

USING GLONASS SIGNAL FOR CLOCK SYNCHRONIZATION

Prof. Yuri G.Gouzhva, Prof. Arvid G.Gevorkyan,
Dr. Pyotr P.Bogdanov, Dr. Vitaly V. Ovchinnikov

Russian Institute of Radionavigation and Time
2, Rastrelli square, St-Petersburg, 193124, Russia

Abstract

Although in accuracy parameters GLONASS is correlated with GPS, using GLONASS signals for high-precision clock synchronization was up to the recent time of limited utility due to the lack of specialized time receivers. In order to improve this situation, in late 1992 the Russian Institute of Radionavigation and Time (RIRT) began to develop a GLONASS time receiver using as a basis the airborne ASN-16 receiver. This paper presents results of estimating user clock synchronization accuracy via GLONASS signals using ASN-16 receiver in the direct synchronization and common-view modes.

INTRODUCTION

At present the use of satellite navigation system signals is one of the most high-precision ways to clock synchronization on global scale. Various aspects of time synchronization via GPS signals are discussed in diverse references, for example [1, 2]. Over the last 2 - 3 years, several experiments of time synchronization via GLONASS signals were also held [3, 4]. But using GLONASS signals for clock synchronization was limited for a long time because the lack of commercial time receivers. Therefore RIRT carried out a number of experiments to estimate the possibility of using the commercial airborne ASN-16 receiver as the GLONASS time receiver. Results of these experiments and its analysis are presented in this paper. This results demonstrate that the use of ASN-16 gives the clock synchronization accuracy about 20 ns for one day in a direct synchronization mode and about 10 ns for one day in a common-view mode. To provide the automation of the measurements and their processing the interface between ASN-16 and PC was held.

BRIEF ANALYSIS OF GLONASS

The full-deployed Russian GLONASS should consist of 24 satellites placed within three orbital planes by 8 satellites each plane [5]. The orbital planes are separated by 120° . Satellite orbits are the circular ones with eccentricity less than 0,01, revolution period of 11 h 45 min, altitude of 19100 km and inclination of 64.8° .

Now the space segment consists of 12 - 15 healthy satellites disposed in first and third orbital planes. The satellites are equipped with a cesium time/frequency standard with daily frequency instability no more than $5 \cdot 10^{-13}$ [5]. This provides accuracy of satellite time synchronization relative to System Common Time (SCT) about 15 ns (σ) with uploading time and frequency corrections (TFC) to the satellite twice a day.

SCT is generated on the basis of main synchronizer (MS) time. Hydrogen frequency standards with daily frequency instability no more than $5 \cdot 10^{-14}$ are used as a part of MS. The difference in SCT and UTC (SU) should be less than 1 ms. The accuracy of SCT corrections uploaded to the satellite once a day should be less than 35 ns (σ).

When UTC (SU) is corrected by an integer number of seconds, the time of all system components including SCT are corrected too. However, there exists a constant offset of 3 h between SCT and UTC (SU) due to GLONASS monitoring specific features. Full deployment of GLONASS is scheduled on the end of 1995 [6]. Besides flying tests of modernization satellite named GLONASS-M will start in 1994. The main characteristics of this satellite will be an increased satellite life (span up to 5 years) and use of a new spaceborne time/frequency standard with daily frequency instability no more than $1 \cdot 10^{-13}$. This enables to realize a synchronization of satellite times with an error not worse than 10 ns (σ) with uploading TFC to the satellite once a day. No special measures to degrade the GLONASS signal are planned.

CLOCK SYNCHRONIZATION VIA GLONASS SIGNALS

There are four main methods of clock synchronization via satellite navigation systems signals: direct synchronization, common-view, clock transportation and very-long base interferometry (VLBI) Techniques Over Short Baselines [1]. But the methods of the most utility are the first two ones, which principles are shown in Fig.1.

The direct synchronization method is the most simple. It provides the global coverage and requires no other data than those received from satellite navigation message. The time difference between the user clock and the SCT or UTC (SU) is given by the relationship (1):

$$\Delta T = S - (D/C - \tau_{ion} - \tau_{trop} - \tau_{rec}) + \Delta T_{sat} + \Delta T_{sct} \quad (1)$$

where
 S - measured pseudorange between the satellite and the user, i.e. the difference between two identical codes, one received by the receiver, whereas the other one generated by the receiver; each of these codes is synchronized by its own clock;
 D - range from the satellite to the user;
 C - speed of light;
 τ_{ion} - propagation delay due to the ionosphere;
 τ_{trop} - propagation delay due to the troposphere;
 τ_{rec} - receiver delay;
 ΔT_{sat} - difference between satellite clock and SCT;
 ΔT_{sct} - difference between SCT and UTC.

