A TEST OF THE USE OF GLONASS PRECISE CODE FOR HIGH-PRECISION TIME TRANSFER

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Abstract

In a first attempt to evaluate performance of the GLONASS P-code time transfer, one-site measurements are used to show that single-channel GLONASS precise code, combined with temperature-controlled antennas, reduces the noise experienced by time receiving equipment to a few hundred of picoseconds for a one-day averaging times, thus allowing frequency comparison at a level of a few parts in 10^{15}.

INTRODUCTION

Although not as well known as the GPS, the Russian global satellite navigation system GLONASS possesses comparable capabilities for navigation, precise geodetic positioning, and time-transfer applications [1]. During the last few years studies of time and frequency comparisons of remote atomic standards have seen several interesting developments involving GLONASS: C/A-code single-channel measurements led to similar to GPS performances for continental links; intercontinental links were affected by lack of post-processed GLONASS precise ephemerides [2].

But the performance of single-channel GPS and GLONASS C/A-code common-view time transfer, uncertainty of about 3 ns, is barely sufficient for the comparison of current atomic clocks and needs to be improved rapidly to meet the challenge of the clocks now being designed. For this reason the timing community is engaged in the development of new approaches to time and frequency comparisons. Among them are techniques based on multi-channel GPS and GLONASS C/A-code measurements, GPS carrier-phase measurements, temperature-stabilized antennas, and standardization of receiver software. This paper reports on the first test of GLONASS P-code for time transfer, and on specially protected receiver antennas. A one-site comparison shows that for single-channel GLONASS P-code time and frequency transfer a stability of 2 parts in 10^{15} is obtained over one day (200 picoseconds/day). These results indicate that GLONASS P-code time and frequency transfer in multi-channel mode should reach at least a stability of 1 part in 10^{15} over one day (100 picoseconds/day) for short baselines.

ADVANTAGES OF GLONASS

The Russian Global Navigation Satellite System (GLONASS) was inaugurated in 1982 and is still under development. GLONASS offers the international community in time metrology a useful additional tool for high-accuracy time transfer. The GLONASS constellation broadcasts a C/A-code signal free of Selective Availability (SA) and unencrypted P-code signal, unlike the GPS P-code, which is subject to Anti-Spoofing (AS) encryption.

The GLONASS P-code has two main advantages for precision time synchronization. First, GLONASS P-code has a wavelength that is 1/10th that of GLONASS C/A-code and about 1/5th that of GPS C/A-code. This has the effect that GLONASS P-code pseudo-range measurements are considerably more precise than comparable GPS or GLONASS C/A-code measurements. Second, GLONASS P-code is transmitted on both L1 and L2 frequencies, so it allows high-precision ionospheric delay measurements.

Originally GLONASS signals were broadcast on 48 frequencies (24 frequencies in the future) in contrast to GPS, which is broadcast on 2. This causes some difficulties with the delay biases, which vary with frequency. These, however, can be resolved, so the GLONASS system provides the net advantage that it is less vulnerable to intentional or unintentional jamming.

Until recently no post-processed GLONASS precise ephemerides are available. This, however, has changed as the Scientific Assembly of the International Association of Geodesy decided, on 3-9 September 1997 in Rio de Janeiro, to organize an International GLONASS Experiment (IGEX) in 1998. The IGEX begun on 19 October 1998 with participation of several tens of geodetic and timing institutions, and the first GLONASS precise ephemerides expressed in the ITRF are already available to civil users at the end of 1998. This will make the use of GLONASS more efficient for intercontinental time links. Other improvements will follow, among them rigorous transformation parameters between the WGS 84 reference frame used by GPS and the PZ-90 reference frame used by GLONASS.

