TESTING THE STABILITY OF THE GNSS RECEIVER OSCILLATOR

Siniša Delčev, Jelena Gučević, Olivera Vasović Šimšić

Keywords: Allan standard; frequency oscillators; GNSS receiver; stability

ABSTRACT

With the development of GNSS technology, receivers have become smaller, lighter and more compatible. The improvement is also reflected in the application of better and more reliable components. Among others, one of the main components of the receiver should be singled out - the frequency (time) oscillator. Oscillator stability is one of the sources of GNSS receiver errors that are tested under real conditions. The paper deals with the comparison of the stability of receiver oscillators from different eras (from 15 years ago and now). It is generally accepted that the properties and types of oscillators are determined by applying the Allan standard [1], [2]. By comparing the measurement data and Allan's standards, it can be concluded that the oscillators of the newer generation are more stable compared to the older versions.

ISPITIVANJE STABILNOSTI OSCILATORA GNSS PRIJEMNIKA

Ključne reči: Alanov standard, frekvencija oscilatora, GNSS prijemnik, stabilnost

KRATAK SADRŽAJ

Sa razvojem GNSS tehnologije, prijemnici su postali manji, lakši i kompatibilniji. Poboljšanje se ogleda i u primeni boljih i pouzdanijih komponenti. Između ostalih, treba izdvojiti jednu od glavnih komponenti prijemnika – frekvencijski (vremenski) oscilator. Stabilnost oscilatora je jedan od izvora grešaka GNSS prijemnika koji se testiraju u realnim uslovima. Rad se bavi poređenjem stabilnosti oscilatora prijemnika iz različitih epoha (od pre 15 godina i sada). Opšte je prihvaćeno da se svojstva i tipovi oscilatora određuju primenom Alanovog standarda [1], [2]. Upoređivanjem mernih podataka i Alanovih standarda, može se zaključiti da su oscilatori novije generacije stabilniji u odnosu na starije verzije.

INTRODUCTION

Due to the development of technology for their production, GNSS receivers have become more compact, smaller, lighter, etc., compared to older models. The advantage of new GNSS receivers' models is also reflected in some new functions, such as eBubble, and IMU sensor, which have achieved greater efficiency in operation. Thanks to improvements in GNSS receiver manufacturing and data processing, as well as the appearance of new and improved existing GNSS constellations, the accuracy of measurements has also increased.

To prove the accuracy of the GNSS receiver position measurements, it is necessary to perform its calibration in real-world operating conditions. One of the most important components of a GNSS receiver is its oscillator, i.e. oscillator stability. An oscillator generates constant frequency oscillations that are used to measure time [3]. Any deviation from the nominal frequency causes an error in the measured length [4], i.e. pseudo length between a GNSS receiver and a satellite. For economic reasons, quartz oscillators are installed in GNSS receivers, which are of lower quality than those installed in GNSS satellites (the atomic clocks). Quartz oscillators change their characteristics over time, i.e. can change the broadcast frequency.

Alan's standard is generally accepted as an indicator of oscillator quality [5]. In addition to indicators of oscillator stability, this standard can also define the type of oscillator (clock) [6].

Allan standard

The Allan variance (AVAR) is named after David W. Allan and is expressed mathematically as $\sigma_y^2(\tau)$. It is also known as the two-sample variance. It is a statistical measure of frequency stability in clocks, oscillators and amplifiers. The Allan deviation (ADEV) is the square root of the Allan variance, $\sigma_y(\tau)$.

The *M*-sample variance is a measure of frequency stability using *M* samples, the time *T* between measurements, and the observation time τ. The *M*-sample variance is expressed as (1):

$$\sigma_y^2(M,T,\tau) \tag{1}$$

Allan's variance assesses stability due to noise processes, not systematic errors or imperfections such as frequency drift or temperature effects. Allan variance and Allan deviation describe frequency stability.

There are different variations and modifications of the Allan variance, of which the modified Allan variance (MAVAR) or the total variance (MVAR) and Hadamard variance should be emphasized. Time-stability variants such as time deviation (TDEV) and time variance (TVAR) are also used. The Allan variance and its alternatives have proven extremely useful outside the scope of timing and are a set of improved statistical tools used whenever noise processes are not unconditionally stable, thus a derivative exists.

