GLONASS ONBOARD TIME/FREQUENCY STANDARDS: TEN YEARS OF OPERATION

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Abstract

The GLONASS onboard time/frequency standards are one of the main elements determining the accuracy of phase synchronization of navigation signals emitted by the satellites and, consequently, the accuracy of navigation and timing determination by the users. In this connection, the maintenance of their accuracy and reliability parameters during operation is very important. The present paper submits the results of analysis of GLONASS onboard time/frequency standards operation as of 18 January 1996, when the space segment was completed by all 24 satellites.

INTRODUCTION

With the launching on 14 December 1995 of the last three satellites, the construction of the space segment of Russian Global Navigation Satellite System GLONASS was completed.

Three cesium-beam frequency standards, with a daily instability not more than 5×10^{-13} and a lifetime of 1 year each, are installed onboard the satellites. The monitoring and control of standards operation are executed on the basis of telemetric parameters and estimates of accuracy characteristics. Accuracy characteristics are estimated by means of processing the measured differences between satellite time scales generated by the standards' pulses and the common system time scale generated by the Main Synchronizer.

While being one of the main units of the GLONASS, the onboard time/frequency standards determine the normal satellite operation and the system's accuracy parameters as a whole. In this connection the maintenance of necessary accuracy and reliability parameters of onboard standards during its operation is a very important task. This paper presents the main characteristics of the GLONASS onboard standards, the technique of their accuracy parameter estimation, and the results of an analysis of the standards' operation as of 18 January 1996.

GLONASS ONBOARD STANDARDS CHARACTERISTICS

Since the second GLONASS stage of development, which began in May 1985, cesium-beam frequency standards have been used on all satellites as space-based frequency and time standards. The main specifications of these standards are given in Table 1.

The given characteristics of the frequency standards provide the mutual synchronization of satellite navigation signal phases with an accuracy of no more than 20 ns (σ) for a 12-hour interval.[1]

Three frequency standards are used on each satellite: one is in operation and two others are in "cold" reserve. The checking and control of standard operation are executed on the basis of telemetric information and estimates of accuracy characteristics. Switch-on of the reserve standard is executed by a command from the ground station in case of malfunction of the standard's operation or deterioration of its accuracy characteristics.[2]

ESTIMATION TECHNIQUE OF STANDARD ACCURACY CHARACTERISTICS

The estimation of the accuracy characteristics of GLONASS onboard frequency standards is based on processing the measured offset between satellite time scales, generated by the standard's signals, and System Common Time (SCT), generated by the Main Synchronizer (MS) of the system. The determination of the satellite time shift relative to SCT is executed on the basis of simultaneous one-way and two-way measurements of the range to the satellite, carried out by the phase monitor unit (PMU), located together with the MS.[1]

The daily measured offset between satellite time scales and SCT (3 to 5 results) are processed by means of least-squares approximation using a linear model for time scale differences, and the individual values of fractional frequency uncertainty of the onboard standards are determined. Calculated then in terms of these values for each 10-day observation period are the following parameters:

the fractional frequency uncertainty of the standard

$$\left(\frac{\Delta f}{f}\right)^{*} = \frac{1}{N}\sum_{k-1}^{N}\left(\frac{\Delta f}{f}\right)_{k},$$

the instability for averaging time 1 day (square root of the N-sample variance)

$$\delta^{*} = \sqrt{\frac{1}{N-1}\sum_{k-1}^{N}\left[\left(\frac{\Delta f}{f}\right)_{k} - \left(\frac{\Delta f}{f}\right)^{*}\right]^{2}},$$

where $\left(\frac{\Delta f}{f}\right)_k$ is the individual value of fractional frequency uncertainty of the onboard standard, and N = 10 – the number of individual values for a 10-day observation period.

With due account of the error of a measured offset between the satellite time scale and SCT by means of a PMU not exceeding 5 ns (σ) and an instability for an averaging time of 1 day for the MS not exceeding 5×10^{-14}, the error of individual values of the fractional frequency uncertainty of the onboard standard does not exceed 7.3×10^{-14}.[3] Thus, at the 0.95 confidence level, true values of fractional frequency uncertainty of standard are within $\pm\, 2.8 \times 10^{-14} \times \left(\frac{\Delta f}{f}\right)^{*}$ and the instability for an averaging time of 1 day is within (0.7 - 1.55) $\times\delta^{*}$. Therefore, the adopted estimation technique of GLONASS onboard standard accuracy parameters is considered valid.

GLONASS ONBOARD STANDARD PARAMETERS AT OPERATION

For the GLONASS space segment as of 18 January 1996, the numbers of operating frequency standards and their accuracy characteristics are given in Table 2.