ONE-SITE COMPARISON

For the determination of GLONASS frequency biases, described in the paragraph below, and a test of GLONASS P-code time transfer, we use a one-site comparison of time receivers. A one-site comparison calls for the computation of common views for two independent time receivers located at the same site, connected to the same clock, and with antennas separated by no more than several meters. Comparisons at short distances allow the cancellation of common clock errors and certain other systematic errors. If the software used by the receivers is identical, no error should arise from satellite broadcast ephemerides, antenna coordinates, or imperfect modelling of the ionosphere and troposphere. Any constant bias measured is caused by delay differences of the two time-receiving systems, including the receiver itself, the antenna, and the cables, and any observed noise arises in the hardware and in multipath effects. In fact, the noise ascribed to space factors for the comparison over several hundred kilometers is almost equally well cancelled as that for the one-site comparisons. The particular advantage of a one-site comparison, however, is the elimination of the clock discrepancies, so that only the noise of the receiving equipment is observed. This can serve to characterize the receiving equipment.

GLONASS FREQUENCY BIASES

GLONASS data are subject to a receiver bias which may be different for each GLONASS frequency [3]. The spread of these biases across satellites can reach 15 nanoseconds and, therefore, mask other noise sources.

Based on the data available so far, GLONASS frequency biases appear to be a function of temperature and relate to specific receivers. But once calibrated with respect to a reference receiver, and provided that temperatures are maintained via laboratory air-conditioning together with a TSA antenna set-up, these values remain pretty constant and can therefore be compensated in the software. Figure 2 shows one-site GLONASS P-code common-view values dt_i, for each track i, between two time receivers, for the GLONASS frequencies Nos. 1, 4 and 10. One can see clearly the biases between the values of dt_i resulting from the use of different GLONASS frequencies. For each GLONASS P-code frequency, the dispersion of the mean value of the dt_i over the whole period of computation is of the order of 0.8 ns.

In order to estimate the GLONASS frequency biases, let the mean value of the dt_i over the whole interval of computation for the common views using the frequency f, be written as follows : $\langle dt_i \rangle_f$. We can arbitrarily choose the frequency No. 10 as a reference frequency and then define a bias for the frequency f as follows :

$$B_f = \langle dt_i \rangle_{10} - \langle dt_i \rangle_f$$

The biases so estimated for the two involved receivers are listed in Table 1.

Table 1. GLONASS P-code frequency biases with respect to frequency No 10.

GLONASS Freq. No. f	B_f /ns
1	-7.8
4	-5.4
6	-2.3
9	-0.2
10	0
12	-1.0
13	-1.1
21	-1.3
22	-0.6
24	-1.6

A TEST OF GLONASS P-CODE

In a one-site comparison test we demonstrate the improvement brought about by the use of GLONASS P-code for common-view time transfer by comparing the results with those obtained from GLONASS and GPS C/A-code common-view time transfers. We used a one-site test specifically to analyze the noise of our time receiving equipment: 1) when used with GPS and GLONASS C/A-code in single-channel and multi-channel modes, both with and without a TSA (temperature–stabilized antenna) antenna; and 2) when used with GLONASS P-code in single-channel mode, both with and without a TSA antenna.

Figure 3 shows some examples of one-site comparisons over a period of about eight days using the same pair of receivers equipped with TSA antennas throughout. We observe that C/A code comparisons are affected by some systematic changes. The GLONASS C/A-code data are slightly noisier than GPS C/A-code data, as the delays depend on the frequency. After removing the bias specific to each GLONASS frequency and activating the TSA antennas,the GLONASS P-code comparison shows outstanding performance [4].

Time deviations of one-site comparisons were computed for four cases (Figure 4):

- GPS C/A-code single-channel without TSA antennas,
- GPS C/A-code multi-channel without and with TSA antennas,
- GLONASS P-code single-channel with TSA antennas and biases compensated for different GLONASS frequencies.

Except for GLONASS P-code the level of noise for the all above comparisons is about 3 ns. The gain in stability between GPS C/A-code single-channel and a multi-channel comparison is in line with our expectations according to the considerations reported above.

The multi-channel comparison without TSA antennas is affected by a systematic effect which becomes evident at about 3×10^4 second. This effect is removed when the TSA antennas are activated. However, a smaller systematic effect with a period of several hours persists: this may have its origin in the antenna cables. Recent data from another pair of receivers of the same type equipped with TSA antennas exhibit no systematic effect.