The range from the satellite to the user is computed on the basis of broadcasted ephemerides X_i, Y_i, Z_i and the known coordinates of the receiver antenna X_A, Y_A, Z_A . The difference between satellite clock and SCT is determined on the basis of TFC τ_i, γ_i . The difference between SCT and UTC is directly contained in the navigation message as a SCT correction τ_s .

Since GLONASS navigation messages doesn't include model's parameters for consideration for the ionosphere delay, the ionospheric correction is computed by the user on the basis of parameters which are autonomously stored in the receiver. The tropospheric delay is determined in a similar way.. The receiver delay is calculated by means of its periodical calibration. It follows from the relationship (1), that the clock synchronization accuracy while using direct technique is defined by the following components:

- the error of pseudorange measuring;
- the instability of receiver delay;
- the error of ionospheric and tropospheric influence consideration;
- the uncertainty of the antenna coordinates;
- the error of the satellite ephemerides;
- the error of the satellite clock;
- the error of SCT correction.

The last three components are dictated by GLONASS's characteristics. That's why the clock synchronization accuracy via GLONASS signals in a direct synchronization mode doesn't exceed tens of nanoseconds.

The common-view method is a technique of a mutual clock synchronization. It presupposed simultaneous measurements at the points of clock location via one of the satellite's signals and further exchange of the results of the measurements. In this case, mutual difference of clock times is determined from the relationship (2):

$$\Delta T_{A-B} = \Delta T_A - \Delta T_B \quad (2)$$

where $\Delta T_{A,B}$ - the result of determination of each clock's offset relative to SCT or UTC (SU) in conformity with (1).

It is obvious that, due to the elimination of several components, stipulated by GLONASS characteristics, which are common for A and B clock, its mutual synchronization accuracy increases. Therefore characteristics of the receivers which determine the potential clock synchronization accuracy are of great importance.

USE OF ASN-16 RECEIVER FOR CLOCK SYNCHRONIZATION

In order to estimate the possibility of using the commercial airborne GLONASS ASN-16 receiver as a time receiver, a number experiments was carried out in RIRT. The measurements were held simultaneously using two ASN-16 receivers on the basis of RIRT's secondary time/frequency standard (STFS). The uncertainty of the antenna coordinates was approximately 5 m.

The ASN-16 unit, designed by RIRT, is one-channel one-frequency navigation user equipment. While solving the time task it provides the operation via one chosen satellite with output of 1-Hz and the result of determination of the time difference between this signal and UTC (SU). That's why for clock synchronization via GLONASS signals using of ASN-16 an additional counter of a 1-Hz signal difference in ASN-16 output and user's clock is required. In order to eliminate this defect, one of ASN-16 receiver was reworked to provide a time task solving relative to the external signal of 1-Hz. As a result of this, the ASN-16 receiver takes part of a time receiver. The experiment configuration is shown in Fig.2.

The procedures of experiments were as follows. The 15-minute sessions of measurements were held every half of hour during the day. The data registrations took place every 15 seconds. Then average value $\bar{\Delta}T$ and root-mean-square value δ of the offset between STFS and UTC (SU) were estimated for each session, for every day and over all the interval of the measurements (the drift of the offset between STFS and UTC was eliminated). Simultaneously, the data received had been used for estimation of a mutual clock time difference measurements accuracy using ASN-16 as an average value $\bar{\Delta}T_m$ and rms value δ_m for each session, for every day and over all the interval of the measurements. The results for each session of measurements are given in Table 1, for every day and whole intervals - in Table 2.

The average value of time synchronization accuracy via GLONASS signals in the direct synchronization mode was 6.8 ns for session, 20.6 ns for one day and 23.3 ns for 5-day intervals for the serial ASN-16 receiver and 7.1 ns; 20.8 ns and 24.4 ns respectively for the reworked ASN-16 receiver. Practically absolute coincidence of the results proved that accuracy characteristics of ASN-16 had not become worse due to the reworking the receiver.

The systematic error of mutual synchronization of the clock with the two ASN-16 receivers was close to zero for a day, and the random error was 6.1 ns for a session, 10.3 ns for a day and 10.0 ns for the whole interval.