A diagram of operating time of frequency standards installed on the active satellites is shown in Figure 1. All cases of standard switch-off are caused by deterioration of the daily instability over of a given value of 5×10^{-13}. The histogram of distribution of the frequency standard's operating time is shown in Figure 2. The average value is 16.3 months and the spread is from 2 to 47 months.

The estimation results of GLONASS frequency standard accuracy characteristics show that, for most of standards during intervals of normal satellite operation, the fractional frequency uncertainty $\left(\frac{\Delta f}{f}\right)$ is within $\pm\, 5 \times 10^{-12}$, the instability for an averaging time of 1 day (δ) does not exceed 3×10^{-13}, and a systematic frequency drift is not observed or does not exceed a few parts in 10^{13} per month. Histograms of the distribution of the fractional frequency uncertainty and the instability for an averaging time of 1 day for all standards during 1995 are shown in Figures 3 and 4.

The adduced data show that the problem of maintenance of given characteristics for GLONASS onboard standards during their whole operating life still exists. The increase of accuracy and reliability characteristics of onboard standards is provided in the framework of the creation of the new GLONASS-M satellite. The newly developed cesium-beam frequency standard should have a daily frequency instability no more than 1×10^{-13} and an operating life of 3 years.[1] However, delays with manufacturing of the new satellite have not allowed us to begin the checking of these new standards in real conditions.

CONCLUSION

Full deployment of the GLONASS space segment, consisting of 24 satellites, was completed on 18 January 1996. This fact permits one to speak about a 10-year period of operation of the onboard cesium-beam frequency standards, with a daily instability of no more than 5×10^{-13} and an operating life of 1 year each.

The results of estimation of frequency standard accuracy and reliability parameters show that, for most of them during intervals of normal satellite operation, the fractional frequency uncertainty is within $\pm\, 5 \times 10^{-12}$ and an instability for an averaging time of 1 day does not exceed 3×10^{-13}. The average value of a frequency standard's operating time is 16.3 months.

REFERENCES

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[3] Y.G. Gouzhva, A.G. Gevorkyan, and P.P. Bogdanov 1992, *"Accuracy estimation of GLONASS satellite oscillators,"* Proceedings of the 1992 IEEE International Frequency Control Symposium, 27-29 May 1992, Hershey, Pennsylvania, USA, pp. 306-309.

Table 1. Specifications for GLONASS cesium beam frequency standard

Parameter	Value
Output	5 MHz
Relative frequency accuracy	$\pm 1\times10^{-11}$
Stability, averaging time:	
- 1 s	5×10^{-11}
- 100 s	1×10^{-11}
- 1 hour	2.5×10^{-12}
- 1 day	5×10^{-13}
Temperature change of frequency (1/° C)	5×10^{-13}
Temperatures range (° C)	0 – 40
Power supply (DC)	27 V
Power consumption	80 W
Dimensions (mm)	370×450×500
Weigh (kg)	39.6
Operating life (hours)	17,500

Table 2. GLONASS space segment at the state of January 18, 1996

SN	Date of start	Operating standard	Date of switch on	$\left(\frac{\Delta f}{f}\right)\times10^{-12}$	$\delta\times10^{-13}$	$Drift\times10^{-13}$
1	30.01.92	2	19.11.93	1.3	1.4	0.3
2	17.02.93	1	18.07.95	−7.5	4.9	−5.1
3	20.11.94	3	24.08.95	2.3	3.1	−1.2
4	20.11.94	1	16.12.94	1.0	2.3	0.0
5[1)]	08.12.90	1	15.10.95	−0.3	3.1	−0.1
6	20.12.94	2	30.10.95	0.5	2.4	0.0
7	17.02.93	2	11.05.93	−0.6	1.6	0.4
8	30.01.92	1	20.02.92	0.5	1.4	−0.5
9[2)]	14.12.95	1	07.01.96	—	—	—
10	24.07.95	1	21.08.95	−0.5	1.0	−0.2
11	24.07.95	1	21.08.95	−0.5	1.6	0.6
12	11.08.94	1	07.09.94	−2.0	2.4	0.3
13	14.12.95	1	07.01.96	—	—	—
14	11.08.94	1	07.09.94	−3.8	1.3	0.3
15	24.07.95	1	26.08.95	−2.5	1.8	1.4
16	11.08.95	1	04.09.95	−0.6	1.5	−0.8
17	11.04.94	1	18.05.94	3.0	1.7	−0.2
18	11.04.94	1	16.05.94	2.5	1.4	0.7
19	07.03.95	2	30.07.95	0.5	2.0	0.5
20	07.03.95	1	30.03.95	−0.6	1.6	−1.5
21	30.07.92	3	26.05.95	−0.4	1.4	3.2
22	07.03.95	1	05.04.95	−2.1	2.3	−0.6
23	11.04.94	2	07.10.94	2.3	2.2	−0.7
24[1)]	30.07.92	2	15.07.95	−11.2	4.5	1.8

Note: 1. At present SN 5 and SN 24 put not of action.
2. Reserve satellite No 778 is also set in point 9.