The overall *M*-sample variance is important because it allows dead time to occur in the measurements, and bias functions allow conversion to Allan variance values. For most applications of greatest interest is the special case with 2 samples - the "Allan variance" with $T=\tau$.

Allan's variance is defined as half the time average of the squared differences between consecutive peak frequency readings sampled during the measurement period. Allan's variance depends on the period between samples. Therefore, it is a function of the sample period, denoted as τ, so is the distribution being measured. Allan's variance is not displayed as a single number but as a graph. A clock with good frequency stability over the measured period has a small Allan variance value.

Alan's deviation is most often shown with a diagram (usually with log-log axes) but also with numbers. Since it provides relative amplitude stability, it can be easily compared with other sources of error.

Allan's deviation from $1\cdot10^{-9}$ in the period of observation of 1 s (τ=1 s) should be interpreted as frequency instability between two observations 1 second apart with a relative Root Mean Square (RMS) of $1\cdot10^{-9}$. For a 10 MHz clock, this is equivalent to a 10 mHz RMS sweep. Time deviation variants should be used for the phase stability of the oscillator.

Given a time-series $x(t)$, for any positive real numbers T, τ, define the real number sequence:

$$\bar{y}_i = \frac{x(iT+\tau)-x(iT)}{\tau} \quad i=0,\ 1,\ 2,\ ... \tag{2}$$

Then the M-sample variance is defined as the Bessel-corrected variance of the sequence $(\bar{y}_0, \bar{y}_1, \ ... \bar{y}_{M-1})$:

$$\sigma_y^2(M,T,\tau) = \frac{M}{M-1}\left[\frac{1}{M}\sum_{i=0}^{M-1}\bar{y}_i^2 - \left(\frac{1}{M}\sum_{i=0}^{M-1}\bar{y}_i\right)^2\right] \tag{3}$$

where:

t – is reading on the reference clock (in arbitrary units);

$x(t)$- is the reading of the clock under test (in arbitrary units), as a function of the reading of the reference clock. It can also be interpreted as an average fractional frequency time series;

$\bar{y}_n$ - is the n-th fractional frequency average over the observation time τ;

M - is the number of clock reading intervals used in computing the M-sample variance;

T - is the time between each frequency sample;

τ - is the time length of each frequency estimate, or the observation period.

Dead-time can be accounted for by letting the time T be different from that of τ.

The Allan variance is defined as:

$$\sigma_y^2(\tau) = \left\langle \sigma_y^2(2,\tau,\tau)\right\rangle = \frac{1}{2}\left\langle \left(\bar{y}_{n+1}-\bar{y}_n\right)^2\right\rangle = \frac{1}{2\tau^2}\left\langle \left(x_{n+2}-2x_{n+1}+x_n\right)^2\right\rangle \tag{4}$$

where ⟨...⟩ denotes the expectation operator.

The condition T=τ means the samples are taken with no dead time between them.

The Allan deviation is defined as the square root of the Allan variance:

$$\sigma_y(\tau) = \sqrt{\sigma_y^2(\tau)} \tag{5}$$

METHODS AND PROCEDURES

For calculation of Allan’s deviation measurements over a longer period are required, for the results to be as objective as possible. Therefore, for this experiment, each GNSS receiver logged data for at least 90 minutes. GNSS receivers were set to have a registration interval of 1 second. The GNSS receiver test polygon was positioned in an open sky environment, ensuring that there were no obstacles in the area that could obstruct the satellite signals.

RESULTS AND DISCUSSION

After logging in, the data from the GNSS receiver was copied to the computer and transferred to the RINEX format using the appropriate software. From the collected data based on the moments of signal registration from the GNSS satellite, differences were made from the registration interval, i.e. 1 second, up to 10^{-12} seconds. Based on these differences, the file needed for further calculations was created (Figure 1).

```
   0.        0.000000551484
   1.        0.000001102935
   2.        0.000001654343
   3.        0.000002205773
   4.        0.000002757234
   .........................
6007.        0.003292279602
6008.        0.003292825865
6009.        0.003293372161
6010.        0.003293918390
6011.        0.003294464587
```

Figure 1. Allan standard calculation file layout.

Further processing was done in the software AlaVar 5.2 (by Alaa Makdissi) [7].

