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TESTING THE STABILITY OF GPS OSCILLATORS WITHIN SERBIAN PERMANENT GPS STATIONS NETWORK

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Abstract − Periodic tests of quartz oscillators incorporated in GPS receivers in Serbia are performed in accredited metrological laboratories by the procedure adopted in metrological laboratory ML160. However, receivers of Serbian permanent stations network (AGROS) are permanently mounted on the top of roofs of local cadastral offices, spread along territory of Serbia. They cannot be taken to a metrological laboratory for calibration because of need for constant work. A method for testing their oscillator stability is presented in this paper.

Keywords: stability, permanent station, oscillator, LabView

1. INTRODUCTION

Oscillators in geodetic GPS receivers and satellites materialize GPS time scale, as well as, coherently derive satellite signals of different frequencies. Modern oscillators are based on oscillator phenomenon of atoms of Hydrogen (H), Rubidium (Rb), Caesium (Cs), or quartz crystals (x).

Stability of their properties during time is a main factor of the total quality of a system. It is defined as a statistical estimation of frequency fluctuations of signals in a given time interval. Short-term stability is usually related to fluctuations in an interval shorter than 100 s. Long-term stability defines measuring intervals longer than 100 s, but is usually given for a time period longer than one day.

Many factors affect the stability of oscillator frequency. Changes in environment can cause significant instability of frequencies. For example, large magnitude changes (tens of dB) can be noticed when a phase noise of the oscillator is calibrated in a laboratory with very quiet environment, as well as, in an environment with vibrations, such as car moving. Some of influential factors are: time, temperature, acceleration, ionized radiation, etc.

Long-term stability of quartz oscillators of GPS receivers is calibrated by comparing 1PPS output of a testing receiver with secondary time and frequency standard. Both 1PPS outputs are connected to a frequency meter. The time difference of 1PPS ticks between two receivers is measured. Changes of time differences through measuring interval indicate the characteristic of oscillator stability.

Metrological laboratory ML160 developed another method for testing permanently mounted GPS receivers, specifically for AGROS receivers.

AGROS (Fig. 1) is a permanent service of precise satellite positioning in the territory of the Republic of Serbia. AGROS network is designed to solve a series of problems, primarily in the field of surveying and cadastre, but also in many other activities that are an integral part of a wide range of economic activities and scientific research (vehicle navigation, works in agriculture and forestry, air transportation, aerophotogrammetry, forming GIS systems, engineering-technical works, etc.).

The method is based on processing raw GPS data files acquired by AGROS receivers. Observables for a 24 hours interval are downloaded in Receiver Independent Exchange (RINEX) format from a monitoring centre and are processed in our laboratory.

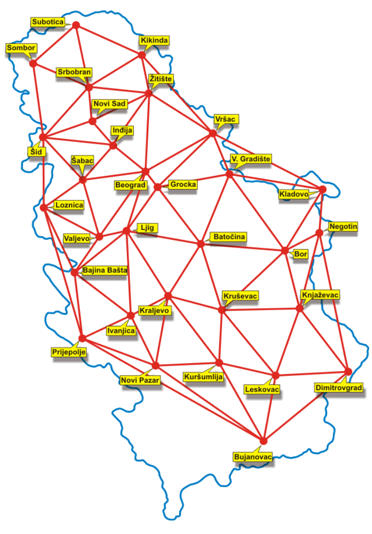

Fig. 1 Serbian permanent stations network (AGROS)

2. METHODS

The following periodic function defines an output signal of a real oscillator [4]:

$$U(t) = U_0 \sin\left(2\pi f_0 t + \varphi(t)\right) = U_0 \sin \Phi(t), \qquad (1)$$

with amplitude of a signal U_0, nominal frequency f_0, phase $\Phi(t)$ and phase error $\varphi(t)$. Total difference between frequency $f(t)$ and nominal frequency f_0 is calculated by:

$$\Delta f(t) = f(t) - f_0 = \frac{1}{2\pi}\frac{d\varphi(t)}{dt} = \frac{\dot{\varphi}(t)}{2\pi}. \qquad (2)$$

The value of frequency difference is influenced by many parameters, such as: aging of a material, changes in temperature, pressure and humidity, voltage, physical vibrations, radiation and magnetic field [7].