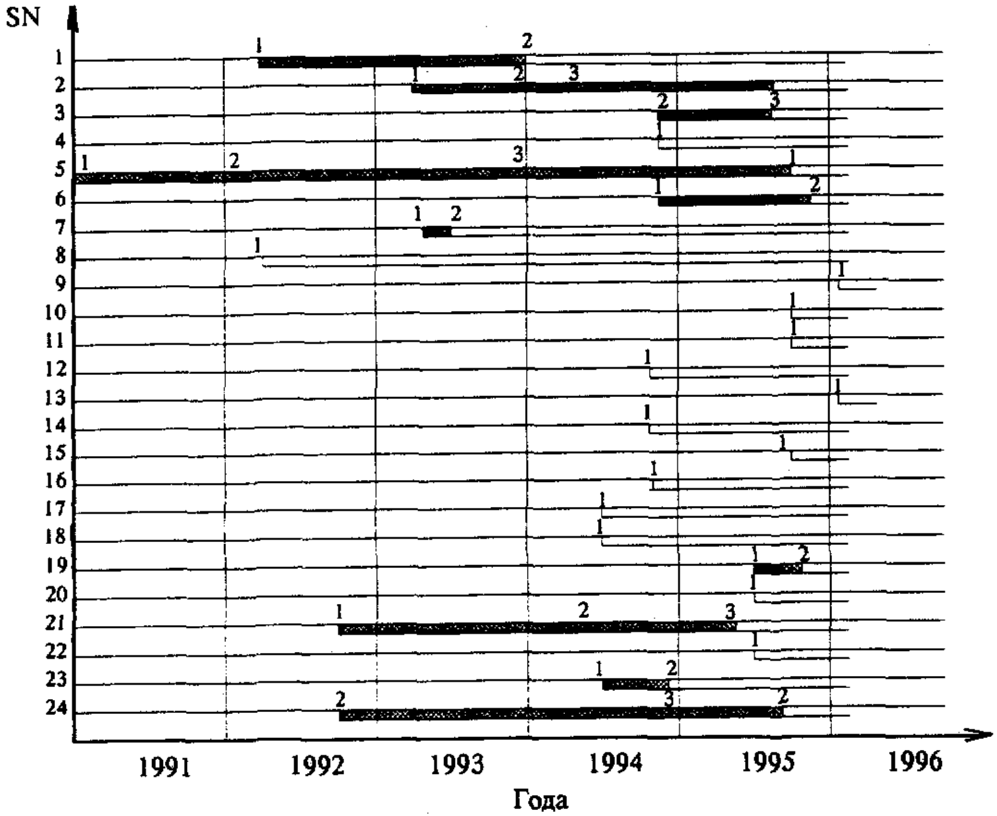

Figure 1. Diagram of operating time for GLONASS on-board standards

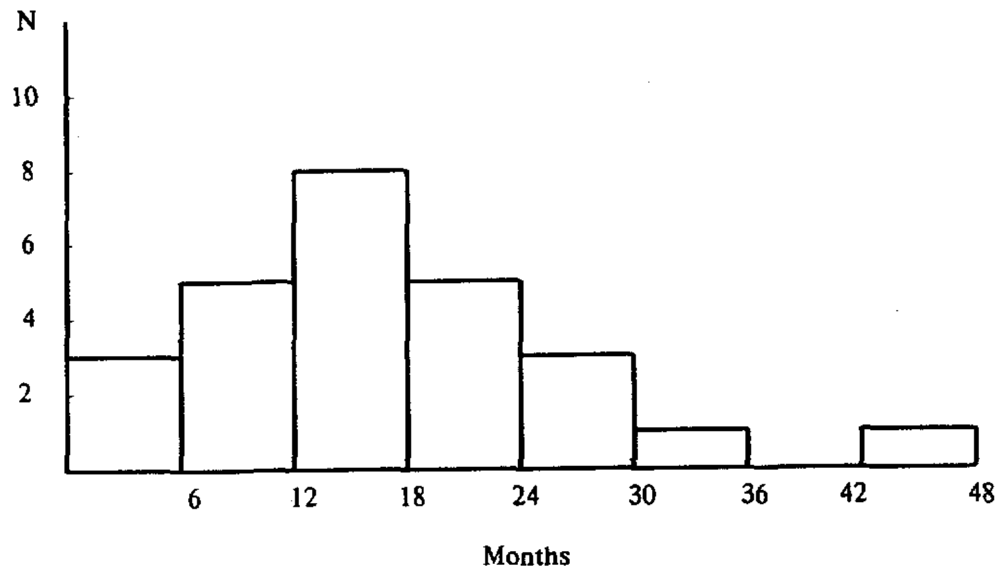

Figure 2. Distribution of operating time for GLONASS on-board standards

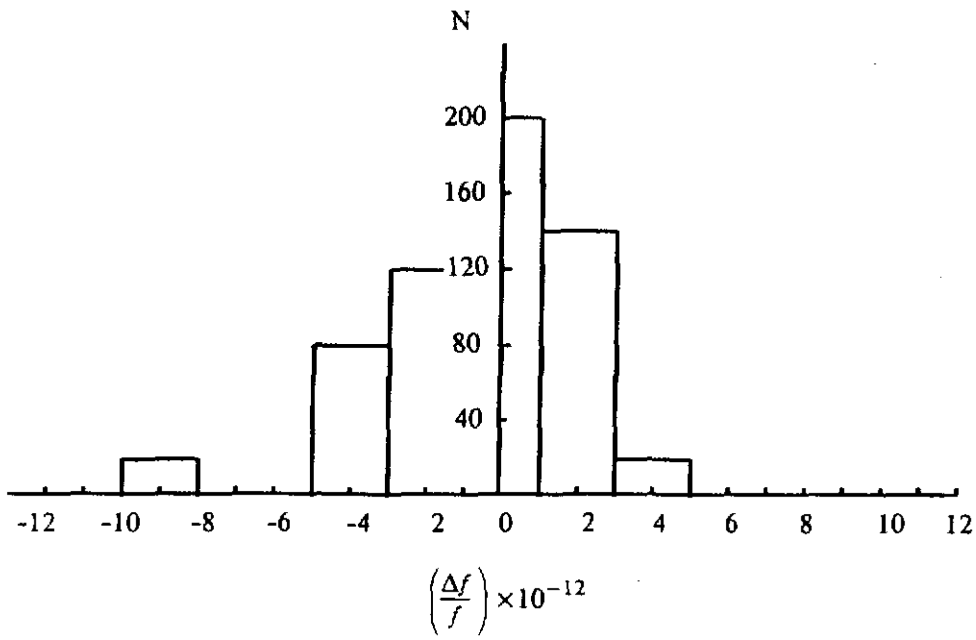