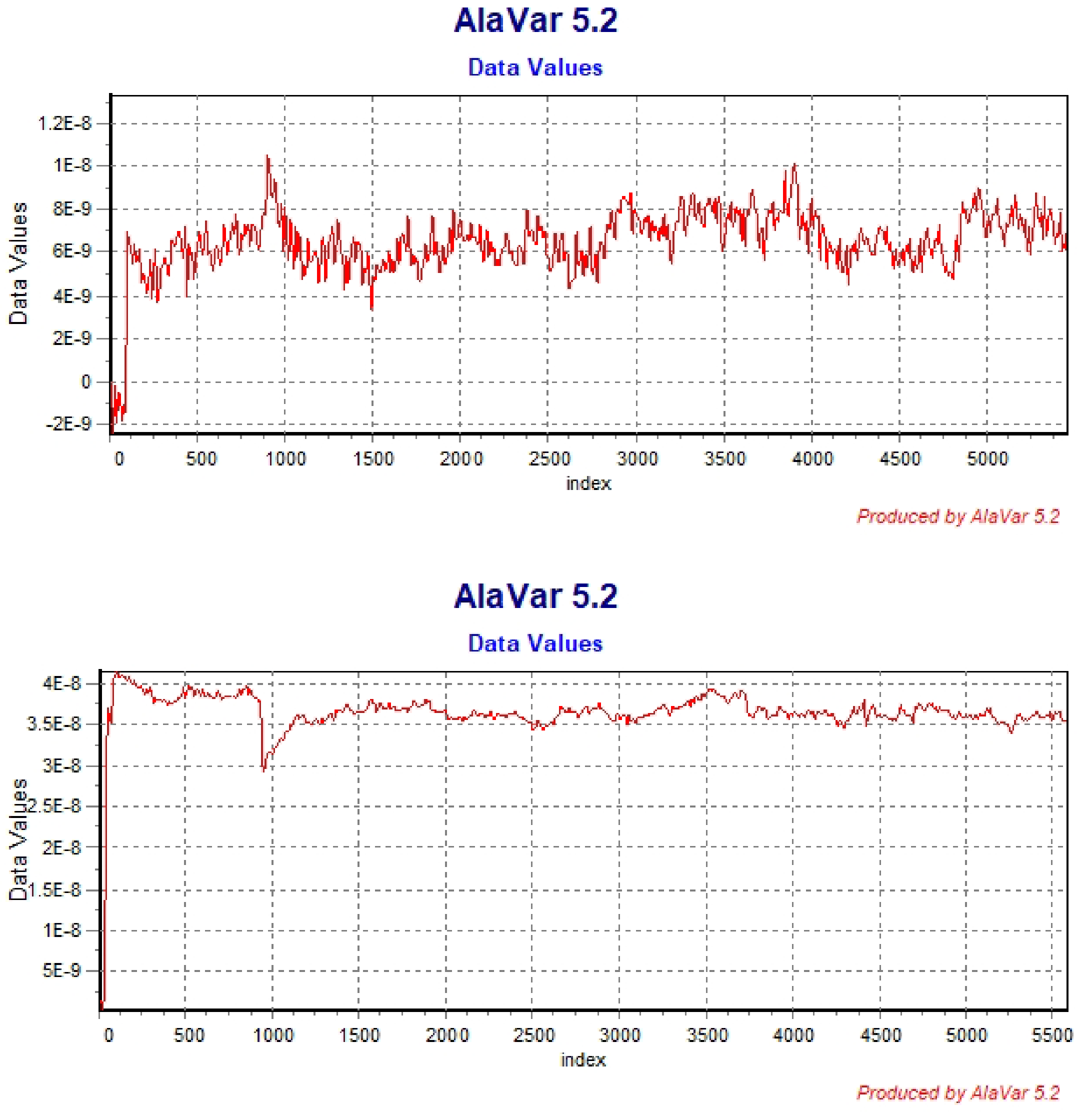
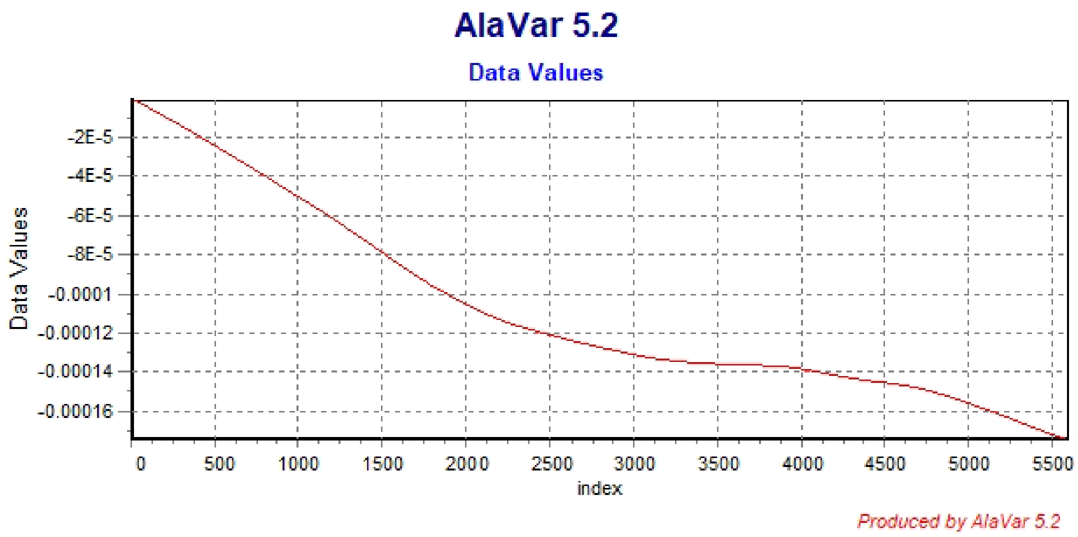


