CLOCK COMPARISON WITH GEODETIC GPS RECEIVERS

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ABSTRACT

The conventional Common View (CV) time transfer requires specially designed satellite timing receivers. In case if a clock comparison is executed in the frequency domain, standard geodetic receivers can be used. In this paper we present the results of DLR CV experiments with geodetic receivers. In the first experiment we compared the performance of the CV procedure based on geodetic receivers with the performance of that based on timing receivers. In the second experiment we assessed the noise floor of the CV procedure based on geodetic receivers using three geodetic receivers installed on the same site and connected to the same reference oscillator.

Keywords: clock, comparison, Common View , geodetic receiver, performance

INTRODUCTION

Commercial timing receivers (with a few exceptions) are based on rather old engines with old tracking technologies. On the other hand, a lot of innovations have been implemented in commercial geodetic receivers. Some of them are collocated with the timing ones at timing laboratories that contribute their data also to International Service for Geodynamics (IGS).
Therefore, the implementation of geodetic receivers for clock comparisons has been intensively studied (see, e.g. [DEFR-01], [SENI-01], [DACH-01]). Two solutions were proposed: 1) combination of a geodetic receiver with a time interval counter, 2) direct use of geodetic receivers for frequency comparisons. We have chosen the latter approach. GPS observations from a permanent GPS/GLONASS monitoring station, operated at DLR at Oberpfaffenhofen, and another two geodetic receivers were used for experiments.
Two experiments were performed to test CV procedure based on geodetic receivers. Calibration aspects were not taken into account because we were interested to investigate the stability of the clock comparison results, i.e. the precision of the method.

1. CLOCK COMPARISONS AND COMMON VIEW

The *time* difference between two clocks is given by

$$x(t)=\frac{\phi_2(t)-\phi_1(t)}{2\pi} \qquad (1)$$

where ϕ stands for the instant phase of an oscillator signal and t for the true time.

The difference x(t) includes two terms, a deterministic and a stochastic one. The deterministic term is usually modelled with a square polynomial, thus

$$x(t)=x_0+at+\frac{c}{2}t^2+x_r(t) \qquad (2)$$

Here $\mathbf{x_0}$ is the initial clock offset, **a** frequency offset, **c** linear frequency drift and $\mathbf{x_r}$ noise term.

A linear model is adopted for the deterministic part of the *frequency* difference of two clocks:

$$y(t)=\frac{\nu_2(t)-\nu_1(t)}{\nu_1(t)}=a+ct+y_r(t) \qquad (3)$$

where $\mathbf{y_r}$ is a noise term and ν_i - instant frequency of clock **i**.

Terms $\mathbf{x_0}$, **a**, and **c** can be obtained by a simple least-squares fit of measured clock differences. Kalman filtering and the method of finite differences are also used.
Common View allows to measure the time difference between two remote clocks. The time difference between the laboratories is calculated as

$$x(t)=[t_{sat}(t)-t_1(t)]-[t_{sat}(t)-t_2(t)] \qquad (4)$$

where t_i is local time of laboratory **i** and $t_{sat}(t)$ is satellite time.

Conventional CV requires special satellite timing receivers which include a time interval counter (TIC) to measure the difference between the estimate of satellite time, i.e. $t_{rec}(t)+[t_{sat}(t)-t_{rec}(t)]_{estimated}$ (here $t_{rec}(t)$ is the internal receiver time), and the time of the siting laboratory, i.e. t_i. Moreover, the internal delays of the receiver hardware (including antenna and cabling) are to be calibrated.
A geodetic receiver does not include a TIC. Its internal time is synchronized to the time of the first satellite having been locked. After each receiver reset, the synchronization is re-established, and the receiver time suffers a leap. The offset between the internal time of a geodetic receiver time and the reference time scale of the siting laboratory is unknown. Therefore eq. (4) is transformed to

