Temperature measurement channel (**optional**)

The interval between the counts of temperature measurement is fixed at 10 s. Measurements in channel for temperature recording start and stop same way as in the other channels. When you press the "Start all channels" / "Stop all channels" on available channels for temperature recording the measures will also the start (stop). You can change the name in the temperature fields of the channel. By default, the "reference signal" contains the string "FMC" and the "measured signal" - the string "Temperature N", where N is the number of the sensor. When measurements are running the field "Number of counts" displays the number of obtained temperature counts. The rest of the fields in the table for the channel remain empty.

Similarly to the phase difference measurement the Program creates the current temperature graphs, as well as temperature variations and the average temperature variation dependence from the averaging interval. The formulas for the calculations

are the same as in the phase measurements processing, but temperature is used instead of the phase difference.

6.1   Current measurement graphs

In "Plots" row of the table of the main window you can open the graphs of phase difference, relative frequency difference, Standard deviation or Allan deviation by pressing the corresponding button.

The program can show the decimated phase difference values, and average values of the relative frequency difference on averaging intervals of 1 s, 10 s, 100 s, 1000 s and 3600 s. To select the averaging interval for the frequency or the decimation factor for phase you need to press the right mouse button in the required channel field in the "Plots" row, and select the time interval (see Figure 6.3).

Figures 6.4 and 6.5 show examples of phase difference and relative frequency difference graphs for averaging intervals of 100 s and 1 s respectively. Graphs show up to 1000 last entries for any averaging interval.

Line of mean relative frequency difference can be displayed on the frequency graph (Figure 6.5).