The level of noise for the GLONASS P-code comparison, using TSA antennas and after removing the bias specific to each frequency, is about 600 picoseconds. The reduction in noise level between GPS C/A-code single-channel and GLONASS P-code single-channel comparison is about 5. The use of GLONASS P-code in multi-channel mode should provide an improvement in stability similar to that found for GPS C/A-code. Consequently, the expected time stability with an averaging time of one day should be several tens of picoseconds: this corresponds to a frequency stability of several parts in 10^{16}. Multi-channel GLONASS P-code time transfer will be the object of our next study as suitable receivers are now available.

CONCLUSIONS

As GLONASS P-code, unlike GPS P-code, is available to civilian users, it is in the general interest to take best advantage of it. There are two main reasons for this. First, GLONASS P-code has a wavelength that is 1/10th that of GLONASS C/A-code and about 1/5th that of GPS C/A-code, which has the effect that GLONASS P-code pseudo-range measurements are considerably more precise than comparable GPS or GLONASS C/A-code measurements. Second, GLONASS P-code is transmitted on both L1 and L2 frequencies, so it allows high-precision ionospheric delay measurements.

As now practiced, GPS and GLONASS C/A-code time transfer are limited mainly by hardware instabilities and, over long distances, by uncertainty in the determination of ionospheric delays. The use of GLONASS P-code combined with the use of temperature-stabilized antennas provides an improvement to resolve these two problems. GLONASS post-processed precise ephemerides, necessary for long-distance links, are now available.

GLONASS P-code single-channel data obtained in the course of a one-site comparison shows a noise reduction of 5 relative to GPS C/A-code single-channel data performance. The use of GLONASS P-code in multi-channel mode promises a gain in stability by a factor of about 3. Consequently for short baselines, the expected time stability for an averaging time of one day should be of about 100 picoseconds, which corresponds to a frequency stability of 1 part in 10^{15}.

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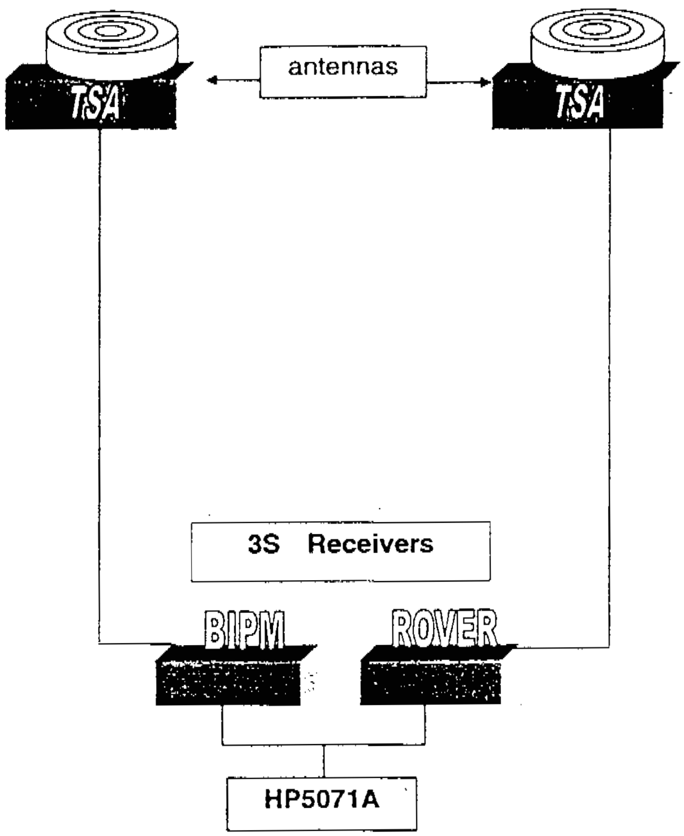

Figure 1. Scheme of one-site comparison with two TSA antennas.

