Report on the APMP Round-Robin GPS Common-View Time Transfer Receiver Intercomparison Experiment: Round 1 - October 1999 to May 2000

Introduction

The purpose of this intercomparison is to compare the electronic delays between (and including) the antenna and the reference input of the GPS common view time transfer receivers used for the realisation of UTC at several laboratories in the Asia-Pacific region.

It is difficult to measure these delays directly, since to do so would require signals from GPS satellites to be simulated and injected into the antennas. The equipment required for this task is very expensive, and could not easily be shipped between laboratories.

Instead, an Allen-Osborne model TTR6 GPS common-view time transfer receiver (serial # 267) belonging to NML was shipped in sequence to the following laboratories during the period October 1999 to May 2000:

Start: National Measurement Laboratory, Australia (NML)
Telecommunications Laboratory, Taiwan (TL)
National Astronomical Observatory, Japan (NAO)
Communications Research Laboratory, Japan (CRL)
National Research Laboratory of Metrology, Japan (NRLM)
Korea Research Institute of Standards and Science (KRISS)
The Government of the Hong Kong Special Administrative Region Standards and Calibration Laboratory, Hong Kong, China (SCL)

Finish: National Measurement Laboratory, Australia (NML)

The travelling receiver was shipped with an antenna and antenna cables. The antenna cables were sufficiently long for installation at all laboratories except SCL, where longer cables were obtained and installed by SCL staff. The electronic delay of the antenna cables was measured at NML, and each laboratory was encouraged to check this measurement. A notebook PC (loaned by TL) was provided, and it was equipped with software and cables for configuration of, and data downloading from, the TTR6 receiver.

Each laboratory installed and operated the receiver and antenna for a period of approximately 3 weeks. The CCTF-format data files generated by the travelling TTR6, as well as those generated by the time transfer receiver of each host laboratory, were emailed to NML. Each laboratory also provided detailed information concerning the delays between their realisation of UTC and each receiver.

The aim of the data processing at NML was to compare the epoch of the local realisation of UTC as measured by the host time transfer receiver with that measured by the travelling time transfer receiver. If all measurements were made perfectly and all delays were accurately known, the difference between the two measurements at each laboratory should be zero.

If the internal delay of any of the participating receivers is known, the internal delays of all other participating receivers may be calculated using the results of this intercomparison.

Data processing

Each participating laboratory sent to NML the CCTF-format data generated by their own GPSCV receiver (the "Host" receiver) and that generated by the NML travelling receiver.

The data were processed as follows:

1) The raw "Reference – GPS" ($REFGPS_{raw}$) values from each receiver for each 780 second common-view track were corrected for the difference, if any, between the delay parameters reported by the host laboratory, and the actual parameters reported by the receiver in the CCTF data file:

   $$REFGPS = REFGPS_{raw} - \Delta$$

   Where

   $$\Delta = (\delta_{INT} + \delta_{ANT} - \delta_{REF})_{Reported} - (\delta_{INT} + \delta_{ANT} - \delta_{REF})_{Receiver}$$

   and

   δ_{INT} = the internal time delay of the GPSCV receiver (ns)
   δ_{ANT} = the time delay of the receiver's antenna and antenna cable (ns)
   δ_{REF} = the delay between the UTC(Host laboratory) 1 pps signal and the "1 pps input" BNC connector on the GPSCV receiver (ns)

   and the subscripts "Reported" and "Receiver" refer respectively to the values reported directly to NML by the host laboratory and those actually appearing in the CCTF data files generated by the GPSCV receivers. This separation of "Reported" and "Receiver" values was necessary in order to deal with cases where parameters were measured or corrected after the CCTF data was recorded. It should be clearly understood that the "Reported" values are assumed to be the correct values.

   The combined delay δ_{ANT} of the antenna and antenna cable is difficult to measure accurately. Consequently, NML follows the convention that δ_{ANT} represents the time delay of the antenna cable only, and the unknown intrinsic time delay attributable to the antenna is incorporated in the value (equally difficult to measure) for the internal delay of the receiver.

2) The differences $\varepsilon(t)$ between the corrected REFGPS values for the host and travelling GPS receivers were calculated for each common-view track with starting time t:

   $$\varepsilon(t) = REFGPS_{Host}(t) - REFGPS_{Trav}(t)$$

3) Values for ε(t) for tracks where one or both receivers failed to maintain lock on the satellite for the full 780 seconds were discarded. Values for ε(t) at times during which the data was invalid for any other reason reported by the host laboratory were also discarded.

4) A least squares fit was performed on the differences ε(t), and the mean and slope of the line of best fit, along with the root-mean-square (RMS) deviations of the data about this line and the standard deviation of the mean, were recorded.

The raw data and "Mathematica" calculation files are available for inspection at:

ftp://time1.tip.csiro.au/pub/timedata/gps/APMP_data/GPS_Calibration/

Results and discussion

The results of the data processing are presented in table 1, the differences calculated in processing step 2 (above) are plotted in figure 1, and the values for the delay parameters are presented in table 2.