An approximate coincidence between the random error of the mutual synchronization of the clock for a session and that of the clock synchronization in direct synchronization mode can be explained by the fact that within one session the influence of the parts, stipulated by receivers characteristics, prevail upon the parts, stipulated by GLONASS characteristics. So there were no essential synchronization accuracy increase. However, for the averaging over a day, the clock synchronization accuracy in a common-view mode is twice better then for direct synchronization mode.

PROSPECTS FOR ASN-16 RECEIVER USE

In order to provide a wider use of ASN-16 as GLONASS time receiver the task of its interfacing with a PC was solved. This provides fully automatic process of measuring and data processing. Module of data exchange between ASN-16 and PC interface is a board installed in PC. With this interface module the setting of ASN-16 operation modes and the reception of the necessary measuring and processing data is provided. The rate of the data output from ASN-16 is 1 second with a period of change of 2 seconds.

The developed software for PC realizes as follows:

- the GLONASS state indication;
- measurements programs generating and realizing;
- data reception and registration;
- real-time time/navigation tasks solving;
- statistical processing and analysis of data;
- ASN-16 operation monitoring;
- data exchange with other users.

The creation of such a measurement system on the basis of ASN-16 receiver and PC will make possible more careful estimation of GLONASS characteristics as the time transfer system and to begin using GLONASS signals for high-precision clock synchronization.

CONCLUSION

The results of the experiments held in RIRT have shown that already at present GLONASS provides time synchronization accuracy about 10 - 20 ns. While using ASN-16 receiver, clock synchronization accuracy of 20 ns for one day in a direct synchronization mode and about 10 ns for a day in a common-view mode is provided.

The further increasing of time synchronization accuracy via GLONASS signals with ASN-16 may be realized using direct pseudorange measurements and solving a time task with PC.

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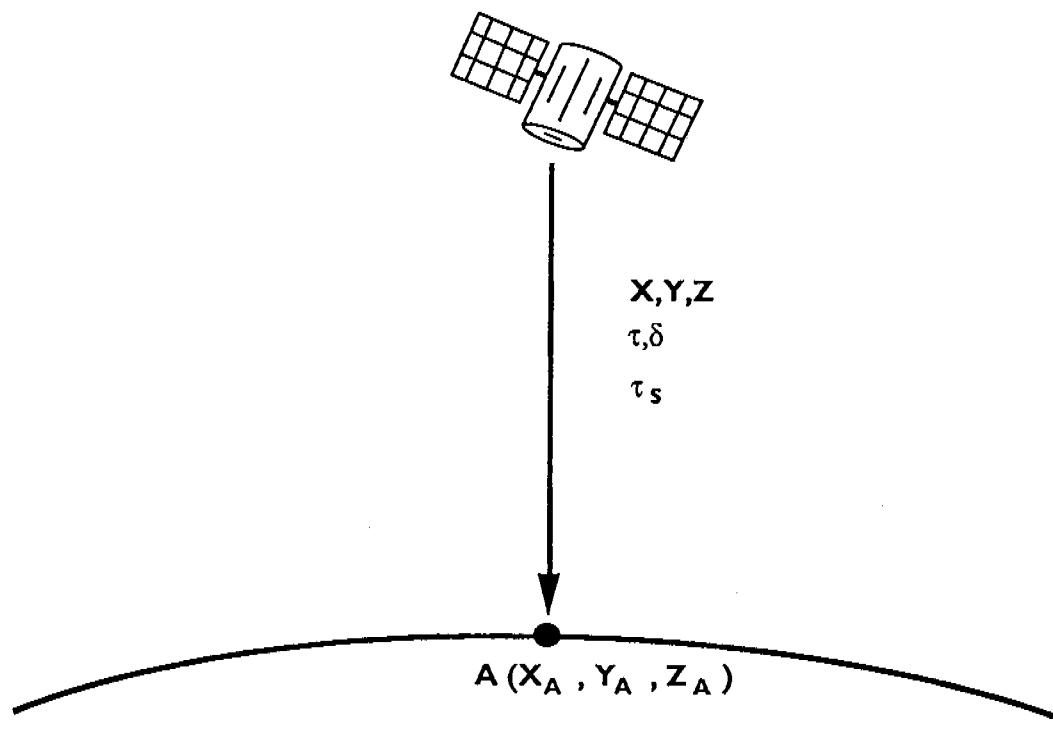
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Table 1. The estimations of time synchronization accuracy via GLONASS signals for sessions

