LATEST CALIBRATION OF GLONASS P-CODE TIME RECEIVERS

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Abstract

The Russian GLONASS navigation system, although not yet finished, provides interesting opportunities for international time metrology. Its P-code signal shows an outstanding performance. In particular, it allows calibration of GLONASS time receivers with an uncertainty below 1 ns.

Our paper reports the latest differential calibration of GLONASS P-code time receivers located at the AOS and the BIPM, by means of a portable receiver. Receiver time biases were determined for different GLONASS frequencies. Removing these biases, reaching sometimes 10 ns, allows time transfer with an accuracy of around 1 ns.

1 INTRODUCTION

Over the last 50 years, the accuracy of atomic clocks has improved by an order of magnitude every 7 years. Today, they reach a stability in frequency of 1 part in 10^{16}. The stability of the international reference time scales, International Atomic Time (TAI) and Coordinated Universal Time (UTC), is presently about 10^{15} over a period of a few weeks. Meanwhile, the standard uncertainty of GPS C/A-code common view, currently the most widely used method of time transfer (and the main method providing the data for the calculation of TAI and UTC), is still a few nanoseconds.

To enable comparisons of increasingly stable clocks, it is important to improve time transfer methods. One of the new approaches to time and frequency comparisons consists of using GLONASS (Global Navigation Satellite System) P-code. Use of GLONASS in standard CGGTTS common-view mode was introduced into time metrology in 1996 by W. Lewandowski et al. **[1,2]**. Studies of this approach have been continued by J. Azoubib, W. Lewandowski, and J. Nawrocki in 2000 and 2001 **[3,4]**.

2 ADVANTAGES OF GLONASS

The GPS and GLONASS systems share basically the same concept. A substantial difference between GPS and GLONASS is in the signal structure. GPS uses Code Division Multiple Access (CDMA): every satellite transmits the same two carriers modulated by PRN-codes particular to each satellite. GLONASS uses Frequency Division Multiple Access (FDMA): two individual carrier frequencies are assigned to each satellite, but the PRN-codes are the same for all satellites.

Hence, the GPS carrier frequencies f_{L1} and f_{L2} are invariable:

$$\boldsymbol{f_{\mathrm{L1(GPS)}} = 1575.42\ \mathrm{MHz}}$$
$$\boldsymbol{f_{\mathrm{L2(GPS)}} = 1227.60\ \mathrm{MHz}}$$

and the individual GLONASS carrier frequencies f_{L1}^{k} and f_{L2}^{k} are defined by:

$$f_{\mathrm{L1(GLONASS)}}^{k} = 1602.0\ \mathrm{MHz} + 0.5625k\ \mathrm{MHz}$$
$$f_{\mathrm{L2(GLONASS)}}^{k} = 1246.0\ \mathrm{MHz} + 0.4375k\ \mathrm{MHz}$$

where k is the carrier number assigned to the specific satellite.

Both GPS and GLONASS have freely accessible C/A-code that modulates L1 only. Like the GPS precision code, the GLONASS P-code modulates both carriers, but unlike GPS it is also freely accessible.

The GLONASS P-code has two main advantages for high-precision time transfer. Firstly, the GLONASS P-code modulation onto both L1 and L2 carrier frequencies allows high-precision measurements of ionospheric delays. Secondly, the GLONASS P-code chip rate is one-tenth that of the GLONASS C/A-code and one-fifth that of the GPS C/A-code. This means that GLONASS P-code pseudo-range measurements are much more precise than GPS or GLONASS C/A-code measurements.