Figure 2. Deviations from the interval 1 s - older GNSS receivers, models manufactured before 2009 (Leica and Sokkia)

Deviations from the nominal interval of 1 s are shown in the diagrams. Figure 2 shows an example of how the differences look with GNSS receivers manufactured before 2009 (it is similar to some other models), and Figure 33 with newer ones (manufactured after 2015). It appears that older models of GNSS receivers exhibit a distinct period, typically lasting 1-2 minutes, at the beginning of data registration that differs significantly from the subsequent measurements. This can be interpreted as the "warming up" period of the oscillator, that is, as the time interval required by the oscillator to achieve operational stability.



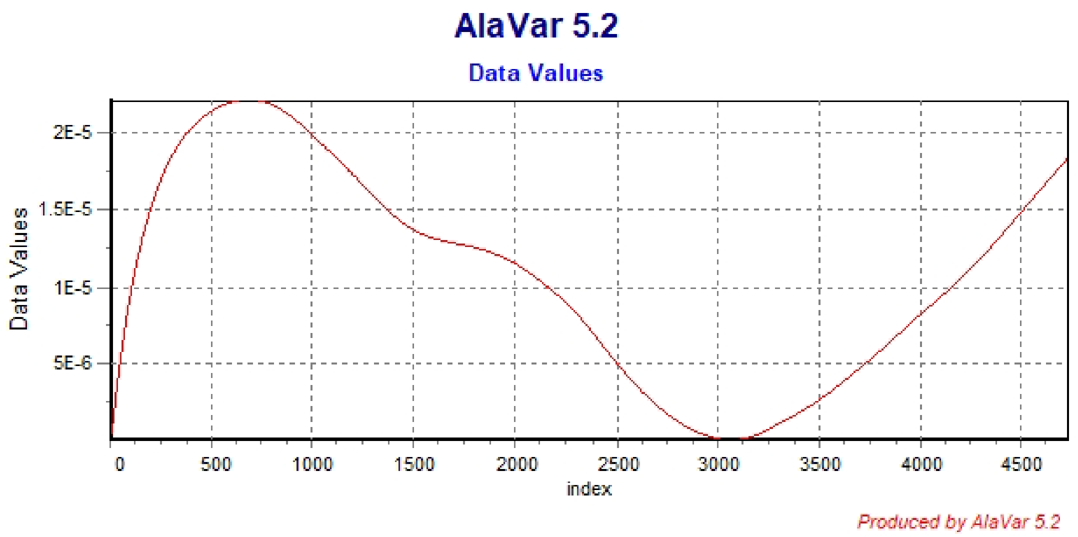


Figure 3. Deviations from the interval 1 s - GNSS receivers of the newer generation, manufactured after 2015 (Stonex and Ruide)

During data processing in the AlaVar software, the calculation option "Phase to frequency" with an interval of τ=1 s and the level of significance (confidence) 1σ (i.e. 0.683) was used. In the major number of cases, as a result of the measurement processing in the software, the message "The noise type for The phase data is White FM" appeared, while in a smaller number of cases the noise type "White PM" was displayed.