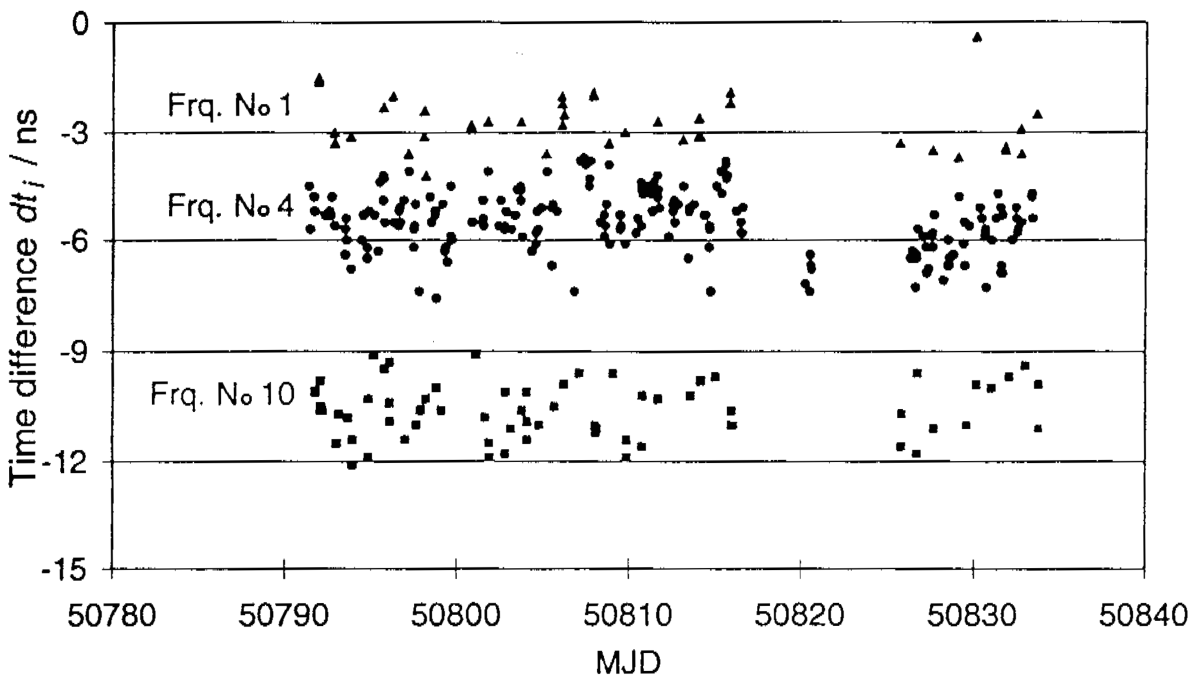

Figure 2. GLONASS P-code frequency biases – one site GLONASS P-code common-view values dt_i.