		GLONASS	GPS
operator		Military Space Forces (Russia)	Department of Defense (USA)
nominal number of satellites		24*	24
orbit altitude		19 100 km	20 200 km
orbital planes		3	6
orbital inclination		64.8°	55°
period of revolution		~ 11 h 16 min.	~ 11 h 58 min.
ground track repetition		8 sidereal days	1 sidereal day
reference frame		PZ-90	WGS-84
time reference		UTC (SU)	UTC (USNO)
ephemeris representation		position, velocity and acceleration	orbital parameters
signal separation		Frequency Division Multiple Access (FDMA)	Code Division Multiple Access (CDMA)
carrier frequencies	L1	1602.00 – 1614.94 MHz	1575.42 MHz
	L2	1246.00 – 1256.06 MHz	1227.60 MHz
	L1/L2	9 / 7	77 / 60
code chip rate	C/A	0.511 MHz	1.023 MHz
	P	5.113 MHz	10.23 MHz
code length (bits)	C/A	511	1023
	P	$5.113 \cdot 10^{6}$	$2.3547 \cdot 10^{14}$
navigation message length		2 min. 30 s	12 min. 30 s

*The present number of GLONASS satellites is below its nominal value.

Table 1. GPS vs. GLONASS.

3 DETERMINATION OF GLONASS FREQUENCY BIASES

The differential calibration of a GLONASS time receiver is realized by a one-site comparison with a portable receiver through common views **[5]**. Both receivers are connected to the same clock and the antennas are separated by at most a few meters.

Such a comparison at short distance eliminates the common-clock error and errors resulting from satellite broadcast ephemerides, ionospheric and tropospheric delays, and antenna coordinates; only the noise of the receivers is observed.

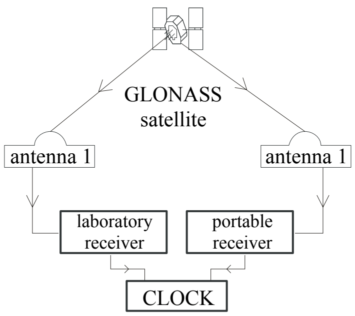

Figure 1. Scheme of differential calibration.

The bias for the frequency k with reference frequency No. 6 is given by

$$B_k = \left(\overline{dt_i}\right)_6 - \left(\overline{dt_i}\right)_k$$

where $\left(\overline{dt_i}\right)_k$ is the mean value of the GLONASS P-code common views using the frequency k over the whole interval of computation.

The most recent differential calibrations of GLONASS equipment were made in the late 1990s.
We detail measurements that took place at the Bureau International des Poids et Mesures (BIPM), the Astrogeodynamical Observatory of Space Research Centre, Polish Academy of Sciences (AOS, Borowiec), Royal Observatory of Belgium (ORB, Brussel), and the Nederland Meetinstituut, Van Swinden Laboratory (NMi-VSL, Delft). Receiver No. 0017 (BIPM A) was chosen as reference; it had been compared with portable BIPM receiver No. 0019 in 1997 **[5]**.

Lab.	Local Receiver Ser. No.	Portable Receiver Ser. No.	Period	Number of Common Views
BIPM	0017 (BIPM A)	0019 (ROVER)	11/09 – 23/10/97	899 (L1)
BIPM	0025 (BIPM D)	0017 (BIPM A)	31/08 – 02/10/98	739 (L1) 698 (L2)
AOS	0030 (AOS)	0017 (BIPM A)	11/01 – 24/01/99	922 (L1)
ORB	0022 (ORB)	0017 (BIPM A)	02/02 – 12/02/99	412 (L1) 398 (L2)
VSL	0018 (VSL 18)	0017 (BIPM A)	15/02 – 27/02/99	807 (L1) 783 (L2)

Table 2. Some calibrations of GLONASS P-code receivers made in the 1990s by the BIPM.

The GLONASS P-code frequency biases are shown in Figure 2. It can be seen that they differ not only for every GLONASS frequency, but also for each receiver.