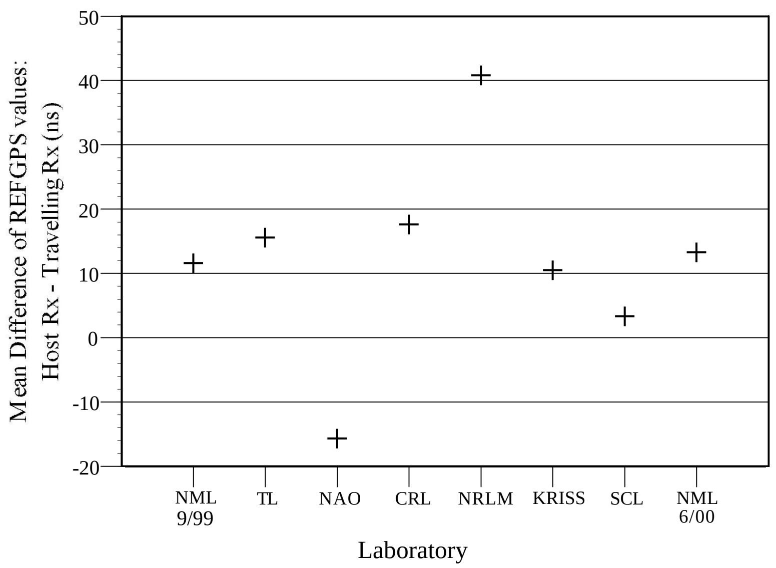

Figure 1: Results of comparisons between the NML travelling GPSCV receiver and those of the participating laboratories (see also table 1).

With the exception of two outliers (NAO and NRLM), all the difference values fall within a 20 ns range.

The value (68 ns) for the internal delay of the NML Travelling GPSCV TTR6 receiver was determined from the BIPM round-robin intercomparison of such receivers, which took place in 1996 (BIPM Rapport-97/1). There is unfortunately some evidence that an error was made at NML during this intercomparison, and because of this, and the poor records kept at NML at that time, this value for the internal delay of the receiver should be regarded as unreliable. This is why the reported value for the NML host GPSCV receiver (also a TTR6) is 50 ns, rather than 68 ns.

Consequently, the results of the present intercomparison do not represent an absolute calibration of each participating receiver. However, if one or more of the participating laboratories are presently confident that the reported value for the internal delay of their GPSCV receiver has been correctly determined by some other means, then these results may be used to transfer this calibration to the receivers belonging to the other participating laboratories. The same principle applies if any of the participating GPSCV receivers are calibrated at a later date.

In the present intercomparison, all receivers were of the Allen-Osborne TTR6 type, and it is likely that the internal delays and antenna delays of these receivers are similar. In order to investigate this hypothesis, the results presented in table 1 were recalculated with the reported internal delays of the host and travelling receivers set to 50 ns. The results, presented in table 3 and plotted in figure 2, fall (with the same two exceptions as above) within the range 0 ns to –10 ns, and therefore support this hypothesis, as well as the validity of the measurements and calculations.

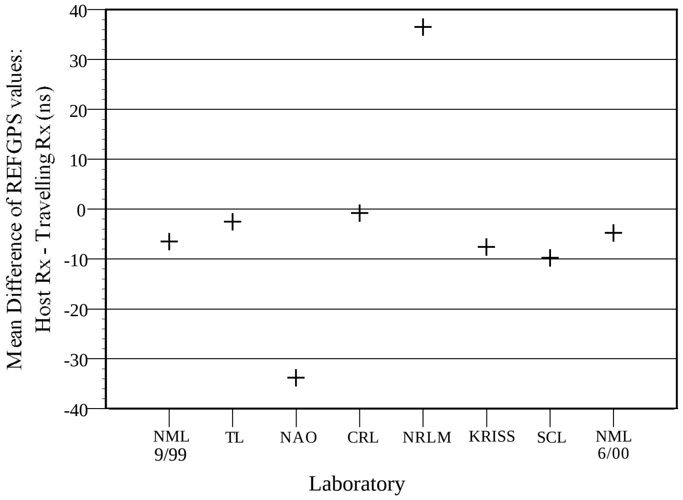

Figure 2: Results of comparisons between the NML travelling GPSCV receiver and those of the participating laboratories, calculated with the assumption that the internal delays of all participating GPSCV receivers are identical (50 ns) (see also table 3).

A drift of 1.7 ns between NML's TTR6 receiver and the travelling receiver was observed over the period of the intercomparison (see tables 1 and 3). This drift is significantly larger than the statistical uncertainty intrinsic to the CCTF data, and cannot be accounted for by uncertainty in the measurement of cable delays. When the travelling receiver returned to NML in May 2000, it was prone to losing lock on some satellites before the end of the 780 s CCTF tracks. The antenna of the travelling receiver was found to be affected by moisture which had entered its casing, and drying the circuit board appeared to restore the tracking reliability of the receiver. It is possible, but not certain, that the gradual ingress of moisture into the antenna of the travelling receiver over the period of the intercomparison could be responsible for the apparent drift in the system's internal delay. The antenna has now been more carefully sealed in preparation for the next round of the intercomparison.