The average value is calculated by formula (3.1.2) for the current graph. This value may vary significantly for frequency graphs with different averaging intervals, and can also be different from the value obtained by the Kalman filter and shown in the table..
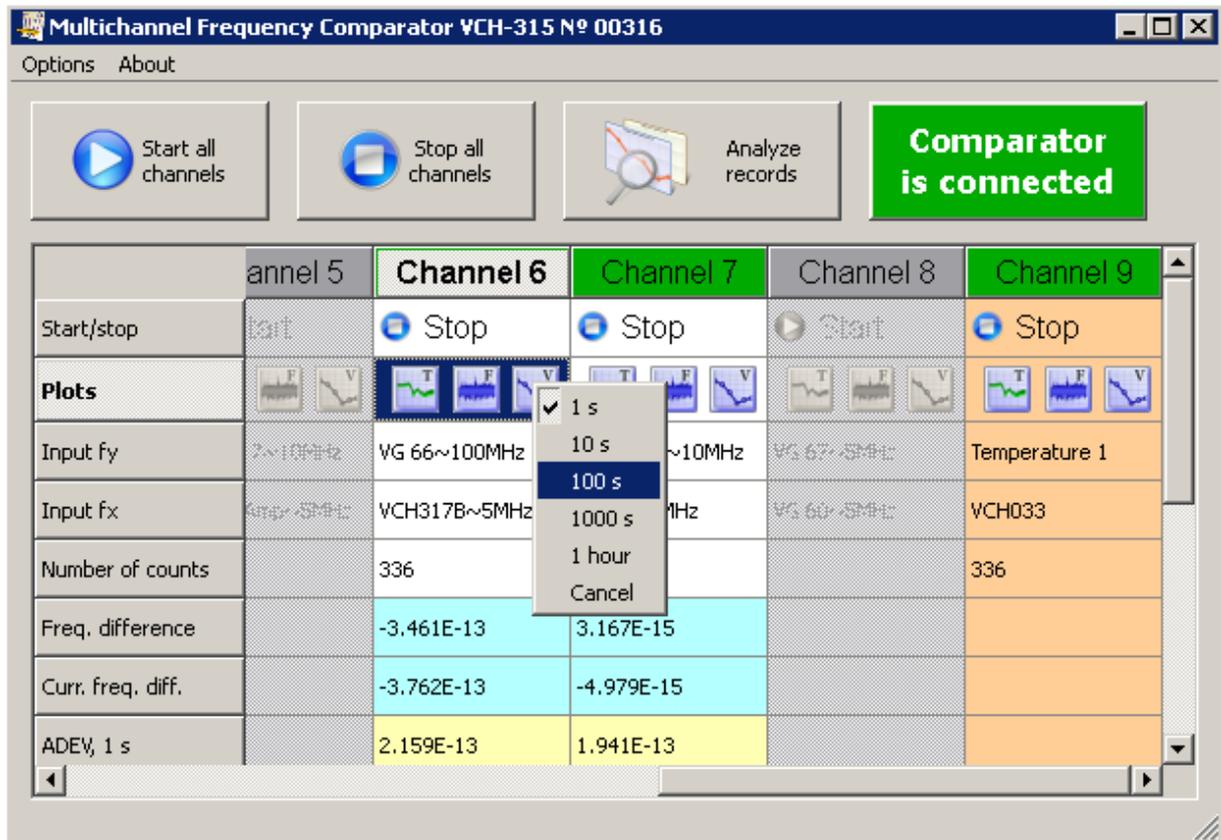
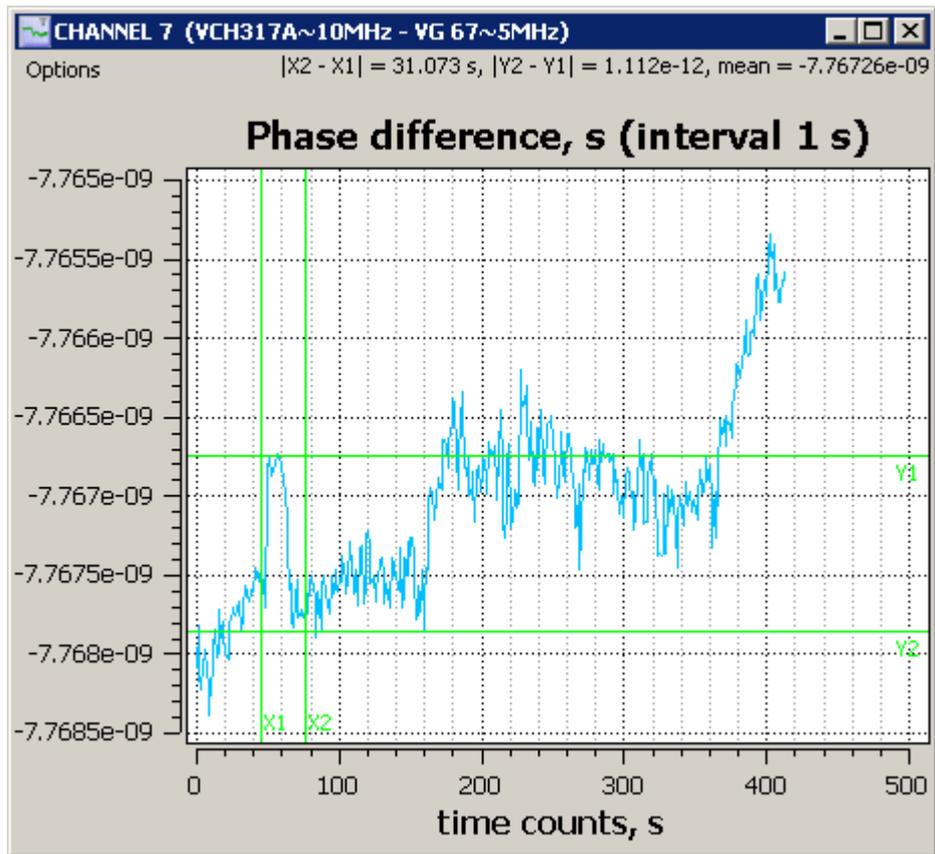**Figure 6.3** – Main window. Selecting averaging interval for the phase and frequency graphs