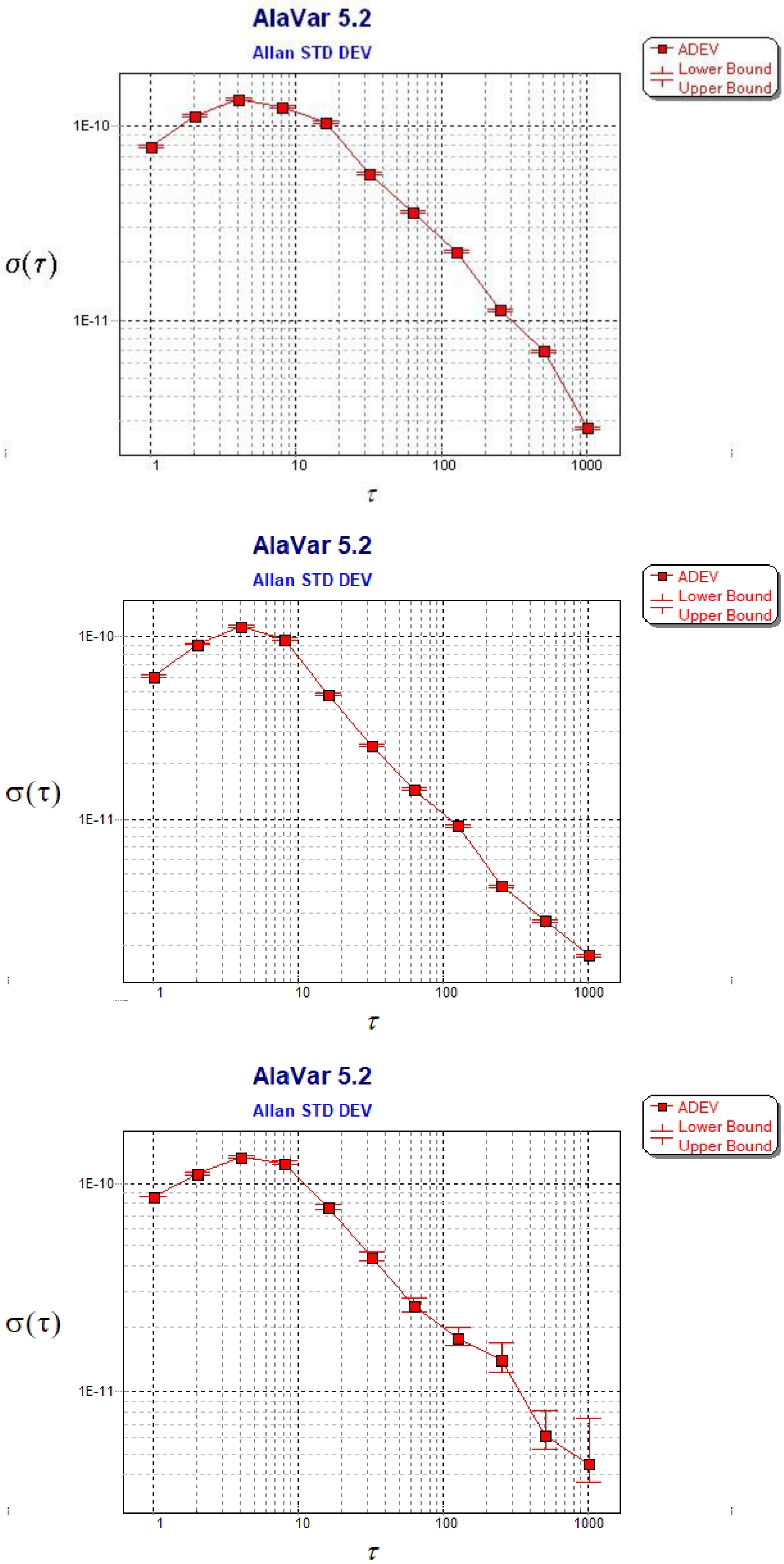
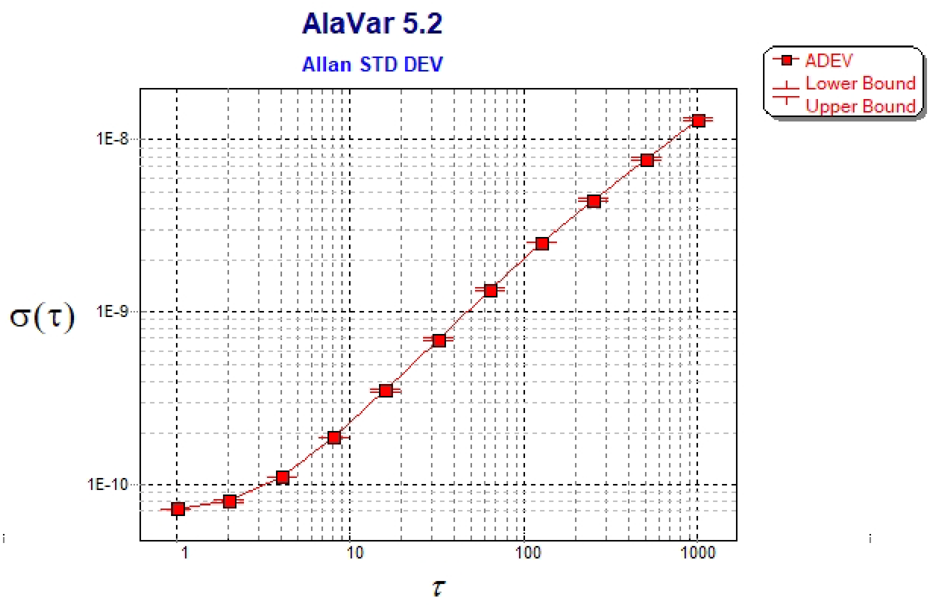