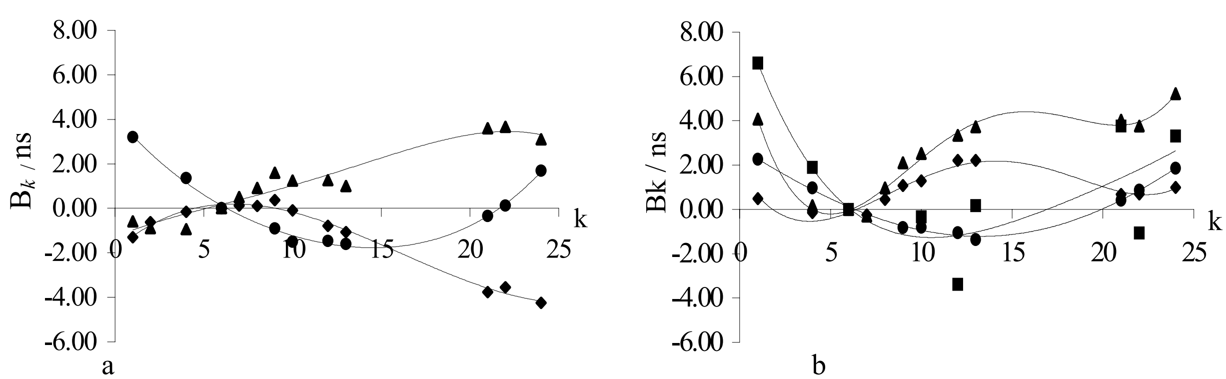

Figure 2. GLONASS P-code frequency biases with respect to frequency No. 6:

a)
● receiver No 0030 (AOS) L1
▲ receiver No 0018 (VSL) L1
◆ receiver No 0018 (VSL) L2

b)
● receiver No 0025 (BIPM D) L1
■ receiver No 0025 (BIPM D) L2

▲receiver No 0022 (ORB) L1 ◆receiver No 0022 (ORB) L2

Figure 3 shows an example of one-site comparisons of two receivers. The GLONASS C/A code multi-channel data are noisier then the GPS data. However, the GLONASS P-code single-channel comparison with frequency biases removed shows outstanding performance. Corresponding time deviations are shown in Figure 4.

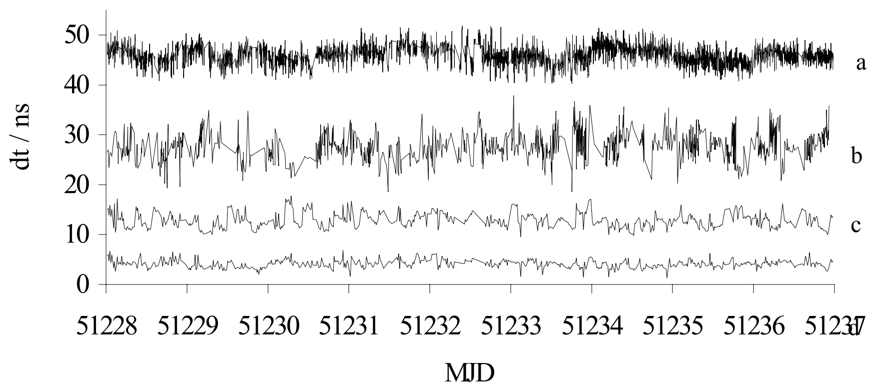

Figure 3. One-site comparisons at the VSL:
a GPS C/A-code multi-channel;
b GLONASS C/A-code multi-channel;
c GLONASS P-code single-channel;
d GLONASS P-code single-channel with frequency biases removed.