Lessons learned from Round 1 of the APMP intercomparison

Several laboratories appear to have adopted the value (250 ns) for the antenna delay and antenna cable delay presented in the TTR6 user's manual. In order to improve the consistency of intercomparisons such as the present one, it will necessary to adopt a convention for clearly expressing the two contributions to this delay. The convention adopted by NML is mentioned in a previous section of this report, but other conventions could be at least equally valid and useful. If such a convention is adopted and antenna cable delays are measured by all laboratories who have not already done so, the present results can be corrected. A resulting improvement in the consistency of the results is expected.

The time allowed (4 weeks) for the transport to, and setup up and data acquisition at, each participating laboratory was probably sufficient. The only significant difficulties and delays experienced were related to the notebook PC, which suffered hard disk problems at TL, but were corrected by TL staff. The problem recurred at NRLM and could not be corrected and replacement notebook PC was shipped from NML. The results of the experiment were not affected by this problem.

Conclusion

In the light of the experienced gained in round 1 of this intercomparison, no fundamental changes are planned for round 2. When the results of the recent (1999) BIPM intercomparison of GPS/GLONASS receivers are published, it will almost certainly be possible to use the present results to establish an absolute time delay calibration for the GPSCV receivers at all of the participating laboratories.

Acknowledgments

NML is very grateful for the excellent and highly professional cooperation of the staff of the laboratories which participated in this experiment. We also thank the Chairman of the APMP Technical Committee on Time and Frequency, Dr C. S. Liao of TL, for his encouragement and support, and the loan of the notebook PC which was used for part of the intercomparison.

Laboratory	Start MJD	End MJD	Mean Difference of REFGPS values: Host Rx – Travelling Rx (ns)	Slope of line of best fit (ps/day)	RMS Deviation σ (ns)	# of Tracks N	Standard Error in the Mean $\frac{ó}{\sqrt{N}}$ (ns)
NML (Sept 1999)	51388	51417	12.3	-34 ± 14	3.4	840	0.12
TL	51480	51496	16.3	-13 ± 32	3.0	348	0.16
NAO	51512	51546	-15.0	-32 ± 70	3.3	1205	0.10
CRL	51551	51566	18.3	30 ± 30	3.9	415	0.19
NRLM	51569	51594	41.5	31 ± 30	5.5	775	0.20
KRISS	51626	51643	11.2	30 ± 29	3.9	689	0.15
SCL	51648	51662	4.0	-22 ± 60	3.9	256	0.24
NML (June 2000)	51704	51735	14.0	-27 ± 16	3.4	324	0.19

Table 1: Results of comparisons between the NML travelling GPSCV receiver and those of the participating laboratories (see also figure 1) .

Laboratory	Mean Difference of REFGPS values: Host Rx – Travelling Rx (ns)
NML (Sept 1999)	-5.7
TL	-1.7
NAO	-33.0
CRL	0.0
NRLM	37.3
KRISS	-6.8
SCL	-9.0
NML (June 2000)	-4.0

Table 3: Results of comparisons between the NML travelling GPSCV receiver and those of the participating laboratories, calculated with the assumption that the internal delays of all participating GPSCV receivers are identical (50 ns) (see also figure 2).

Laboratory	Host Receiver Type	Host Receiver Serial #	Reported Host Receiver Parameters (ns)			Entered Host Receiver Parameters (ns)			Reported Trav Receiver Parameters (ns)			Entered Trav Receiver Parameters (ns)		
			Int Delay	Ref Delay	Ant Delay	Int Delay	Ref Delay	Ant Delay	Int Delay	Ref Delay	Ant Delay	Int Delay	Ref Delay	Ant Delay
NML (Sept 1999)	AoA TTR6	446	50	102	235	68	102	235	68	102	234.5	68	102	230
TL	AoA TTR6	461	50	51	229	50	51	229	68	51	234.5	68	51	235
NAO	AoA TTR6	276	50	106	250	50	0	250	68	106	234.5	68	51	235
CRL	AoA TTR6	418	49.7	515.9	219.6	49.7	515.9	250	68	734.98	234.5	68	527.4	235
NRLM	AoA TTR6	457	64	89	250	64	89	250	68	0	234.5	68	0	235
KRISS	AoA TTR6	415	50	576	250	50	576	250	68	582	234.5	68	582	235
SCL	AoA TTR6	417	55	10	728	55	10	728	68	10	720	68	10	720[1]
NML (June 2000)	AoA TTR6	446	50	79	235	68	79	235	68	79.6	235	68	79.6	235

Notes:
1) The NML Antenna cables were not used at SCL because they were not long enough.

Table 2: Delay values provided by participating laboratories ("Reported" values) and values obtained from the raw CCTF output files of the participating GPSCV receivers. The parameters labelled "Entered" were those which were output by the receivers into their CCTF-format data files.