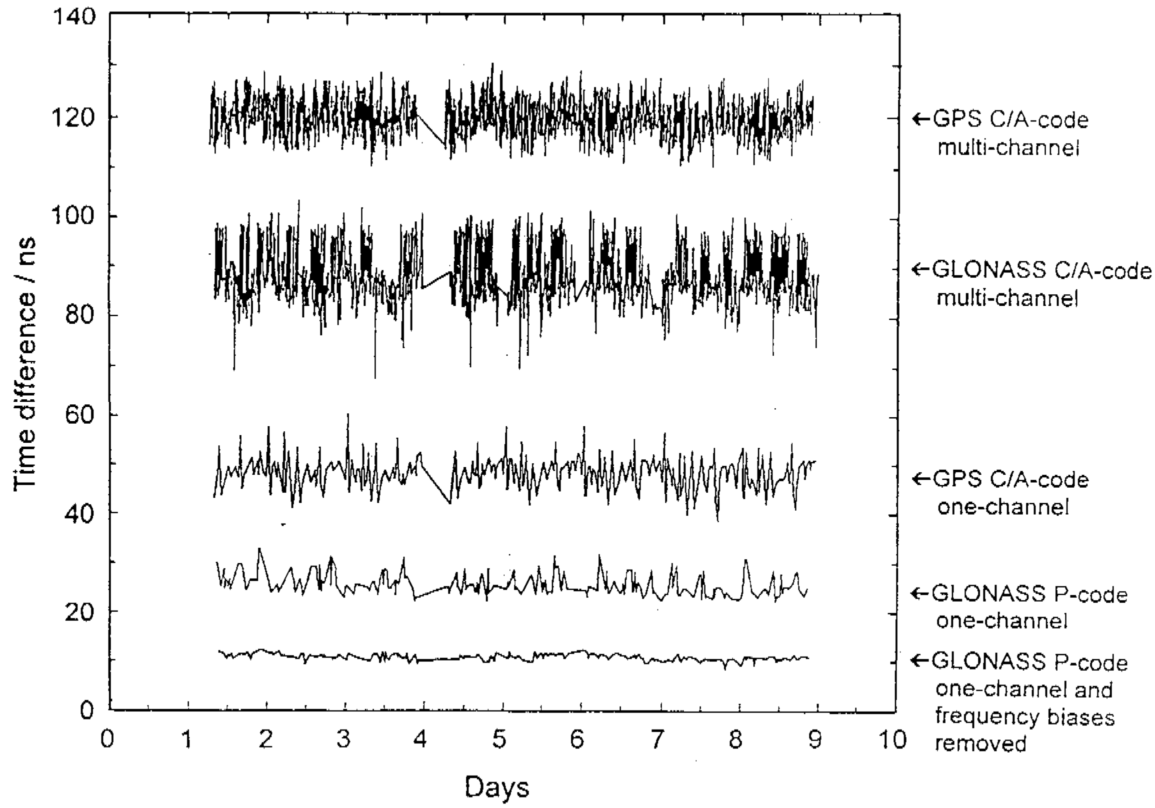

Figure 3. One-site comparisons (two separate TSA antennas on a single site).

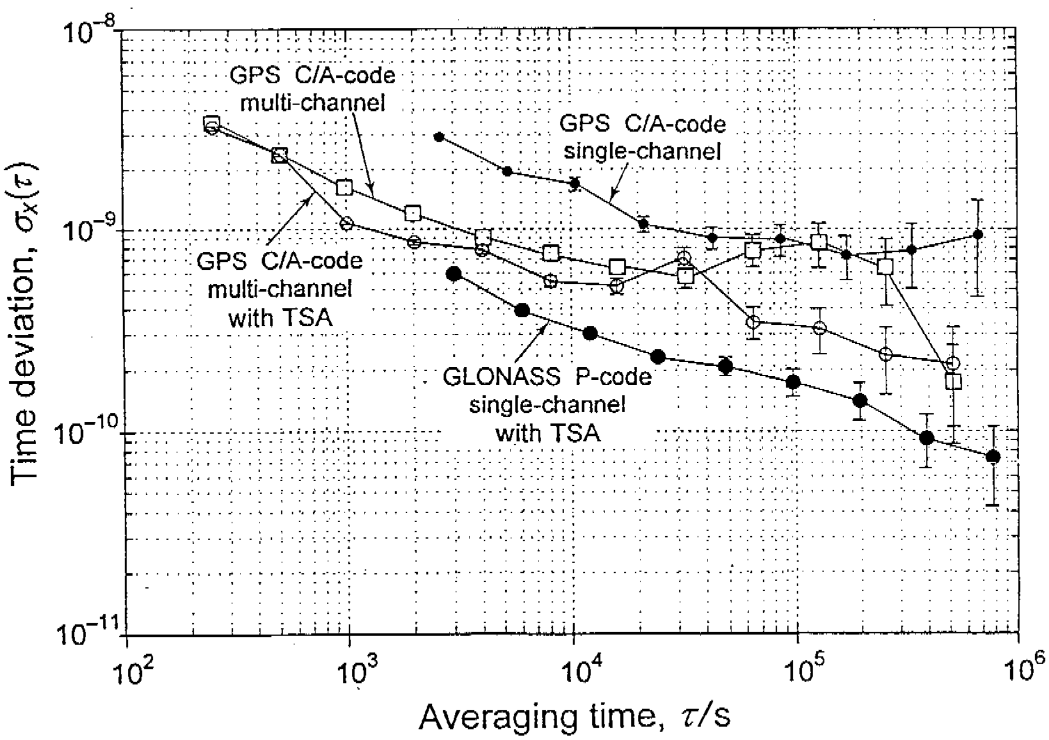

Figure 4. Time Deviation for one-site comparisons (two separate antennas on a single si

Questions and Answers

GERRIT de JONG (NMi Van Swinden Laboratorium): I have a question about the calibration you made between the channels. You took channel 10 as a reference, and then you determined relative calibration values against that frequency. Did you do the same test with another GLONASS receiver? Is the calibration the same for every receiver or do they have to be calibrated individually?