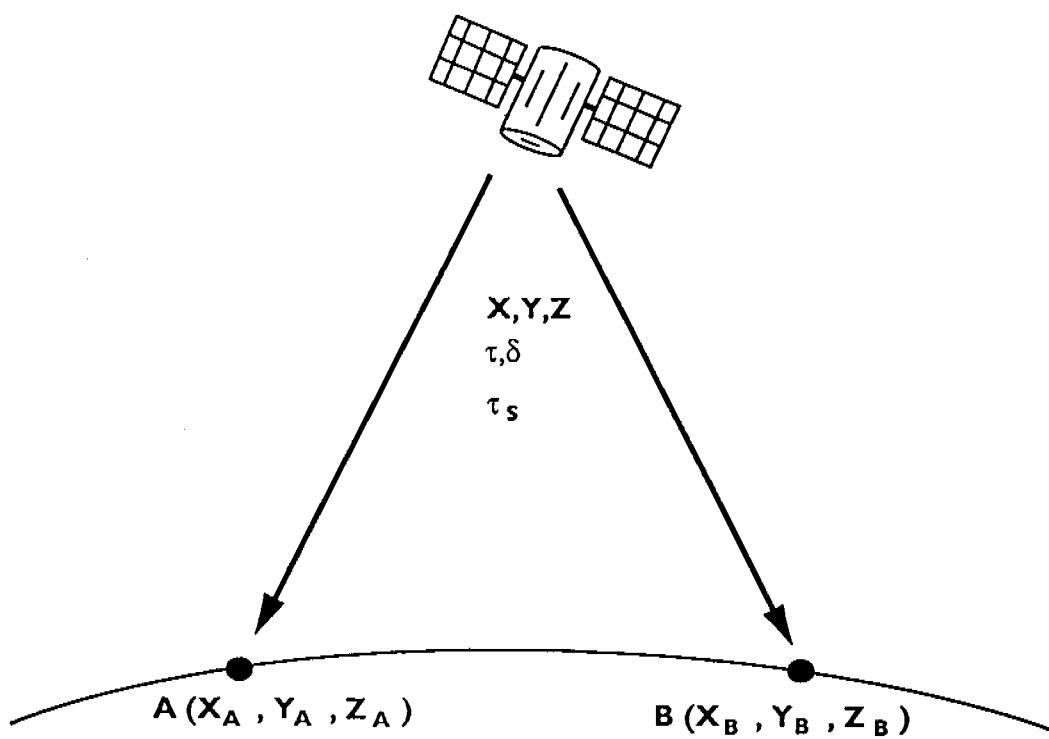
Time	ASN-16 / 1		ASN-16 / 2		common-view	
	h, min	$\Delta \bar{T}$, ns	δ , ns	$\Delta \bar{T}$, ns	δ , ns	$\Delta \bar{T}_m$, ns
8.00	2522.0	3.8	2539.5	10.1	-17.5	10
8.30	2520.0	0.0	2512.0	0.0	8.0	0.0
9.00	2470.0	0.0	2465.0	7.5	5.0	7.5
9.30	2456.0	8.7	2464.0	4.4	-8.0	10.0
10.00	2520.0	9.9	2524.5	4.3	-4.5	10.3
10.30	2510.5	2.2	2507.0	4.9	3.5	5.0
11.00	2524.0	6.4	2528.5	4.6	-4.5	7.5
11.30	2455.5	5.8	2455.0	7.1	0.5	10.2
12.00	2471.5	3.7	2470.0	3.6	1.5	4.5
12.30	2491.0	3.0	2488.0	4.4	3.0	5.4
13.00	2490.0	5.6	2489.5	4.4	0.5	5.5
13.30	2470.5	2.2	2488.5	4.3	-18.5	4.6
14.00	2470.5	2.2	2468.5	4.6	2.0	4.8
14.30	2511.0	3.1	2506.5	5.1	4.5	5.0
15.00	2511.0	3.1	2508.5	4.4	2.5	4.8
15.30	2532.0	3.9	2534.5	7.4	-2.5	8.0
16.00	2532.5	4.0	2514.0	4.0	18.5	6.3
16.30	2491.0	3.0	2490.0	3.6	1.0	4.4
17.00	2572.0	3.5	2571.0	2.2	1.0	4.1
17.30	2492.0	4.1	2491.5	0.0	0.5	4.1