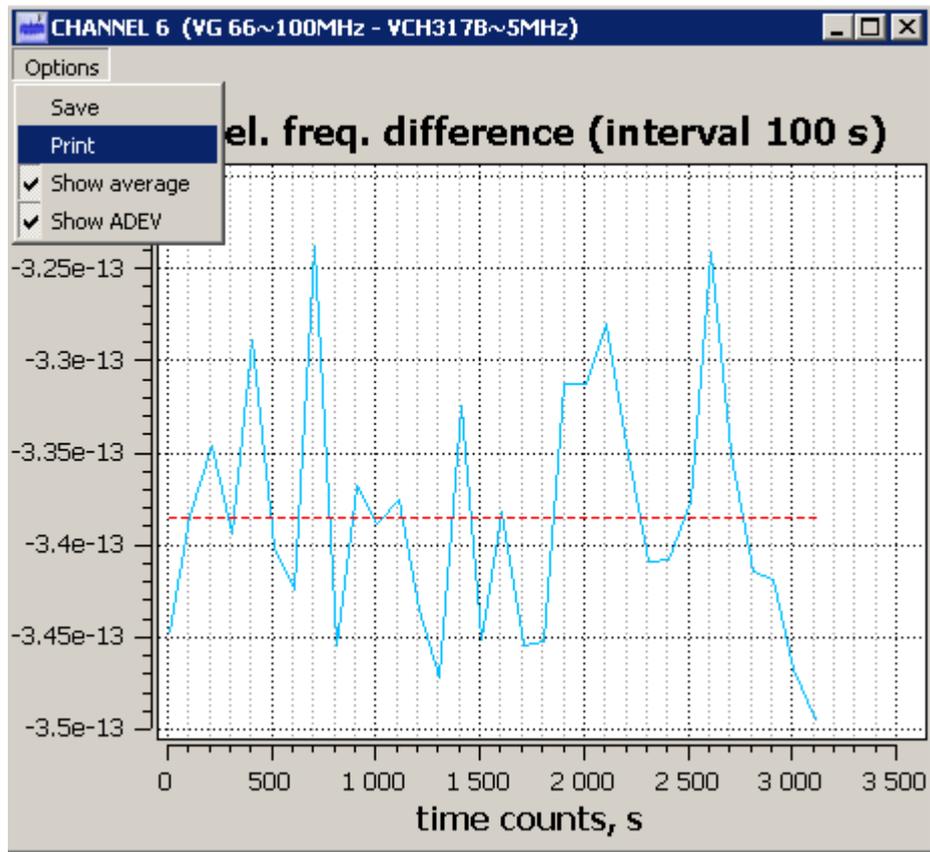**Figure 6.4** – Phase difference graph for averaging interval of 1 s

