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COMPARISON OF LASSO AND GPS TIME TRANSFERS

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Abstract

The LASSO is a technique which should allow the comparison of remote atomic clocks with sub-nanosecond precision and accuracy. The first successful time transfer using LASSO has been carried out between the Observatoire de la Côte d'Azur in France and the McDonald Observatory in Texas, United States. This paper presents a preliminary comparison of LASSO time transfer with GPS common-view time transfer.

1. INTRODUCTION

The idea of using satellite laser techniques for the comparison of remote atomic clocks, known as LASSO (Laser Synchronization from Stationary Orbit), was conceived by M. Lefebvre and J. Gaignebet in 1972. The first successful tests were accomplished in 1989[1]. The first LASSO experimental link was established in 1992 between Observatoire de la Côte d'Azur (OCA) in Grasse, France, and McDonald Laser Ranging Station (MLRS) located at the McDonald Observatory in Fort Davis, Texas[2,3]. LASSO involves very simple physics, light travelling through space, and should easily allow sub–nanosecond time transfer.

At present, the use of the GPS common–view technique permits the comparison of remote atomic clocks at their full level of performance. We already know, however, that over the next few years new and better clocks will become available and that the GPS, as practiced now, will not then provide a system of adequate resolution. The estimated accuracy of intercontinental GPS time comparisons is of several nanoseconds[4,5], but, up to now, this has not been verified by an independent method of comparable or better accuracy. In this context LASSO appears

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to be an outstanding tool for the evaluation and calibration of the GPS time transfer and other time transfer techniques.

During an experiment covering the period from 8 December 1992 to 28 January 28 1993, two remote atomic clocks, separated by about 8000 km, were compared by independent space links, LASSO and GPS common–view. On each site a laser and a GPS receiver were connected to a single clock, a commercial cesium standard (Fig. 1).

The principal difficulty of this experiment was to obtain weather conditions under which LASSO measurements could be carried out. Unfortunately, throughout the experiment the sky was often covered and only in last week were five LASSO measurements accomplished. The experiment has now ended since the geostationary satellite Meteosat 3/P2, on which LASSO package is placed, has been moved to a location not visible from the OCA.

This paper, after giving a brief description of the GPS common–view and LASSO time transfers, reports the preliminary results of the comparison of these two methods.

2. GPS COMMON–VIEW LINK

In common–view time transfer, two remote stations receive signals from the same satellite at the same time and exchange the data to compare their clocks (Fig. 2). The main advantage of this method, introduced in 1980 for GPS[6], is that satellite clock error contributes nothing (satellite time disappears in the difference). Also over distances of up to a few thousands of kilometres the impact of other errors, such as poor estimation of ionospheric delay or broadcast ephemerides, is diminished. During our experiment, time transfer were carried out over a distance of 8000 km. In this case the modelling of the ionospheric delay applied by GPS time receivers should be replaced by measurements of ionosphere and broadcast ephemerides should be replaced by post–processed precise ephemerides. Both improvements will be incorporated in the next report on this experiment.

By using the same type of receiver at each site the consistency of the clock comparison is ameliorated as possible software errors are removed by the common–view approach. In the present study, GPS C/A Code time receivers were of the same type, AOA TTR5 at OCA and AOA TTR6, on loan from the BIPM, at McDonald.

In addition to single frequency GPS time receivers, double frequency GPS receivers providing ionospheric measurements were installed on both sites: a NIMS (NIST Ionospheric Measurement System) at OCA and a Trimble 4000 SST at McDonald.

The coordinates of the GPS antennas were expressed in the ITRF88 reference frame at OCA and the ITRF91 reference frame at McDonald, and were provided by the geodetic link with laser points at each site[7]. The estimated uncertainty of coordinates at each site is 5 cm. The uncertainties of the GPS ground antenna coordinates can have only a sub–nanosecond impact on the accuracy of this GPS common–view link.

The GPS common–view time transfer was realised from the about fifteen daily tracks of Block I and Block II satellites, following a special schedule (Fig. 4). During this experiment, the Block II satellites were subject to Selective Availability, so strict common views were required[8].

A Vondrak smoothing[9], which acts as a low-pass filter with a cut-off period of about five days, was performed on the raw GPS common-view values. The precision of this GPS link, estimated from the residuals of the smoothed values, is about 10 ns and should fall to about 4 ns after application of the measurements of ionosphere and post-processed precise ephemerides[4].