Table 2. The estimations of time synchronization accuracy via GLONASS signals for every day and the whole interval

Date	ASN-16 / 1		ASN-16 / 2		common-view	
	h,min	$\Delta \bar{T}$, ns	δ , ns	$\Delta \bar{T}$,ns	δ ,ns	$\Delta \bar{T}_m$,ns
21.12	2511.0	18.2	2511.5	17.5	-0.5	9.8
22.12	2591.0	22.1	2591.5	16.4	-0.5	9.3
23.12	2688.0	21.5	2685.5	26.8	2.5	10.9
24.12	2778.0	20.9	2780.0	22.4	-2.0	11.4
25.12	2863.0	19.5	2862.5	20.8	0.5	10.2
21-25.12	2686.0	23.3	2662.5	24.3	0.0	10.0



a) The direct-synchronization technique



b) Common-view method

Figure I. The direct-synchronization technique and common-view method via GLONASS signals

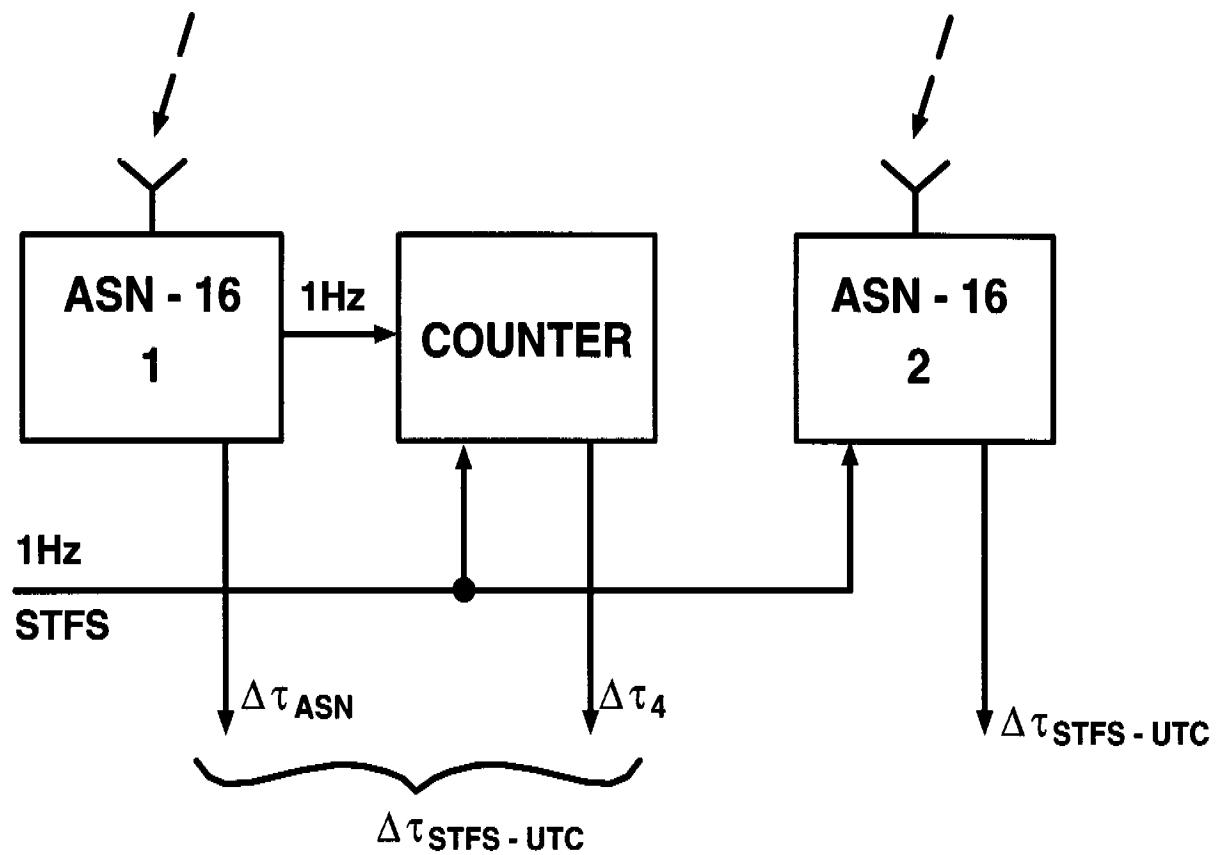


Figure 2. The experiment configuration