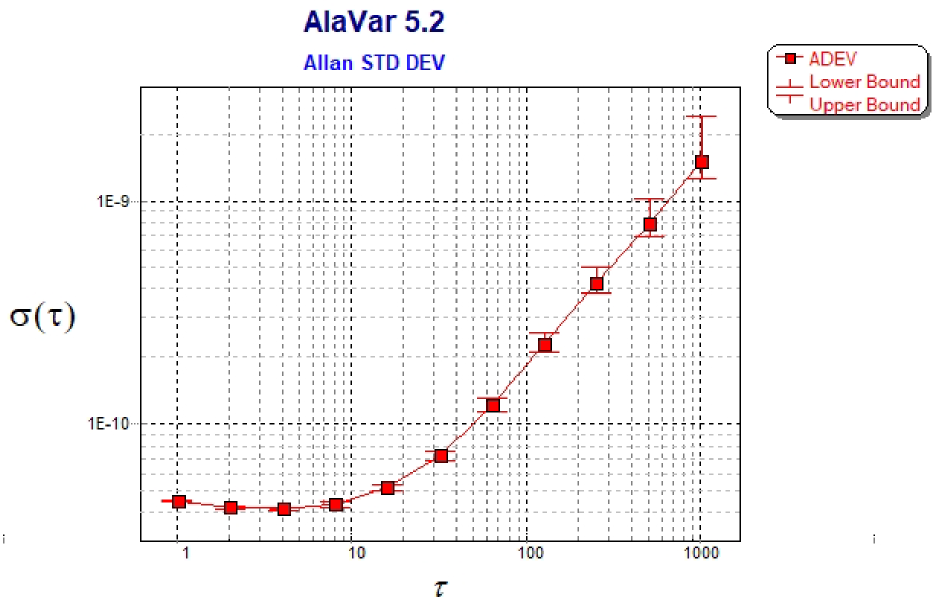