$$x_g(t)=[t_{sat}(t)-t_{rec,1}(t)]-[t_{sat}(t)-t_{rec,2}(t)] \qquad (5)$$

where $\mathbf{x_g}$ is the estimate of the difference between the internal time of two geodetic receivers and

$$t_i(t)=t_{rec,i}(t)+\Delta t_{rec,i}(t) \qquad (6)$$

thus,

$$x(t) = x_g(t) + [\Delta t_{rec,1}(t) - \Delta t_{rec,2}(t)] \qquad (7)$$

The time domain clock comparison with geodetic receivers is ambiguous (see eq. (7), where $\mathbf{x_g}$ is an unknown term). However, these ambiguity and 'post-reset' leaps affect only the term $\mathbf{x_0}$ in eq. (2). Thus, if we use eq. (2) to fit the CV results, then $\mathbf{x_0}$ accumulates the unknown biases and estimates of terms **a** and **c** will provide a frequency domain comparison. Similar experiments were described in [DEFR-01] and earlier publications of the same author.

No calibration of receiver hardware is required to perform a comparison in the frequency domain. The absolute values of receiver and cable delays are not important, they should only be stable over the time of an experiment.

Another problem of the implementation of geodetic receivers for clock comparisons was the format of output data. BIPM has defined a special data format for GPS/GLONASS Common View called CGGTTS [BIPMCV] and a processing procedure for pseudorange measurements. The measurement rate is defined to be 1 s. On the other hand, the standard format for the exchange of GPS/GLONASS observation data is RINEX. RINEX includes only raw pseudorange measurements. The measurement rate is usually 30 seconds as specified by International Service for Geodynamics (IGS). [DEFR-01] has shown that the accuracy of CGGTTS timing data is almost the same for 1 s and 30 s measurement rates. We have developed a RINEX-to-CGGTTS conversion utility similar to that described in [DEFR-01]. This utility was used to process GPS data collected during each of the experiments.

2. FREQUENCY TRANSFER OVER LONG BASE-LINE

We designed a long base-line CV experiment to compare the performance of geodetic and timing GPS receivers. We have used data from IMVP (Institute of Metrology of Space and Time, Mendeleevo), DLR near Munich (designated OPJV) and PTB (Physikalisch-Technische Bundesanstalt at Braunschweig) timing laboratories (see table 1-1).

Equipment	IMVP	PTB	OPJV
Receiver	TTR6	TTR5	Legacy-E
Firm	AOA	AOA	JPS
System	GPS	GPS	GPS/ GLONASS
Data	C1, L1	C1, L1	C1, P1, P2, L1, L2
Channels	1	1	20
Antenna	std. TTR5	std. TTR5	JPS choke-ring
Time reference	active H-maser	Cs	Cs

Table 1-1. Hardware of timing laboratories

* *following acronyms are used in the table:*

L1 Carrier-phase measurement using the first carrier frequency

L2 Carrier-phase measurement using the second carrier frequency

C1 Code-phase measurement using civil ranging code on the first carrier

P1 Code-phase measurement using precise ranging code on the first carrier

P2 Code-phase measurement using precise ranging code on the second carrier

We continuously collected GPS observations at OPJV site from MJD 52208 to MJD 52225. Elevation cut-off angle was set to 10 degrees and the observation rate was set to 30 seconds. All satellites in view were tracked. Raw data were converted into RINEX format using a JPS firmware and then converted into CGGTTS format using an in-house developed utility of DLR. CGGTTS timing data from IMVP and
PTB were obtained from BIPM public FTP archive.