Figure 6.5 – Relative frequency difference graph for averaging interval of 100 s
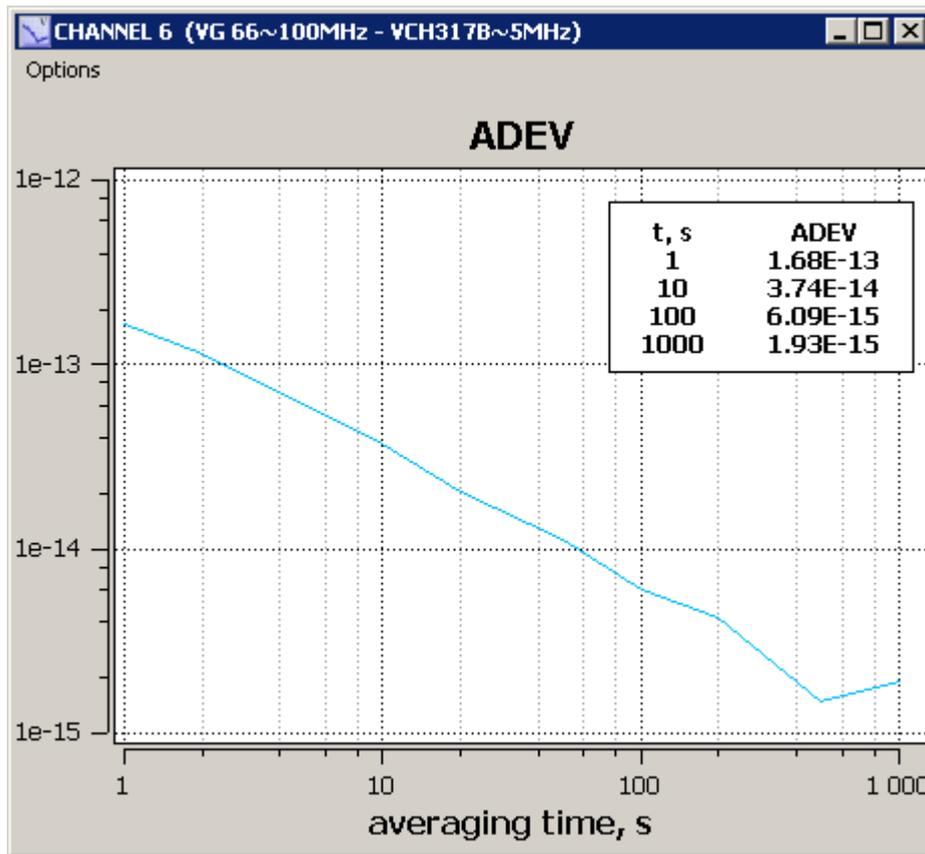
Figure 6.6 – Standard deviation graph

Figure 6.6 is an example of standard deviation graph, that also contains a table of standard deviation values.

All graphs have a marker that appears when you click left mouse button in the graph field. Horizontal and vertical values for the selected point are shown in the upper right corner of the window (Figure 6.5). With a marker you can measure the distance between two points on the graph, to do that select the first point by clicking left mouse button, then hold down the button, move cursor to the second point and release mouse button. The measured horizontal and vertical difference values will be displayed in the upper right corner of the window (Figure 6.4).

Each graph window has the "Options" menu, where you can save the graph to a "bmp" or "jpg" file or print it out.

6.2 Main window menu

Figure 6.7 shows the "Options" menu of the main window.

The "Connection" item opens a "Connect device" (Figure 6.8) window. This window shows the list of available COM-ports (including virtual COM-ports) of the computer. If the connection to the device is found in the list, the corresponding COM-port will be highlighted and the serial number of the connected comparator is shown.
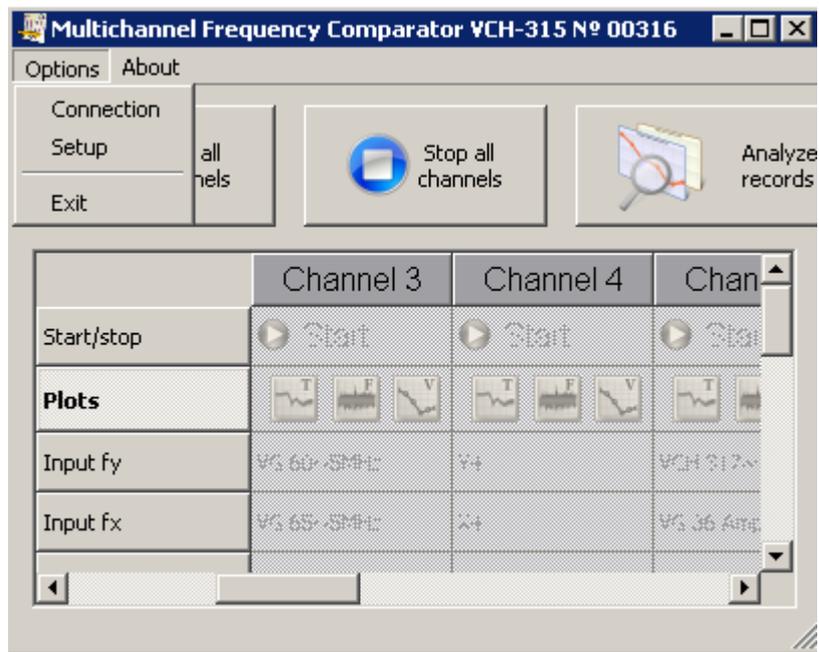