Figure 3. Distribution of the fractional frequency uncertainty for GLONASS on-board standards

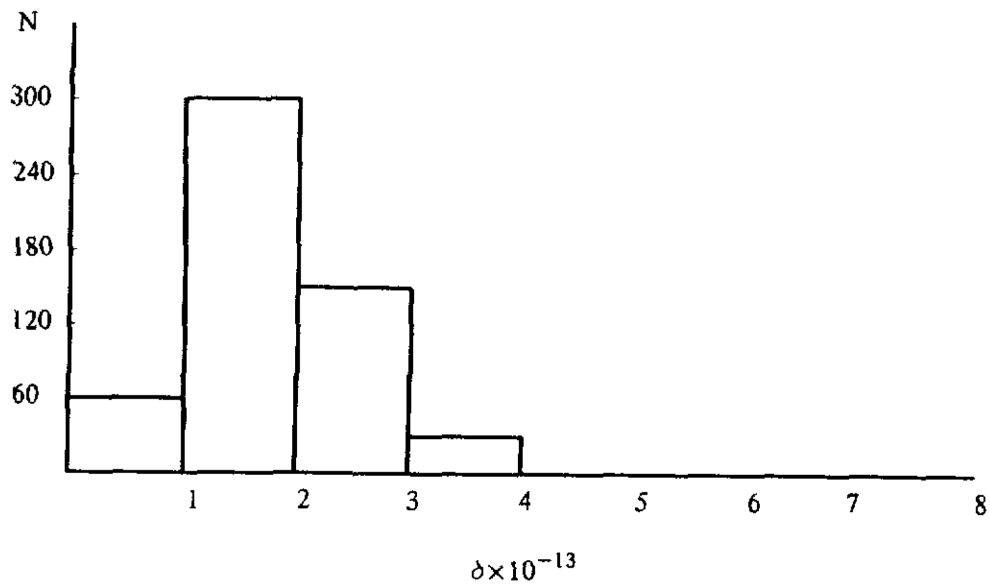

Figure 4. Distribution of instability for averaging time 1 day for GLONASS on-board standards