3. LASSO LINK

The LASSO link was realized through quasi-simultaneous laser firing to the METEOSAT 3/P2 geostationary satellite which was located at longitude 50° West[2,3]. The on board LASSO payload comprises a laser pulse detector, an event timer monitored by quartz oscillator, a retroreflector and uses telemetry downlink transmitter of the meteorological par of the satellite. A laser pulse departure is recorded on the ground station clock, its arrival at the satellite is recorded on the on board-clock and the time of returning pulse is then recorded on ground station clock (Fig. 3). A set of these three epochs is called a triplet. The same scheme is repeated quasi-simultaneously on the second ground station. The recorded arrival times at the satellite are sent back to the Earth. Atomic clocks located in two laser stations are compared using pairs of triplets. A detailed description of the LASSO observation and data processing is given in [2] and in [3] in these proceedings.

Bad weather conditions at the OCA and McDonald prevented simultaneous laser observations for almost the entire period of this experiment. Only during the last week did three cloudless nights at both sites allow LASSO time transfer. The results are given in Table I and Figure 4. The estimated precision of each of the five LASSO comparisons is better than 100 picoseconds[2,3].

4. CALIBRATION OF GPS AND LASSO TIME LINKS

The GPS TTR6 receiver was returned from McDonald back to France at the end of the experiment, where it was compared with the OCA TTR5 receiver. This differential calibration was performed according to the method described in [10]. The estimated uncertainty for the calibration of the GPS equipment is 2 ns.

To calibrate the laser equipment a portable laser station belonging to the ESA was compared in May 1993 with the OCA on-site laser equipment. In July 1993 the portable laser was transported to McDonald, where it was compared with on-site laser equipment. This exercise is described in [11] of these proceedings. As this report was being prepared the results of the calibration of laser equipment were not available. These will be given in future reports on this experiment. We know already that the precision of the calibration at the OCA is estimated at about 100 ps and that at McDonald at a few nanoseconds. This very large uncertainty in the calibration of the McDonald laser is linked to a particular configuration of the timing equipment at this station, which was not designed for ultra-precise time transfer, a problem which was not understood at the beginning of the experiment.

Particular attention should be paid to the link between the timing marks obtained by GPS and by laser timing equipment. In particular GPS receivers treat a stream of 1 Hz pulses provided by local clock, and laser timing equipment treats 5 MHz zero–crossing pulses.

5. COMPARISON OF GPS COMMON–VIEW AND LASSO TIME TRANSFERS

As the GPS common–view link between the OCA and McDonald was calibrated, and its estimated uncertainty is about 10 nanoseconds, it serves as a good reference for a preliminary evaluation of the LASSO link.

For this experiment, the smoothed GPS values were interpolated for the times of occurrence of LASSO observations. Comparisons of the two techniques are given in Table I and Figure 4. Note that the GPS and LASSO results differ by a fairly constant bias with peak–to–peak discrepancy of about 15 ns. The mean of these differences is 192 ns. The root mean square of the residuals to the mean, which is taken as an estimation of the confidence of the mean, is 6 ns.

Table I. Comparison of GPS common–view and LASSO time transfers

1993 Jan.	Epoch			OCA–MLRS byLASSO	OCA–MLRS by GPS	GPS - LASSO	GPS - LASSO -192 ns
	h	m	s	ns	ns	ns	ns
21	2	15	14.4	9933.56	10133	199	7
22	1	41	54.9	9990.05	10175	185	-7
22	1	56	12.1	9990.58	10176	185	-7
26	1	52	01.4	10154.26	10349	195	3
26	2	17	59.4	10155.96	10350	194	2

The bias of about 192 ns between the GPS common views and the LASSO is certainly due to the lack of calibration of laser equipment. In the last column of Table I the 192 ns bias has been removed.

6. FUTURE OF LASSO EXPERIMENT

The experiment described in this paper ended when the geostationary satellite Meteosat 3/P2, on which LASSO package was mounted, was moved to a location not visible from the OCA (75° West). Its mission was scheduled to end some time in 1993.

After this first successful LASSO time transfer experiment, the timing community considered future LASSO missions; a new LASSO generation could be able to reach a 10 ps accuracy of time transfer. One possible carrier of a LASSO payload would be the Russian satellite METEOR 3M during a joint experiment with the European Space Agency "Hydrogen Maser/Meteor 3M Mission"[12]. Other possible spacecraft which might carry LASSO equipment are the GPS

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and GLONASS satellites. GPS Block II satellites are now equipped with laser reflectors; all GLONASS satellites have always been equipped with such reflectors. As these navigation satellites are equipped with atomic clocks very few additional elements would be required to complete the LASSO payload. A detailed description of a possible LASSO implementation on GLONASS satellites is given in[13].