FIgure 6.7 – "Options" menu of the main window

When you click "Refresh and connect" button, if measurements are stopped the current device connection (if established) breaks and port analysis begins in order to find and connect to Comparator. If measurements are going on this option is not available.

When you click "Apply" the Program will try to connect to COM-port selected in the list, if the number of the selected port is different from the current one.

Option "Analyse ports at every program start" means that the analysis of ports and connection to the device, if it is detected (Section 5), will be made again at the

next program start. If this option is selected, next time you start connection attempt will be made at the previously selected COM-port specified in the ini-file.

If PC running the program is connected to multiple Comparators VCH-315 you can select the required COM-port from the list. Click "Apply" to connect to the Comparator via the selected port. When you click "Update and connect" current connection to the device (if it has been established) is broken, ports analysis and connection to the previously selected Comparator will start..
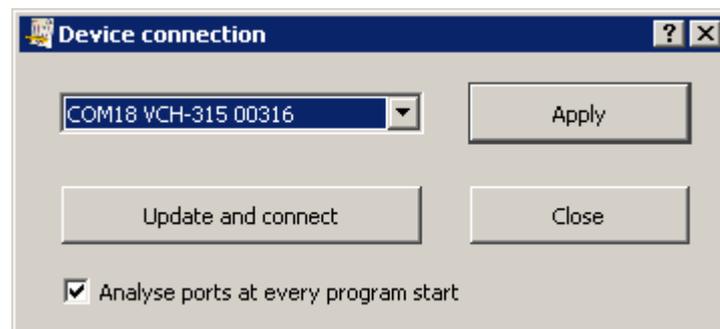

Figure 6.8 – "Device connection" window

Menu item "Setup" (Figure 6.7) opens a window "Frequency stability characteristics setup" (Figure 6.9). You can select statistical functions: SDEV (root mean square relative deviation of the results of pairs of signals frequency difference measurements) and ADEV (root mean square relative random two-sample deviation of the results of pairs of signals frequency difference measurements). SDEV (standard deviation) is always calculated at the entire interval of observation time (since start of measurements). ADEV (Allan deviation) can be calculated at the entire interval of observation time or at a fixed interval preceding the current moment (in a sliding window). If you select a fixed interval you need to set the number of averages, ie the length of the sliding window. The number of averages can be set from 32 to 1000. For example, if you select 100 averages the ADEV observation time at averaging interval $\tau_A = 1$ will be $T = 100$ s, and for $\tau_A = 3600$ s will be $T = 360000$ s.

<u>Note</u>. If frequency jump occurred with 100 averages selected then after 101 seconds ADEV value for $\tau_A = 1$ s will not contain any information about this jump

Note that the number of averages can be changed only when measurements on all channels are stopped. You can change the type of calculated function during measurements. After selecting the necessary statistical function press "Yes" or "Apply", then the changes will take effect, the table and graphs will show the values of selected characteristic.