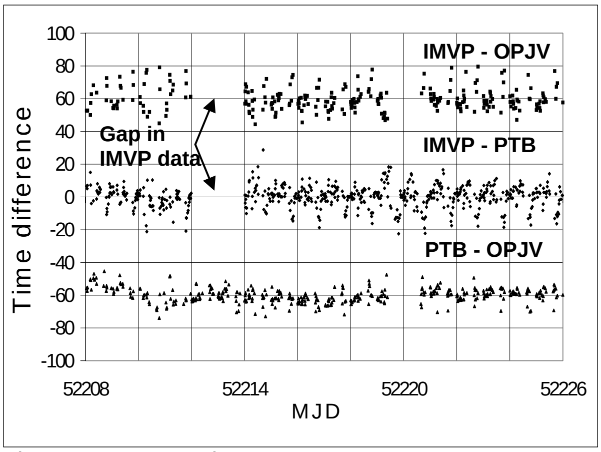

Figure 2-1. CV results

Fig. 2-1 presents the results of CV for the links IMVP-OPJV, IMVP-PTB and PTB-OPJV (standard deviation is 7.0, 6.8 ns and 4.4 ns respectively). Linear drifts and outliers were removed. The vertical shift on the Y-axis of the plot was introduced intentionally to distinguish different data sets. The results exhibit apparent diurnal variations well-known to CV time transfers (see [WEIS-89]).

The Modified Allan deviation (MDEV) of the CV results is shown in fig. 2-2.

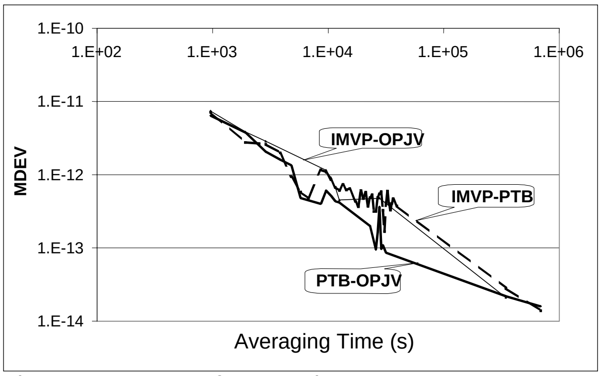

Figure 2-2. MDEV of CV results

The short-term precision was approximately the same for all of the three links. For an averaging time of about 0.5 days the accuracy of PTB-OPJV time transfer is almost 10 times higher than that for the two other links. It may be a result of influence of the ionosphere (the distance between DLR and PTB is 5 times shorter than the two other distances). MDEV plots show that the performance of the geodetic receiver (JPS Legacy at OPJV) was comparable with that of timing receivers.

We have also estimated the frequency offset between IMVP, PTB and OPJV laboratories. Two links were used: IMVP-OPJV and IMVP-PTB. The total period of the experiment was split into 1-day spans, then we made linear fits over the CV results of each of the spans to estimate the frequency offsets. Linear fits over these daily frequency offsets provide estimates of the linear frequency drifts (see fig. 2-3). The amount of data for the IMVP-OPJV link was about two times less than that for the IMVP-PTB link because the receivers followed different observation schedules. The standard deviation of the frequency estimates is 6.3×10^{-14} s/s and 4.5×10^{-14} s/s respectively). It is 2-3 times higher than the error associated with the clocks involved into the experiments (see fig. 3-5) and therefore should be attributed to the method and instrument errors.

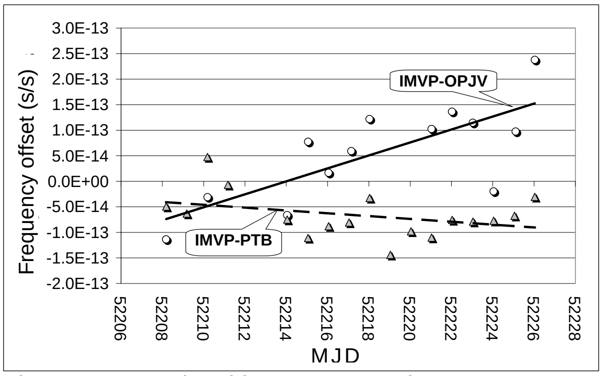

Figure 2-3. Results of frequency transfer

3. ON-SITE COMMON VIEW EXPERIMENT

We have performed an on-site experiment to estimate the noise floor of CV based on geodetic receivers.

