GLONASS Time and UTC(SU)

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Abstract

The paper presents the main principles of GLONASS Time generation and its synchronization to UTC(SU) as well as the main approaches that can increase the accuracy of transmitted GLONASS Time and UTC(SU).

1. Introduction

GLONASS provides high-accuracy determination of position, velocity and time for land, marine, air and other kinds of users. To achieve this the time scales of all space vehicles (SV) are synchronized to GLONASS Time and GLONASS Time is synchronized to Reference Time. Now the accuracy of transmitted GLONASS Time and UTC(SU) meet specified requirements. However, for professional users it is not satisfactory as compared with GPS. The paper presents the main principles of GLONASS Time generation and its synchronization to UTC(SU) as well as the main approaches that can increase their accuracy.

2. GLONASS Time Generation

GLONASS Time is generated as a continuous "paper" time scale on the basis of the Main and/or Reserved Central Synchronizers (CS) using the following equation:

$$\begin{aligned} \Delta T_{GL}(t) &= \Delta T_M(t) + \Delta T_M^{ph}(t_i) + \Delta T_M^{fr}(t_j) - \Delta T^c(t) = \\ &= \Delta T_R(t) + \Delta T_R^{ph}(t_k) + \Delta T_R^{fr}(t_l) - \Delta T^c(t) - \Delta T_{M-R}(t) \end{aligned}, \quad (1)$$

where $\Delta T_{GL}(t)$ — GLONASS Time offset relative to Reference Time;

$\Delta T_M(t)$, $\Delta T_R(t)$ — Main/Reserved CS time offset relative to Reference Time;

$\Delta T_M^{ph}(t_i)$, $\Delta T_R^{ph}(t_k)$ — corrections for Main/Reserved CS phase steering;

$\Delta T_M^{fr}(t_j)$, $\Delta T_R^{fr}(t_l)$ — corrections for Main/Reserved CS frequency steering;

$\Delta T^c(t)$ — correction for controlling GLONASS Time — Reference Time offset;

$\Delta T_{M-R}(t)$ — offset between Main and Reserved CS time scales.

The backbone of CS is Frequency/Time Keeping Facility (FTKF) including four active Hydrogen Frequency Standards (HFS), a system for internal comparisons and a system for steering frequencies and phases of signals from HFS. HFS which provides the best accuracy characteristics on the results of internal comparisons becomes master standard, the others operate as secondary.

Central Synchronizers provide the following accuracy characteristics:
– relative frequency error $\Delta f/f$ below $3 \cdot 10^{-14}$;
– daily frequency instability below $2 \cdot 10^{-15}$.

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GLONASS Reference Time is Universal Time Coordinated of Russia UTC(SU) generated by State Time/Frequency Reference (STFR). In compliance with GLONASS Interface Control Document, GLONASS Time offset relative to UTC(SU) should not exceed 1μs. In 2013 this offset was about 420 ns.

GLONASS Time is corrected by 1 s simultaneously with UTC corrections and, as a result, there is no whole second time offset between GLONASS Time and UTC. However, there is a three-hour constant offset between GLONASS Time and UTC due to GLONASS Terrestrial Control Complex operational principles.

3. GLONASS Time Synchronization to UTC(SU)

The time offset between Central Synchronizer and STFR is determined by GLONASS and GPS signals using the following equation :

$$\Delta T_{STFR-CS} = \Delta T_{STFR-GL(GPS)} - \Delta T_{CS-GL(GPS)} \text{ ,} \tag{2}$$

where $\Delta T_{STFR-CS}$ — CS time offset relative to STFR;

$\Delta T_{STFR-GL(GPS)}$ — GLONASS/GPS Time offset relative to STFR;

$\Delta T_{CS-GL(GPS)}$ — GLONASS/GPS Time offset relative to CS time.

Now the error of calculating Main CS — STFR time offset is about 8 ns (rms) by GLONASS signals and 3 ns (rms) by GPS signals, Reserved CS — STFR time offset 13 ns (rms) by GLONASS signals and 10 ns (rms) by GPS signals. The large error of CS — STFR time offset calculated by GLONASS signals is mostly caused by using not calibrated Reference Equipment with single-frequency GLONASS/GPS receiver at CS and TTS-3 time receiver at STFR.