"Help" menu provides information about the program version and firmware version of the connected comparator.
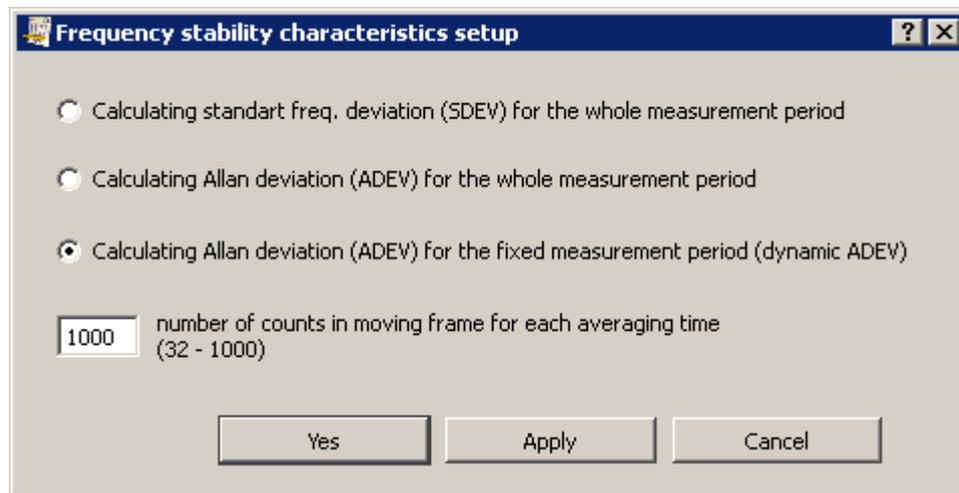

Figure 6.9 – "Frequency stability characteristics setup" window

6.3   Records files

Program saves phase differences samples measurement data. $t_{yx,i}$ in two catalogs "samples" and "ASCII" in its root folder.

In the "samples" catalog data is stored in a format designed for time-frequency measurements data processing program. For each channel, two files are created with "*.inf" and "*.dat" extensions and named in YYMMDD_n format where YY - year,

MM - month, DD - day, n - channel number. If there were no measurements in a day, then files for this day are not created.

Data processing program can be started by pressing the "Analyse" button in the main window (see Section 6). In addition, the processing program can be run on another computer connected via LAN to the computer running the "Multichannel Frequency Comparator" program. In the processing program you need to specify the path to the "samples" directory to work with records.

"ASCII" catalog contains measurement data records in ASCII format for each channel separately. The file name includes date and time of recording start: YYYYMMDD_hh_mm_ss_n, where YYYY - year, MM - month, DD - day, hh - hours, mm - minutes, ss - seconds, n - channel number.

Records are divided into files for days. If recording is continued on the following day, a new file with name that includes the date of the next day and time 00:00:00 (eg 20150601_00_00_00_1) will be created.

The image below shows an example of a file in ASCII-format. The first column contains time of measurement corresponding to the time of the computer that is running the program. The second column contains comparator time counts in seconds. The third column contains comparator $t_{yx,i}$. counts. For phase difference samples in seconds, you must divide $t_{yx,i}$ by fluctuations of the comparator frequency multiplication coefficient K, equal to 10^6, and change the sign (3.1.1)
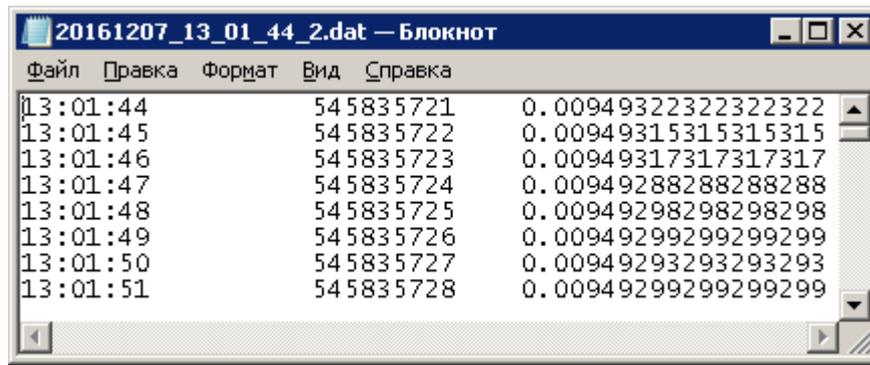
Figure 6.10 – Example of the records stored in ASCII-format