Stochastic part of oscillator output signal is used as a measure of stability, usually in the form of norm value:

$$y(t) = \frac{f_r(t)}{f_0} = \frac{\dot{\varphi}(t)}{2\pi f_0}. \qquad (3)$$

Relative frequency ratio $y(t)$ cannot be determined by measuring. Time discrepancy $x(t)$ of the test oscillator is calculated by:

$$x(t) = \int_0^t y(t)dt = \frac{1}{2\pi f_0}\left(\varphi(t) - \varphi(t_0)\right). \qquad (4)$$

Mean value of the relative frequency discrepancy $y(t_k,\tau)$ is determined from oscillator output using (4). It is related to time interval τ, starting from the moment t_k:

$$y(t_k,\tau) = \frac{1}{\tau}\int_{t_k}^{t_k+\tau} y(t)dt = \frac{1}{\tau}\left(x(t_k+\tau) - x(t_k)\right). \qquad (5)$$

Allan's variance is used as a measure of frequency stability in a time domain, although it is not based on a physical model, but on empirical results of their testing. It is calculated using the following equation:

$$\begin{aligned}\hat{\sigma}_y^2(\tau) &= \frac{1}{2(N-2n+1)}\sum_{k=1}^{N-2n+1}\left(\bar{y}_{k+n} - \bar{y}_k\right)^2 \\ &= \frac{1}{2(N-2n+1)}\sum_{k=1}^{N-2n+1}\left(\frac{x_{k+2n} - 2x_{k+n} + x_k}{n\tau_0}\right)^2\end{aligned} \qquad (6)$$

with mean relative frequency discrepancy $\bar{y}_k$ for the interval τ:

$$\bar{y}_k = \frac{1}{n}\sum_{i=k}^{k+n-1} y_i. \qquad (7)$$

Modified Allan's variance $\mathrm{mod}\,\sigma_y^2(\tau)$ and time variance $\sigma_x^2(\tau)$ are derived from (5) [1]:

$$\begin{aligned}\mathrm{mod}\,\sigma_y^2(\tau) &= \frac{1}{2n^2\tau^2(N-3n+1)}\sum_{j=1}^{N-3n+1}\left(\sum_{i=j}^{j+n-1}\left(x_{i+2n} - 2x_{i+n} + x_i\right)\right)^2 \\ \sigma_x^2(\tau) &= \frac{\tau^2}{3}\,\mathrm{mod}\,\sigma_y^2(\tau)\end{aligned} \qquad (8)$$

Allan's variance $\sigma_y^2(\tau)$ shows a typical dependence related to averaging interval, which can be written as [2]:

$$\sigma_y^2(\tau) \sim \tau^{\mu} \Rightarrow \sigma_y(\tau) \sim \tau^{\eta}. \qquad (9)$$

Exponent μ determinates predominantly process type and it can be identified as a slope of averaging line, when results are observed in a coordinate system with logarithmic axes.

Stability of the oscillator can also be observed in a frequency domain. Single-sided spectral density $S_y(f)$, i.e. Fourier transformation of a random process y_k encompasses all information about oscillator stability. For Fourier frequencies $0 < f < f_k$, it has the following structure:

$$S_y(f) = \sum_{\alpha=-2}^{2} h_\alpha f^\alpha = h_{-2}f^{-2} + h_{-1}f^{-1} + h_0 f^0 + h_1 f^1 + h_2 f^2, \qquad (10)$$

with coefficients h_α characterizing the intensity of noise and border frequency of the system f_k. The exponent α is connected with the exponent in time domain μ by:

$$\alpha = -\mu - 1. \qquad (11)$$

According to changes of phase pseudo ranges on GPS L1 frequency (1575,42 MHz), relative frequency ratio $y(t)$ is obtained by:

$$y(t) = \frac{L(t+\tau_0) - L(t)}{c_0\tau_0}, \qquad (12)$$

with phase measurement $L(t)$ for the epoch t, phase measurement $L(t+\tau_0)$ for the epoch $t+\tau_0$, measuring interval τ_0, speed of light c_0. Value of 1 s is chosen for the measuring interval.

Ionospheric delay is not taken into account during the calculation of relative frequency discrepancies because the period of ionosphere state change is much longer than the basic data collection interval, even in contrary weather conditions. Hopfield model showed similar situation also for the tropospheric refraction, because corresponding correction changed sporadically from one epoch to another within the range of 1-2 mm. Interpolation of precise ephemerides and time discrepancies of satellite clocks is performed by Lagrange polynomial expressions of 17th degree, which assures the millimetre accuracy level. Interpolated satellite positions are corrected for the eccentricity of satellite antennas and signal path time.