7. CONCLUSION

This comparison of GPS common–view and LASSO time transfers between Western Europe and North America shows consistency within stated uncertainties and a bias of about 192 ns. The bias is certainly due to non–calibration of the laser equipment.

After ameliorating of GPS link by inserting measurements of ionosphere and post–processed precise ephemerides, and after differential calibration of the lasers, the agreement between two techniques should be improved.

Although LASSO, because of its sensitivity to weather conditions, is inherently unsuited for operational duties, it is certainly an excellent tool for the assessment of the accuracy of GPS, GLONASS and Two–Way time transfers. The implementation of LASSO on new satellites is a challenge for coming years.

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References

[1] C. Veillet, D. Féraudy, J.M. Torre, J.F. Mangin, P. Grüdler, F. Baumont, J. Gaignebet, J.–L. Hatat, W. Hanson, A. Clements, J. Jespersen, M. Lombardi, D. Kirchner, G. Kirchner, H. Ressler, S. Fassl, W.J. Klepczynski, P.J. Wheeler, W. Powell, A. Davis, M. Granveaud, P. Uhrich, LASSO, *"Two–Way and GPS time comparisons: a (very) preliminary status report"*, Proc. 22nd PTTI meeting, pp. 575–582, 1990.

[2] C. Veillet, P. Fridelance, D. Féraudy, Y. Boudon, P.J. Shelus, R.L. Ricklefs, J.R. Wiant, *"LASSO observations at McDonald (Texas, USA) and OCA/CERGA (Grasse, France)"*, Proc. 24th PTTI meeting, pp. 113–122, 1992.

[3] C. Veillet, P. Fridelance, D. Féraudy, J.F. Mangin, J.M. Torre, J. Gaignebet, P. Grüdler, J.–L. Hatat, J.R. Wiant, R.L. Ricklefs, *"Lasso Time Transfer Between Texas and France"*, in these proceedings.

[4] W. Lewandowski, C. Thomas, *"GPS time transfer"*, Proc. of the IEEE, Special Issue on Time and Frequency, pp. 991–1000, July 1991.

[5] W. Lewandowski, G. Petit, C. Thomas, *"Precision and Accuracy of GPS time Transfer"*, IEEE Trans. I&M, vol. 42, no. 2, April 1993.

[6] D.W. Allan and M.A. Weiss, *"Accurate time and frequency transfer during common–view of a GPS satellite"*, Proc. 34th Ann. Symp. on Frequency Control, pp. 334–346, May 1980.

[7] W. Lewandowski, *"High Accuracy Ground–Antenna Coordinates for GPS Time Transfer"*, in Proc. IAG Symposium G2–Permanent Satellite Tracking Networks for Geodesy and Geodynamics, Vienna, August 1991, in press.

[8] D.W. Allan, M. Granveaud, W.J. Klepczynski and W. Lewandowski, *"GPS time transfer with implementation of Selective Availability"*, Proc. 22nd PTTI meeting, pp. 145–156, 1990.

[9] J. Vondrak, *"A Contribution to the Problem of Smoothing Observational Data"*, Bull. Astron. Inst. Czechoslovakia, 20, pp. 349–355, 1969.

[10] W. Lewandowski, *"Determination of the differential time corrections between GPS time receivers located at the Observatoire de Paris, Observatoire de la Côte d'Azur and the Technical University of Graz"*, Rapport BIPM–91/6,1991.

[11] J. Gaignebet, J.–L. Hatat, W. J. Klepczynski, L. McCubin, *"LASSO Experiment: Intercalibration of the Laser Ranging Stations"*, in these proceedings.

[12] Minutes of the Scientific Meeting on the Definition of the Joint Experiment with H–Masers and Precise Tracking Systems, ESA HO, Paris, November 10th, 1993.

[13] J. Danaher, W. Lewandowski, *"GLONASS/LASSO Concept"*, Presented at LASSO Meeting during 24th PTTI, 1–3 December, 1993.