JACQUES AZOUBIB (BIPM): It is to a specific receiver. The Frequency 10 was arbitrarily chosen. We could have chosen another reference frequency, and it would not have changed anything concerning the stability results we obtained.

We could have also chosen the mean value of the different frequencies and computed the bias as it shifted between this mean value and the different values of dt(i). So the choice of Frequency 10 is completely arbitrary.

GERRIT de JONG: Yes, but my question was not about the choice of that frequency, my question was: is this for two receivers, the BIPM receiver and the Rogue receiver? For instance if you take two receivers, could you get the same calibration factor or not?

JACQUES AZOUBIB: Not at all. I will read from this vugraph: "Once calibrated with respect to the reference receiver, this value remains critical...." Before, I said that it is a function of particular and specific receivers. That means that for each receiver a set of biases should be computed.

DEMETRIOS MATSAKIS (USNO): Did the relative biases change with temperature? You referenced them all to Satellite 10. Do they all go up and down together?

JACQUES AZOUBIB: We have not done any experiments. We got this information from 3S Navigation -- that the biases are related to our frequency comparator.

DEMETRIOS MATSAKIS: I wondered if the relative bias was varying with temperature between the biases of the channels?

WLODZIMIERZ LEWANDOWSKI (BIPM): We were informed by 3S Navigation that the biases can be affected by temperature if the receiver antenna is not protected. That is one of the reasons to develop the temperature-stabilized antennas. Colleagues from 3S Navigation who know electronics said that these biases are sensitive to temperature. To take the full advantage of this technology, we have to stabilize the antenna and the receiver. If stabilized, these biases are pretty constant. This is now easy to do; so this is not a problem.

DEMETRIOS MATSAKIS: The other question I have is a little complicated. I think one of the big exciting things that is coming out of your work will be an ability to check for calibration errors in the GPS receivers on a daily basis. You have already talked about how you see the diurnal term in GPS receivers. We also see 100-day or longer-term variations. I wonder if it has gone on long enough that you can see changes that happen between the BIPM traveling GPS calibrations, so that we know that it really is GPS varying on the longer scale and not the GLONASS.

WLODZIMIERZ LEWANDOWSKI: You underlined a very important point. This use of GLONASS P-Code and the way we are doing this leads us to something extremely interesting, because it gives an excellent reference to calibrate other receivers, GPS, for example. This is just at the beginning. We are on the verge of a series of GLONASS P-Code calibrations. We now have the receiver at the Paris Observatory which will go to our laboratories equipped with GLONASS P-Code receivers. We would like to invite you to also participate in this exercise at several laboratories in Europe. The receiver will also go to South Africa, Australia, and Japan. There are already many laboratories equipped with these receivers. We would like to repeat these calibrations. What we expect – maybe it is too optimistic, but we expect, based on the knowledge of what Jacques has just shown, that we are going to sub-nanosecond calibration of timing equipment. That is very exciting. Because, right now we are at the level of several nanoseconds, even 10 nanoseconds. The receivers delays are changing during the season, up to 10 nanoseconds.

You showed yesterday how well it is behaving. You know, it is within a few nanoseconds of UTC, so we now have to care about one nanosecond or even better calibration. This is something which this study gives us hope to achieve – maybe next year.

JACQUES BESER (3S Navigation): I just wanted to add a clarification. I mentioned yesterday that the antenna pre-amplifier, of course, contains filters. Those filters come from the manufacturer with specifications on them, and you can see that the specification basically indicates delays as a function of frequency, and temperature. So, the manufacturer clearly states that those parabolas, if you want – as temperature changes, not only will the entire "parabola" move up and down, which means an absolute delay will change, also the sides of it will kind of squeeze or enlarge. So, there will be an inter-channel frequency change frequency by frequency, as well as an absolute value. So, that was the answer to your question.

If you saw the data I presented briefly yesterday, you saw that when we turn off one of the TSA antennas and one of the receivers, all of a sudden you see the spreading increasing. That again showed experimentally that the temperature obviously had an effect frequency by frequency.