3. EXPERIMENT AND RESULTS

Observables tested in the experiment are phase measurements on GPS L1 for a reference satellite. Data from 30 permanent stations are obtained by downloading RINEX files from Reference station web-server [3]. All data referred to the same date (November 30th 2008) and 24 hours time period. Selection of date and time window for data collected one can choose from the web form (Fig. 1).

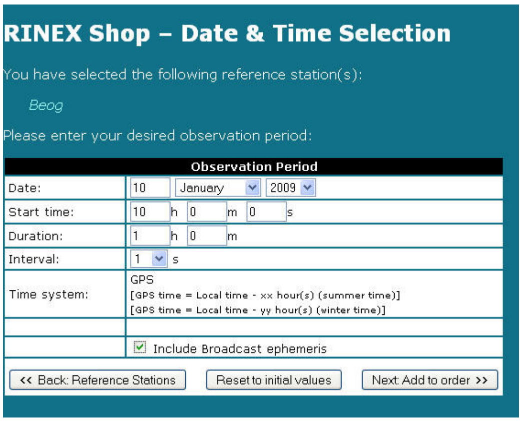

Fig. 1 Date and time selection

Three types of GPS receivers encompass AGROS: Trimble NetRS, Trimble 5700 and Trimble 4000. Random frequency instability in the time-domain is defined by relations (6) and (8). Obtained results for $\sigma_y^2(\tau)$ and $\mathrm{mod}\,\sigma_y^2(\tau)$ fall between 10^{-5} and 10^{-9}. The calculation was performed using MatLab.

Power spectral densities for tested receivers are calculated by programming a custom LabView 8.5 virtual instrument. The block diagram of the virtual instrument is shown in the Fig. 2.

Raw data were converted from RINEX to plain ASCII, with one observable per row. The data was imported into the virtual instrument (*.vi file) and, together with certain pre-processing options, transferred to the input of `psd` command, the MathScript utility for calculating the spectral density. Pre-processing method (none, linear or mean), number of overlapping elements, sampling frequency, and the length of Fast Fourier Transformation can be altered via the application's front panel.

The output results are graph of power spectral density, power fit function, and time-domain exponent, with descriptive type of random process type derived from the calculated numerical value (table 1).

The layout of the front panel is presented in Fig. 3.

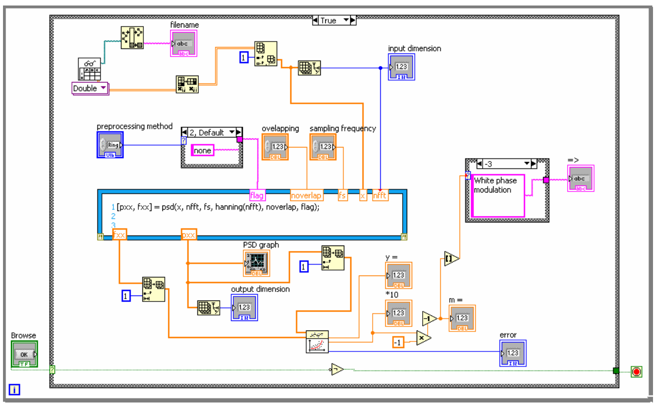

Fig. 2 Block diagram of the virtual instrument

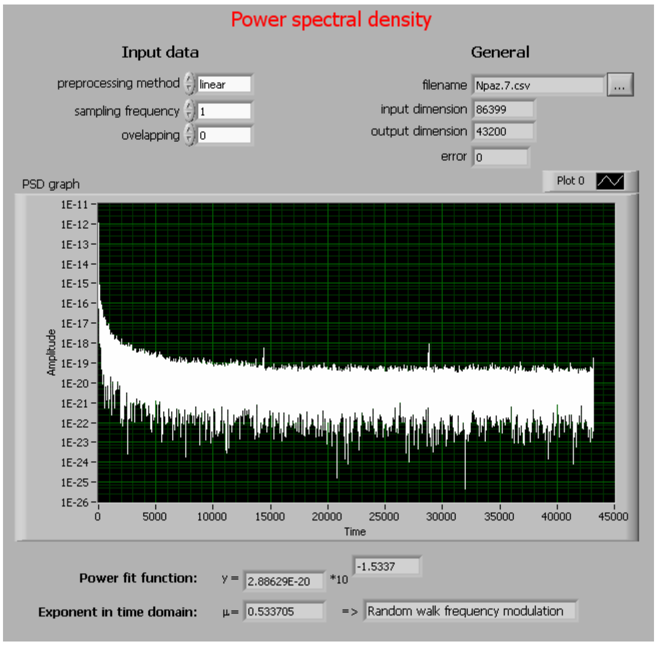

Fig. 3: Application front panel

Two specific graphs of power spectral densities that occurred in our experiment are given in Fig. 4 and Fig. 5.