Figure 4. ADEV, GNSS receivers manufactured before 2009 (Leica, Sokkia and Topcon)

The next output from the AlaVar software is an Allan deviation plot (ADEV) with log-log axes. It is indicative that all ADEV diagrams of older GNSS receivers are almost identical - they have the same trend (Figure 4), i.e. oscillators belong to the same type.

For newer models of GNSS receivers (Figure 5), the ADEV trend is different, i.e. the standard is smaller at shorter time intervals and increases with increasing interval τ. This means that the type of oscillators built into newer models of GNSS receivers is different. This makes sense, as a new model of GNSS receivers is manufactured to be used more in Real-Time Kinematic (RTK) mode with a shorter registration period.





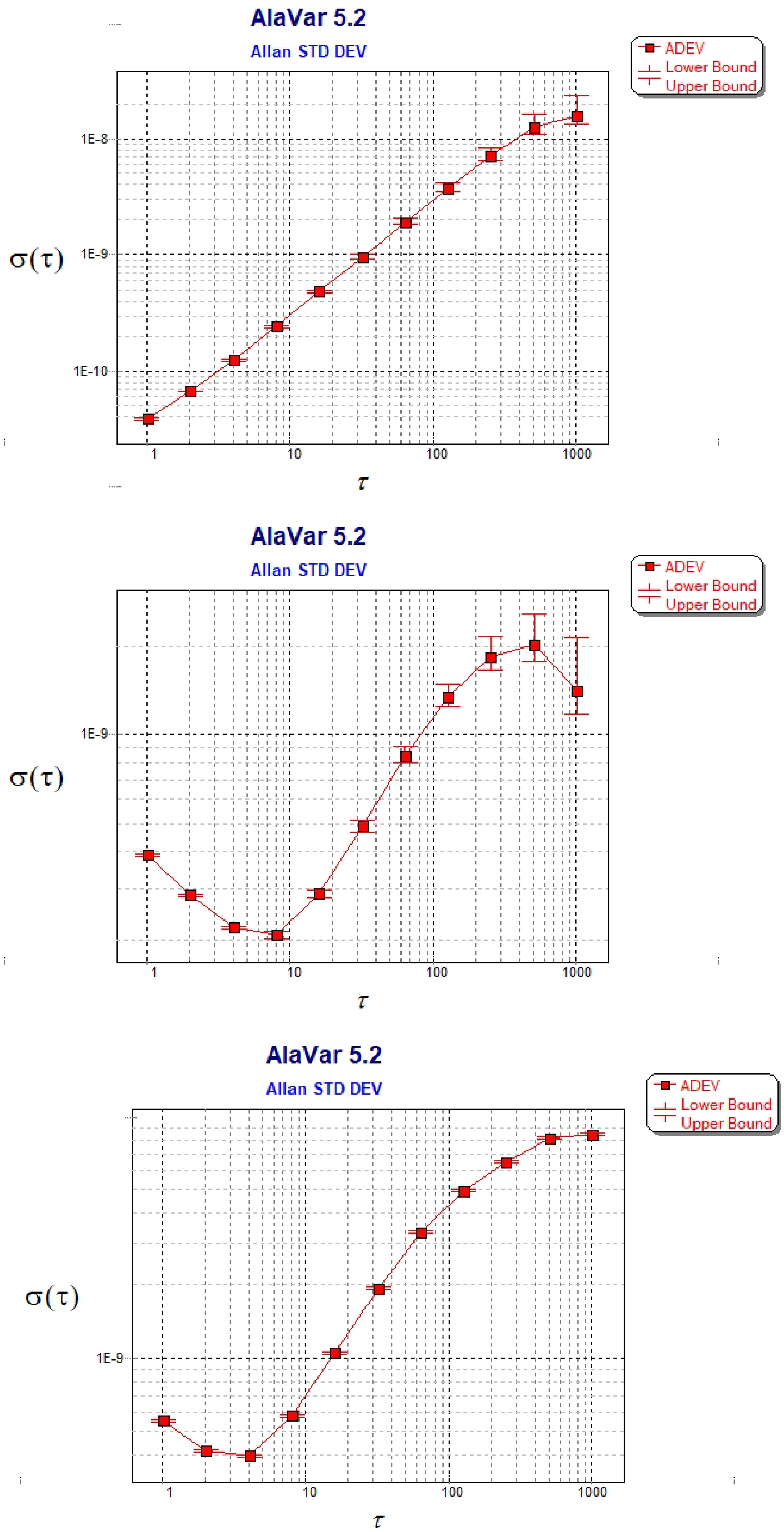


Figure 5. ADEV for GNSS receivers manufactured after 2015 (Stonex, Trimble, Topcon, Foif and Ruide)