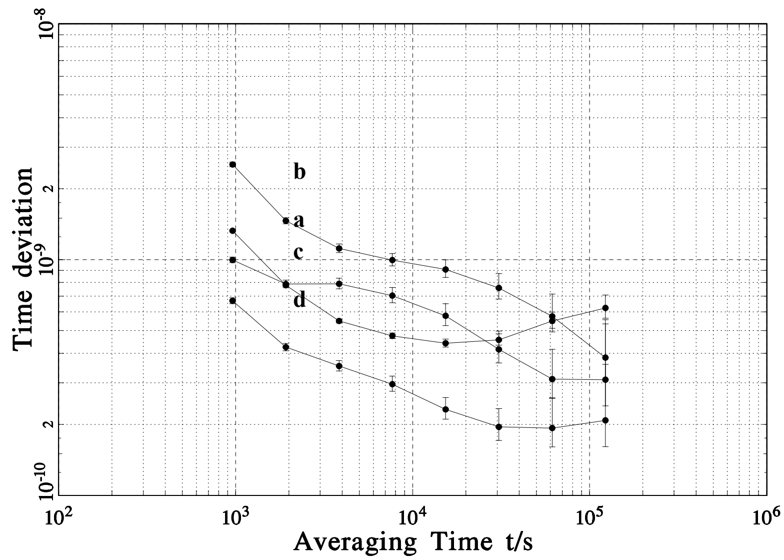

Figure 4. Time deviations for one-site comparisons:
a GPS C/A-code,
b GLONASS C/A-code,
c GLONASS P-code (L1) without corrections for GLONASS frequency biases,
d GLONASS P-code (L1) with corrections for GLONASS frequency biases.

4 APPLICATION OF CALIBRATED GLONASS FREQUENCY BIASES

We applied the frequency biases obtained from the data from January and February 1999 to the time transfer between AOS and NMi-VSL made in February 1999. Using the measurements with broadcast ephemerides and modeled ionospheric delays, the 1-day root-mean-square (RMS) of GLONASS P-code common view after corrections for frequency biases is about 3.7 ns, which is the same as for GPS.

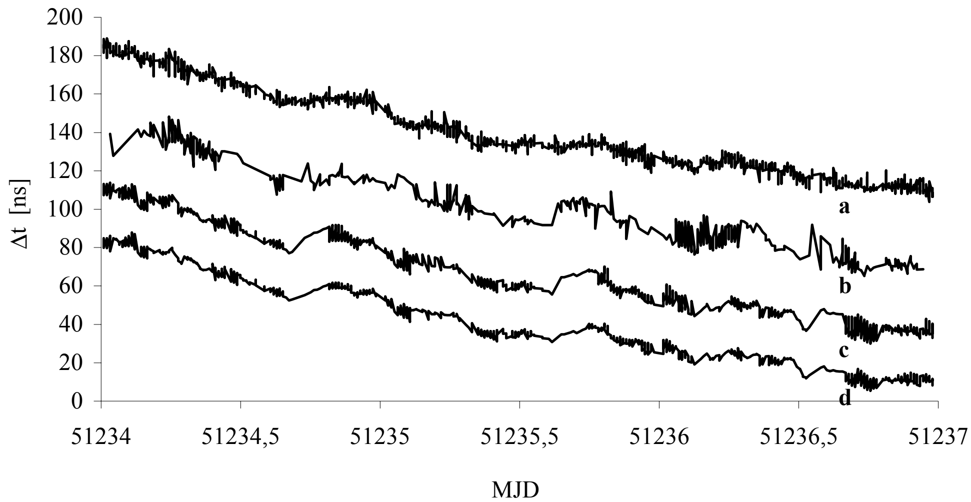

Figure 5. [UTC (AOS) – UTC (VSL)] compared by:

a GPS C/A-code,

b GLONASS C/A-code,

c GLONASS P-code (L1) without corrections for GLONASS frequency biases,

d GLONASS P-code (L1) with corrections for GLONASS frequency biases

(with broadcast ephemerides and modeled ionospheric delay).

5 CONCLUSIONS

The use of GLONASS P-code promises further improvement in the stability of time transfer. Therefore, it is very important to repeat calibrations of GLONASS receivers in order to determine the frequency biases of those currently in operation.

After corrections for ionospheric delay, derived from IGS maps or P-code double-frequency measurements of the ionosphere, and precise ephemerides, clock-comparison uncertainties of less than 1 ns can be obtained **[3,4]**.

New GLONASS calibration exercises, using the new generation of receivers, are programmed for the near future.

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