Coefficient α (11) is estimated from slopes of power spectral densities, which are fitted with power function. Distributions of noise types [6] obtained in the experiment are presented in Table 1.

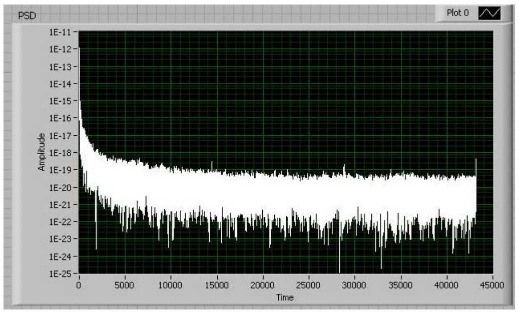

Fig. 4 Power spectral density for station BAJI

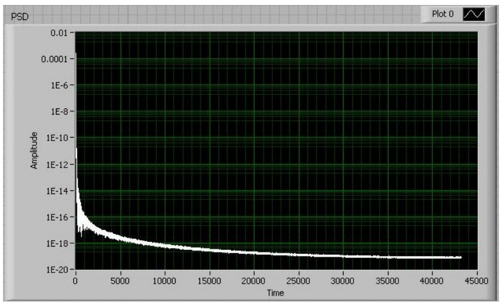

Fig. 5 Power spectral density for station SID

Table 1: Functional characteristics of noise processes

Random process type	µ	#
White phase modulation (WPM)	-3	0
Flicker phase modulation (FPM)	-2	0
White frequency modulation (WFM)	-1	0
Flicker frequency modulation (FFM)	0	17
Random walk freq. modulation (RWFM)	+1	13

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Comparing the exponents in time domain µ between different types of receivers showed that older devices (Trimble 4000 receivers) have less stable oscillators than those of type 5700. Type Trimble 4000 receivers were purchased in mid 90's and for years used in regular geodetic surveys, after installation in AGROS network. The reason of obtained results for type 4000 should be, among other factors, aging of the oscillators.

However, several Trimble 5700 type receivers showed similar results for power spectral densities. The aging cannot influence their results because all 5700 receivers are not older than 7 years. After the investigation of the surrounding of the places where those receivers are mounted, several sources of radiation were founded, so the probable reason for obtained results could be the interference.

Fig. 6 Permanent station KRAL

According to [5], in the case of interference, navigation data is not received. That conclusion was proved in the case of the station KRAL. Fig. 6 shows the displacement of the antenna of the station KRAL. On the right side of the picture there is a communication antenna construction, which is the probable cause of the interference. After several attempts to download and process the data from KRAL, we discovered that data from L2 frequency was not logged at all.

Three more stations, VRSA, INDJ, and SID (Fig. 1), will be, also, moved to new positions, because the users reported the failures during measurements. Calculated Allan variances and power spectral densities confirmed that certain sources of biases exist on all stations.

A lot of factors can influence oscillator stability. Environmental changes can cause large frequency instabilities. For example, station INDJ is located near to the street with high frequency traffic, with high magnitude changes (tens of dB). Other factors of oscillators' instability are: time, temperature, acceleration, ionised radiation.

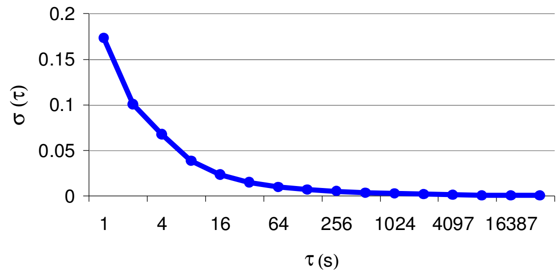

Fig. 7 Allan variance for the station BAJI

Typical graph of Allan variance for type 5700 receiver is presented in the Fig 7.