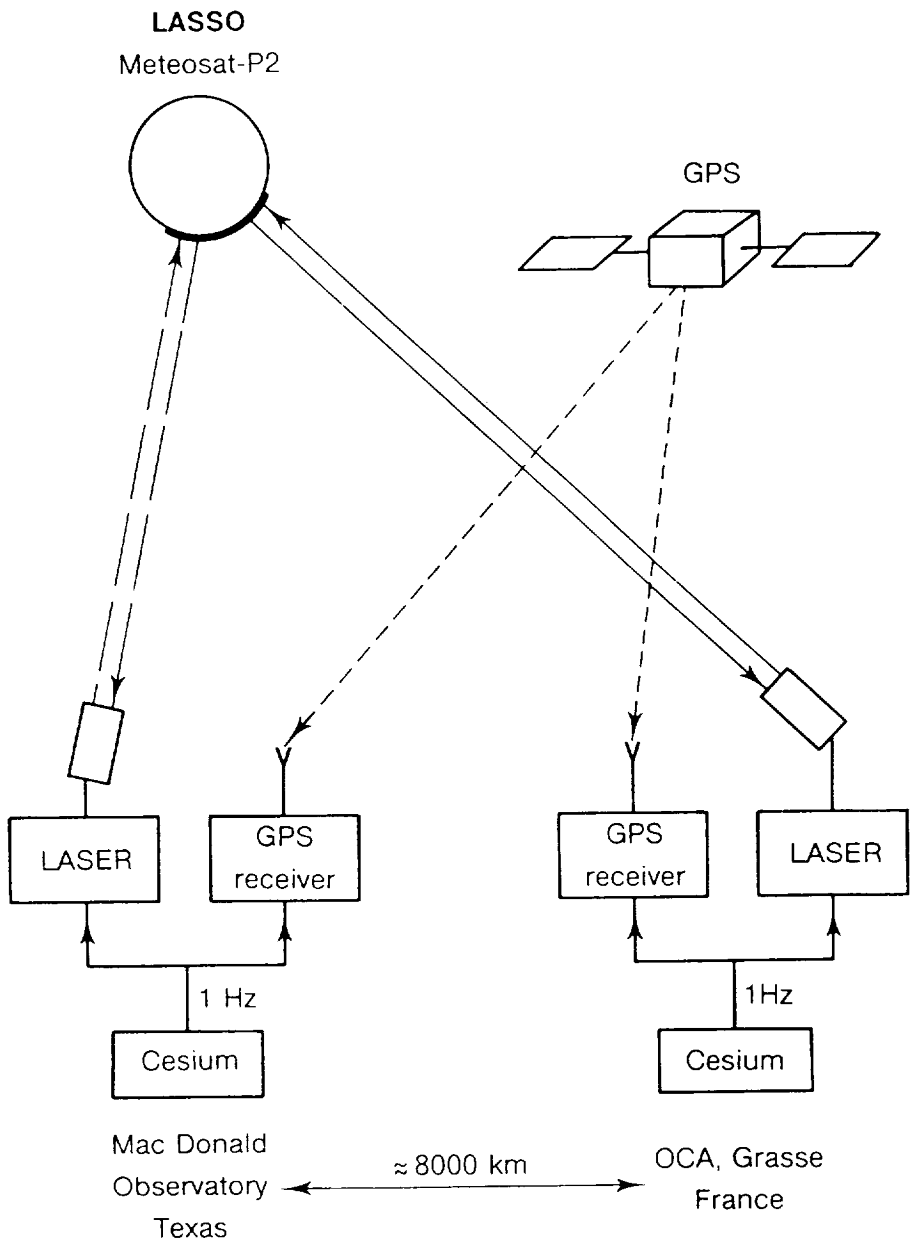
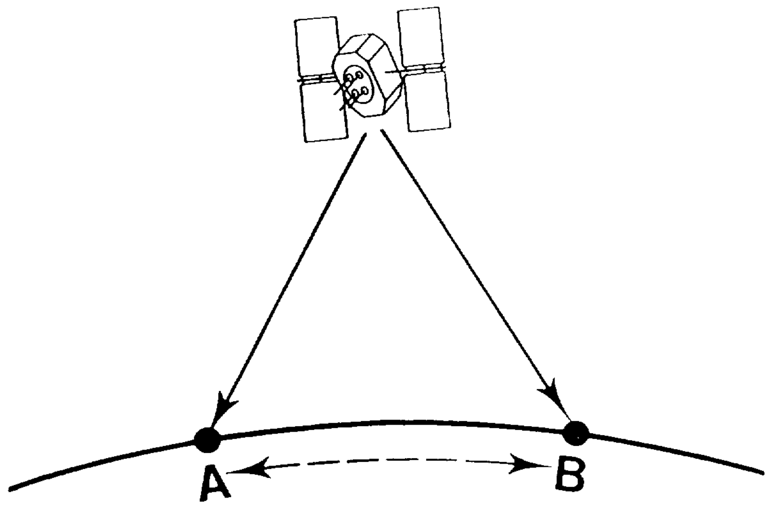


Figure 1. **The experiment configuration.**



clock A - clock B = [clock A - sat. clock]
- [clock B - sat. clock]

Figure 2. GPS common-view time transfer.