The calculated value of CS — STFR time offset is used at CS for monitoring time scale generation and calculating relative frequency error and at GLONASS System Control Center (SCC) for generating GLONASS Time.

SVs “Glonass-M” transmit navigation signals in L1, L2 frequency bands with frequency division multiple access (FDMA) and broadcast the following corrections to users:
– corrections for SV — GLONASS Time offset within ±2 ms;
– corrections for GLONASS Time — UTC(SU) offset within ±1 s;
– corrections for UTC — UT1 offset within ±0,9 s;
– corrections for GLONASS — GPS Time offset within ±1,9 s.

In 2013 the systematic error component of broadcast corrections for GLONASS Time — UTC(SU) offset was approximately 200 ns, the random component did not exceed 10 ns.

The characteristics mentioned above meet specified requirements for GLONASS Time and UTC(SU) transmission accuracy. However, for professional time users they are not satisfactory as compared with GPS.

4. Improvement of GLONASS Time Generation and Its Synchronization to UTC(SU)

The main approaches used to increase the accuracy of GLONASS Time generation and its synchronization to UTC(SU) are:

a) to eliminate the systematic component of corrections for GLONASS Time — UTC(SU) offset;

b) to realize the technique for automatic stabilization of relative frequency error that compensates the drift of the main HFS at CS;

c) to decrease GLONASS Time — UTC(SU) offset;

d) to decrease the random component of broadcast corrections for GLONASS Time — UTC(SU) offset by increasing the accuracy of CS — STFR time comparisons.

To eliminate the systematic component of broadcast corrections for GLONASS Time — UTC(SU) offset the results of STFR comparisons by GLONASS signals were analyzed and the calculated systematic component was subtracted from generated corrections for GLONASS Time — UTC(SU) offset before uploading.

The technique for automatic stabilization of relative frequency error at CS is as follows. The relative frequency error and daily frequency drift of CS master HFS are calculated. Then the frequency of master HFS is set within $1.5 \cdot 10^{-14}$. Beginning with this point, for compensating a drift, a preventive automatic steering of master HFS frequency is performed with calculated time of repetition and minimum possible discrete equal to $1 \cdot 10^{-15}$. The time of repetition can be changed according to the calculated value of frequency drift. Besides, the frequency drift for the secondary HFS is estimated with using a trend of frequency steering codes generated by a system for internal comparisons. The estimated results are used for determining a sign and time interval of steering for each secondary HFS, providing the continuity of CS time scale when switching to a new master HFS. Thus, Central Synchronizer frequency steering is performed with longer repetition time and does not influence accuracy characteristics of CS time scale and, as a result, GLONASS Time.

GLONASS Time — UTC(SU) offset is decreased by additional recalculating and changing the value of controlling correction $\Delta T^c(t)$ that provides the specified accuracy of GLONASS Time — UTC(SU) synchronization. The controlling correction cannot be changed by more than several nanoseconds to keep the specified accuracy of SV — GLONASS Time synchronization, therefore this technique is rather time consuming.

To increase the accuracy of CS — STFR synchronization it is proposed:

– to install similar calibrated GLONASS/GPS time receivers at STFR and CS that can provide determining time scales offset with the error about (3–5) ns and (2–3) ns in *a posteriori* mode at the 1st stage;

– to use time transfer facilities using duplex communication links through satellites in geosynchronous orbit (GEO). It can provide the accuracy about (1–2) ns at the 2nd stage;

– to use laser technologies for time scales comparison that can provide the accuracy better than 1 ns at the 3rd stage.

5. Conclusion

As a result of the proposed technical approaches the following accuracy characteristics of transmitted GLONASS Time and UTC(SU) are planned to be achieved:

– GLONASS Time — UTC(SU) offset no more than 120 ns at the 1st stage, 20 ns at the 2nd stage and 4 ns at the 3rd stage;

– the error of broadcast corrections to GLONASS Time no more than 10 ns at the 1st stage, 5 ns at the 2nd stage and 2 ns at the 3rd stage.

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