However, Allan variance graphs for VRSA, INDJ, and SID showed different trend lines (Fig. 8), which indicate biases due to environmental conditions.

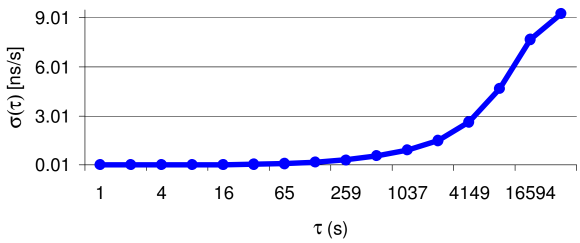

Fig. 8 Allan variance for the station SID

In the case of the station LOZN, Allan variance graph (Fig. 9) follows the typical trend line. According to that, a conclusion can be drawn that collected data is correct. However, when analysing the power spectral density graph (Fig. 10), the specific pattern occurs, which indicates periodical disturbances of an unknown source. Within one sidereal day (24 h session), due to changes in satellite geometry, the influence of multipath effects on phase carrier shows a periodical behaviour [5]. Typical period is 15-30 min, depending on environmental conditions.

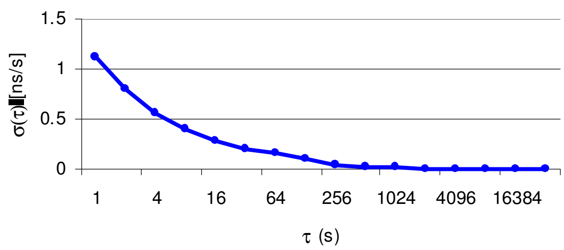

Fig. 9 Allan variance for the station LOZN

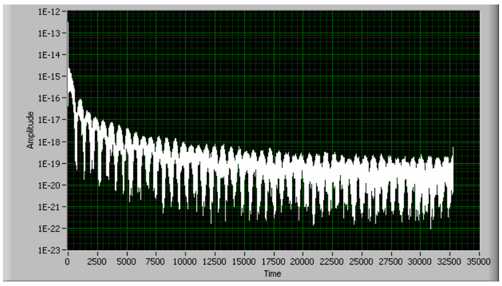

Fig. 10 Power spectral density at the station LOZN

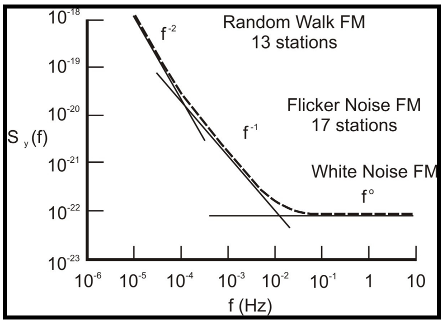

Fig. 11 Distribution of random process types

Oscillators of older receivers (Trimble 4000 series) have random walk frequency modulation noise, mostly because of aging. Also, several modern receivers (Trimble 5700 series) follow the same noise type (RWFM), due to environmental conditions, which makes a total of 13 receivers with RWFM noise type.

Oscillators of all other Trimble 5700 receivers (17 in total) have flicker frequency modulation (FFM).

There are no receivers with white frequency modulation noise type (WFM).

4. CONCLUSIONS AND REMARKS

Obtained results of the experiment showed that older types of GPS receivers have larger Allan's variances. Also, some of modern receivers had similar results. Reasons of such results should be analyzed further, by investigating the environment, particularly multipath reflection, vibrations and radiation. GPS antennas of permanent stations are not calibrated, neither absolutely, nor relatively, which is also a possible reason of obtained results.

Analyzing the noise types from Table 1 and Fig. 11, one can see that oscillators showed only two different functional characteristics, flicker frequency modulation (FFM) and random walk frequency modulation (RWFM).

Since that tested receivers form the active reference GPS network of Serbia, it is extremely important to have at least relative field calibration, although an absolute calibration of GPS antennas is recommended.

GPS receivers should be replaced with receivers having 1 pulse per second (1PPS) output, in order to perform their direct calibration. They should also be equipped with external standard, for example, rubidium oscillator.

Before the mounting of new receivers, one of mitigation techniques of multipath reflection should be used (antenna location, choke-ring antenna, receivers with advanced multipath reduction algorithm).

ACKNOWLEDGMENTS

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