Table 1. ADEV for each GNSS receiver examend

	τ	1	32	256	1024
Year	Model	[s]	[s]	[s]	[s]
Before 2009	Leica	$7{,}85 \cdot 10^{-11}$	$5{,}70 \cdot 10^{-11}$	$1{,}13 \cdot 10^{-11}$	$2{,}77 \cdot 10^{-12}$
	Sokkia	$6{,}09 \cdot 10^{-11}$	$2{,}53 \cdot 10^{-11}$	$4{,}21 \cdot 10^{-12}$	$1{,}77 \cdot 10^{-12}$
	Topcon	$8{,}61 \cdot 10^{-11}$	$4{,}43 \cdot 10^{-11}$	$1{,}43 \cdot 10^{-11}$	$4{,}43 \cdot 10^{-12}$
After 2015	Stonex	$7{,}14 \cdot 10^{-11}$	$6{,}89 \cdot 10^{-10}$	$4{,}48 \cdot 10^{-09}$	$1{,}32 \cdot 10^{-08}$
	Trimble	$4{,}46 \cdot 10^{-11}$	$7{,}19 \cdot 10^{-11}$	$4{,}31 \cdot 10^{-10}$	$1{,}53 \cdot 10^{-09}$
	Topcon	$3{,}87 \cdot 10^{-11}$	$9{,}65 \cdot 10^{-10}$	$7{,}22 \cdot 10^{-09}$	$1{,}60 \cdot 10^{-08}$
	Foif	$3{,}87 \cdot 10^{-10}$	$4{,}88 \cdot 10^{-10}$	$1{,}84 \cdot 10^{-09}$	$1{,}47 \cdot 10^{-09}$
	Ruide	$5{,}49 \cdot 10^{-10}$	$1{,}95 \cdot 10^{-09}$	$6{,}52 \cdot 10^{-09}$	$8{,}48 \cdot 10^{-09}$

Table 1 shows the ADEV for different GNSS receiver models and different τ intervals. Table 1 confirms the assertions regarding the characteristics of the oscillator. In older models, the ADEV value is smaller at longer intervals (τ), while with newer models, it is smaller at shorter intervals. This aligns with the usage patterns, where static GNSS mode measurement was predominantly used in the past, whereas RTK mode is now prevalent.

CONCLUSIONS

The Allan standard is commonly adopted as a reference for studying oscillator characteristics. Using this standard, oscillators of GNSS receivers manufactured in different periods were tested. Testing was performed in static measurement mode by collecting data from the GNSS satellite for at least 90 minutes with a registration period of 1 s. Data processing was performed using the AlaVar 5.2 software.

By comparing the processing results (graphs and tables), it can be concluded that oscillators in GNSS receivers from an earlier period (manufactured before 2009) differ from modern ones (manufactured after 2015). In older GNSS receivers, the stability of the oscillator is better over a longer time interval, and in modern ones over a shorter interval. This corresponds to the way GNSS receivers are used. Previously, the static method of GNSS measurement (lasting from 15 minutes to 2-3 hours) was commonly employed. Now, especially with establishing networks of permanent GNSS stations, the RTK method is widely used, with measurements lasting from a few seconds to 1 to 2 minutes.

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Prof. Siniša Delčev, Ph.D., Geod. Eng.
Faculty of Civil Engineering Subotica
University of Novi Sad
24000 Subotica
Serbia
email address: delcevs@gf.uns.ac.rs

Prof. Jelena Gučević, Ph.D. Geod. Eng.
Faculty of Civil Engineering Subotica
University of Novi Sad
24000 Subotica
Serbia
email address: jgucevic@gf.uns.ac.rs

Olivera Vasović Šimšić, Msc. Geod. Eng.
Department School of Civil Engineering and Geodesy of Applied Studies
Academy of Technical and Art Applied Studies Belgrade
11000 Belgrade
Serbia
email address: oliveravasovic@vggs.rs