Equipment	OPZ1	OPZ2	OPJV
Receiver	Z12	Z12	Legacy-E
Firm	Ashtech	Ashtech	JPS
System	GPS	GPS	GPS/ GLONASS
Data	C1,P1,P2, L1,L2	C1,P1,P2, L1,L2	C1, P1, P2, L1, L2
Channels	12	12	20
Antenna	navigation (Marine III)	choke-ring	JPS choke-ring
Time reference	Cs		

Table 2-1. Receiver equipment used in on-site experiment

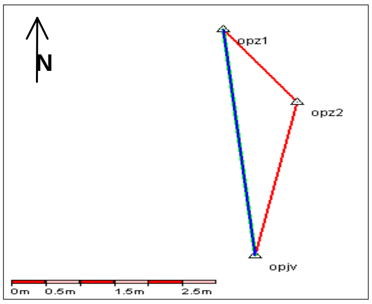

Figure 3-1. Antenna area layout

Three geodetic receivers were installed at the DLR site in Oberpfaffenhofen (see fig. 3-1) and connected to the same reference clock. Unique IDs were assigned to each antenna-receiver pair (see table 2-1).

We collected GPS data from all the three receivers from MJD 52208 to MJD 52225. The measurement rate was set to 30 seconds, and the cut-off elevation angle was set to 10 degrees. All satellites in view were tracked. No temperature compensation of receivers and antennas was implemented. We converted raw measurements and navigation data into RINEX format and then produced three CGGTTS files, one for each of the receivers. Each CGGTTS file includes timing data for the whole time span of the experiment. No resets of the receivers were done. So no specific leaps of receiver time were observed. Some data were lost because of a PC failure.

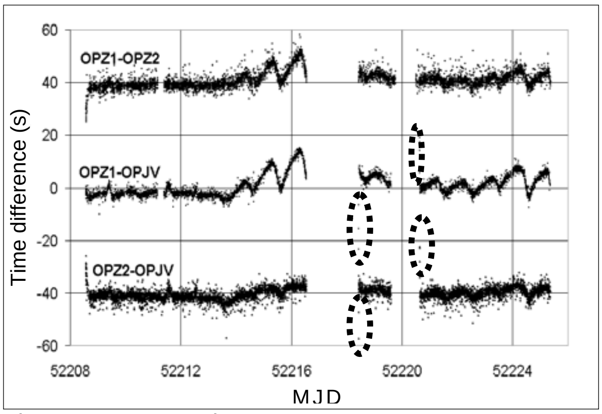

Figure 3-2. CV results

CV was performed over the links OPZ1-OPZ2, OPZ1-OPJV, OPZ2-OPJV. Influence of the ionospheric and tropospheric errors to the CV results was eliminated because the distances between the receiver antennas were very short. So it was possible to estimate the noise level of CV based on geodetic receivers in this plain implementation.
The standard deviation of CV over OPZ1-OPZ2, OPZ1-OPJV and OPZ2-OPJV links is 3.1 ns, 4.0 ns, and 2.3 ns respectively. It reflects the influence of the receiver antenna: OPZ2 and OPJV had choke ring antennas and OPZ1 only a non-precise navigation antenna. JPS and Ashtech receivers exhibited different performance of satellite tracking, therefore a few outliers were found in the results of CV (see dashed oval in fig. 3-2).