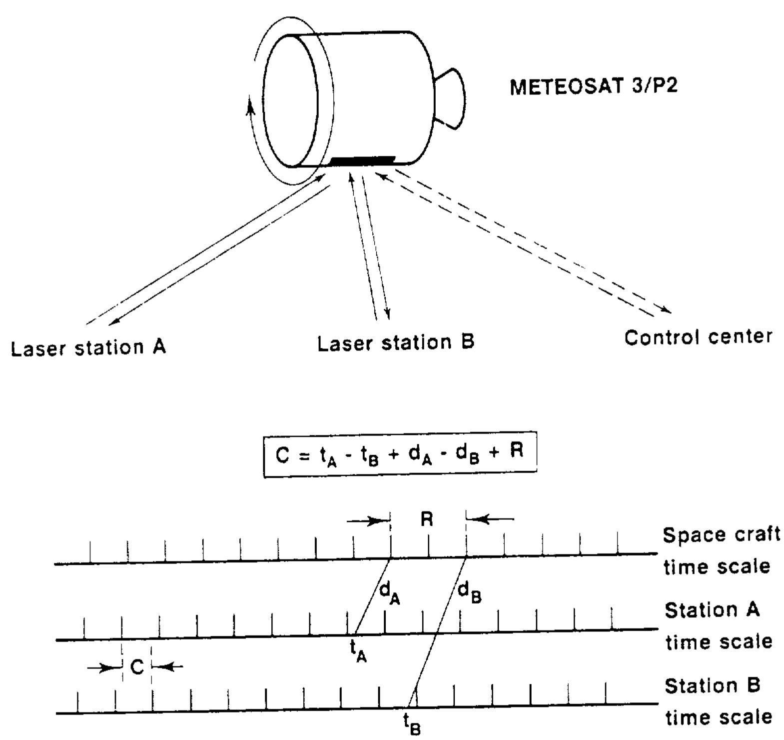


Figure 3. LASSO time transfer.

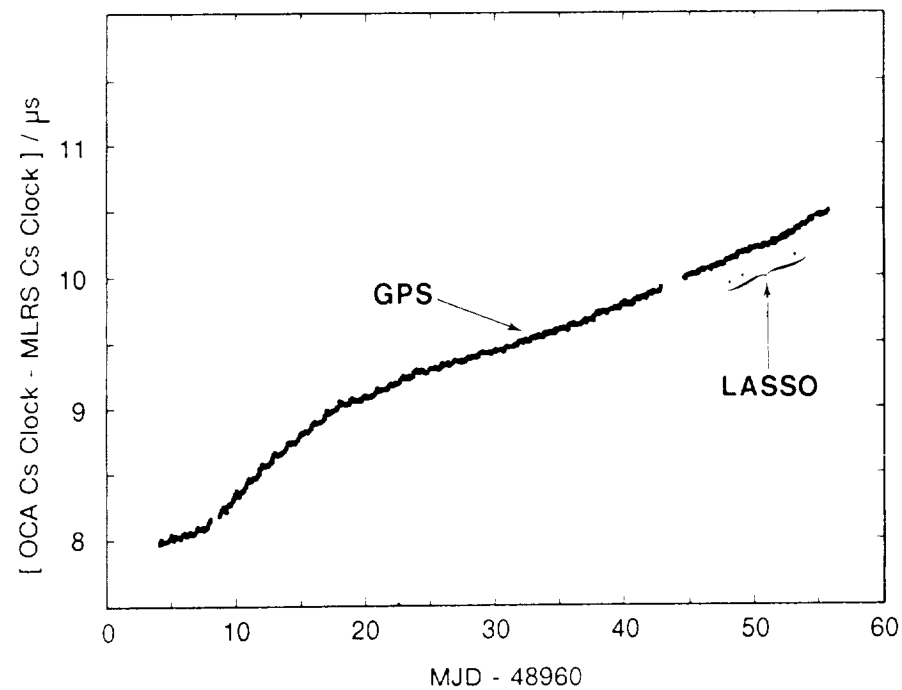


Figure 4. [OCA Cs Clock - MLRS Cs Clock] by GPS common-view and by LASSO.