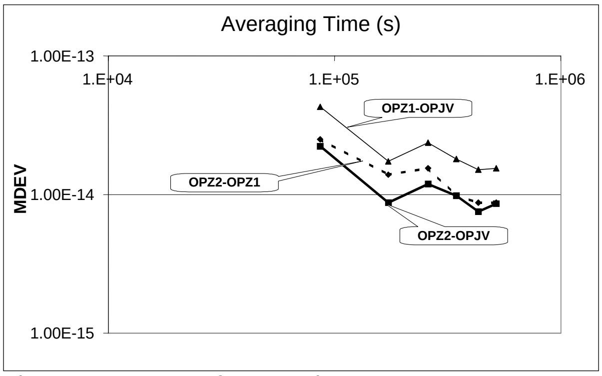

Figure 3-3. MDEV of CV results

Fig. 3-3 presents MDEV of daily averaged CV results. The implementation of precise antennas appeared to be an important point: it improved the long-term performance of CV by a factor of about 2 (compare the results for OPZ1-OPJV and OPZ2-OPJV links) . Another interesting outcome of the experiment was the mitigation of the influence of a non-precise antenna for OPZ1-OPZ2 link (both OPZ1 and OPZ2 are equipped with Ashtech receivers and antennas). JPS and Ashtech receivers exhibited different satellite tracking performance. This effect should be investigated further.

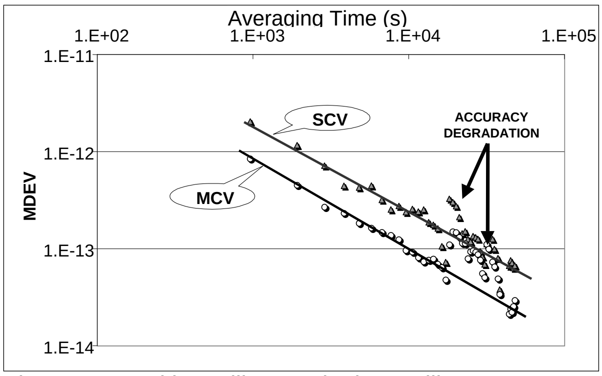

Figure 3-4. Multi-satellite vs. single satellite CV

Additionally, the accuracy of a single satellite time CV (SCV) described in [BIPMCV] was compared with the accuracy of multi-satellite CV (MCV) (see fig. 3-4). The SCV procedure deals with observations of only one satellite per epoch. The MCV approach uses the processing technique from [BIPMCV] for all the satellites tracked simultaneously by two laboratories.
The MCV approach improved the short-term accuracy by a factor of about 2.5 (for an averaging time up to 1 day). The accuracy degradation for intervals of $3-6\cdot10^4$ s has an obscure nature. This effect is also reported in [HAHN-98]. It might be caused by temperature variations of antenna and receiver delays.
Finally, we compared the performance of SCV and MCV with the performance of primary frequency standards, i.e. Cs clock (HP5071A) and active H-maser (CH1-75) (see fig. 3-5).

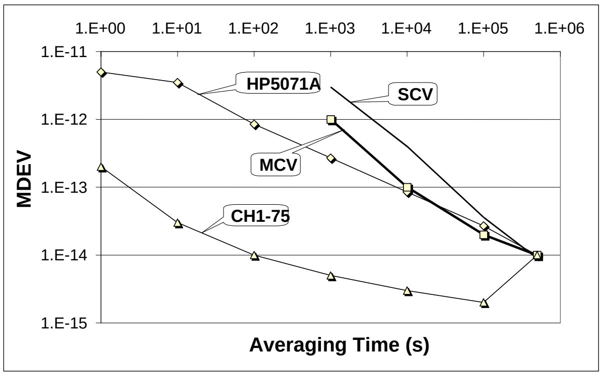

Figure 3-5. CV vs. performance of primary standards

After averaging over 3 hours the precision of MCV reached that of the primary Cs standard, and after averaging over 1 day the MCV noise was reduced to the level of an active H-maser. Thus, the short-term noise of CV is higher than the noise of primary standards and only the medium- and long-term performance of precise clocks can be assessed correctly.

CONCLUSION

The results of the experiments have shown that the performance of geodetic receivers in timing applications is not worse than that of timing receivers.
We have also assessed the noise floor of clock comparisons based on geodetic receivers and found that it is comparable to the performance of primary frequency standards after an averaging period of at least 3 hours. Periodic affects found in the results of CV should be assigned to environmental variations of receiver and antenna delays.
Future work will concentrate on the elimination of temperature variations of receiver delays and implementation of precise satellite ephemeris and ionospheric parameters. We also plan to use a more sophisticated algorithm of data processing.

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