LASSO observations at McDonald (Texas, USA) and OCA/CERGA (Grasse, France)

A preliminary analysis

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Abstract

The LASSO observations between USA and Europe have been made possible with the move of Meteosat 3/P2 toward 50°W. Two Lunar Laser Ranging stations participated into the observations : the MLRS at McDonald Observatory (Texas, USA) and OCA/CERGA (Grasse, France). Common sessions were performed since April 30, 1992, and will be continued up to the next Meteosat 3/P2 move further West (planed for January 1993). The preliminary analysis made with the data already collected by the end of November 1992 shows that the precision which can be obtained from LASSO is better than 100 ps, the accuracy depending on how well the stations maintain their time metrology, as well as on the quality of the calibration (still to be made.) For extracting such a precision from the data, the processing has been drastically changed compared to the initial LASSO data analysis. It takes into account all the measurements made, timings on board and echoes at each station. This complete use of the data increased dramatically the confidence into the synchronization results.

1. INTRODUCTION

The LASSO experiment has been described in a previous paper (Veillet et al, 1990) together with its first phase realized thanks to TUG satellite laser station (Graz, Austria), and OCA/CERGA lunar laser ranging facility (Grasse, France). Since that time, Meteosat 3/P2 (MP2), the satellite carrying LASSO on the geosynchronous belt, has been moved toward West, and is finally located at 50°W since December 1991.

In Europe, only the OCA/CERGA LLR station was able to range successfully to MP2 at such a low elevation (13°... from Grasse).

In the USA, two sites were suitable for LASSO observations :

- The 48" telescope at Goddard SFC (Greenbelt, Maryland), with a large aperture and a good longitude, is

unfortunately in a poor area for observing faint objects in the sky. It has been very busy with other important experiments, and, when available, had to face difficulties for acquiring visually the satellite.
- MLRS (McDonald Laser Ranging Station) has two important advantages. It is located at an good astronomical site, and it ranges successfully to the Moon. MP2 is then an easy target ...

A transatlantic phase of LASSO started at the beginning of 1992 with the following structure :
- MLRS and OCA/CERGA are the basic stations.
- *GSFC 48" is willing to participate, but depending on the other programs to be pursued, and on the capabilty* of seeing the satellite.
- OCA/CERGA prepares the schedule for the common observations.
- ESA/ESOC maintains the LASSO operations, providing on a weekly basis the raw data received from the satellite.
- OCA/CERGA receives the data from ESOC, the ranging measurements from the participating stations, and analyses them.

This organization worked all along 1992, and the observations together with their first (and preliminary) results will be presented below after a short description of the technical components of the experiment, i.e. LASSO and the two participating stations.

2. LASSO

The experiment has been described in various papers (i.e. Veillet et al, 1990). It is flying on board Meteosat 3/P2 and is made of two components :
- A laser pulse detector is linked to an event timer monitored by an oscillator. The arrival time of a pulse sent from a ground station is then recorded and the measurement sent back to the Earth together with the meteorological data.
- A retroreflector array sends back to the transmitting station part of the incoming light.

LASSO data are made of epochs recorded on different time scales :
- start time of a laser pulse from a participating station on its own time scale
- arrival time of a laser pulse at MP2 on the LASSO time scale
- return time of the reflected light on the same time scale as the start time

Every transmitted laser pulse gives a start time. If detected by LASSO, it gives an arrival time, and if echoes are received, a return time. A set of these three epochs for a same laser pulse is called **a triplet**. But a laser pulse can give only *a start and arrival time, or a start and return time. At the beginning of LASSO*, it was planned to make use of the triplets only. We will see later that, in the two other cases (two epochs only), there is still a valuable information.

3. The network

3.1 MLRS

The McDonald Laser Ranging Station (MLRS) is located at the McDonald Observatory (Ft Davis, Texas), an excellent astronomical site. A 2.7-m telescope has been used for Lunar Laser Ranging (LLR) for two decades, and replaced by a smaller station devoted to LLR as well as Satellite Laser Ranging. MLRS entered the LASSO network because MP2 is quite far from the Earth (geosynchronous, at 36000 km ...) and its reflector array small. Compared to the current satellites used in SLR (Lageos, Ajisai, Starlette, Etalon, ...), it is a target which is not easy ! Attempts made from other SLR sites have shown this fact very clearly. But compared to the Moon, it is an easy target, in spite of a high magnitude which makes its visual acquisition difficult.

For the transatlantic phase of LASSO described here, MLRS has been the only site used within the USA. When organizing this phase, it was anticipated to work also with the 48" telescope at the NASA Goddard Space Flight Center (GSFC). Unfortunately, due to other experiments to be performed at the same time, and to the difficulty in acquiring MP2 visually, GSFC did not join the network.

3.2 OCA/CERGA LLR

The OCA/CERGA LLR station started observing LASSO soon after the launch of MP2 in 1988. Originally, the SLR station located nearby was supposed to be the LASSO site at the observatory. But MP2 had become a difficult target for the new generation SLR stations equipped with lasers delivering shorter pulses for a better range measurement, but then less powerful.

The previous phase of LASSO permitted to work with Graz (Austria) SLR station (Veillet et al, 1990). But with MP2 at its new 50° W location, only CERGA and San Fernando (Spain) were practical sites in Europe. San Fernando station, currently under refurbishment, was unable to join the network. Its location is more favourable than CERGA where MP2 is seen at only 14° elevation.

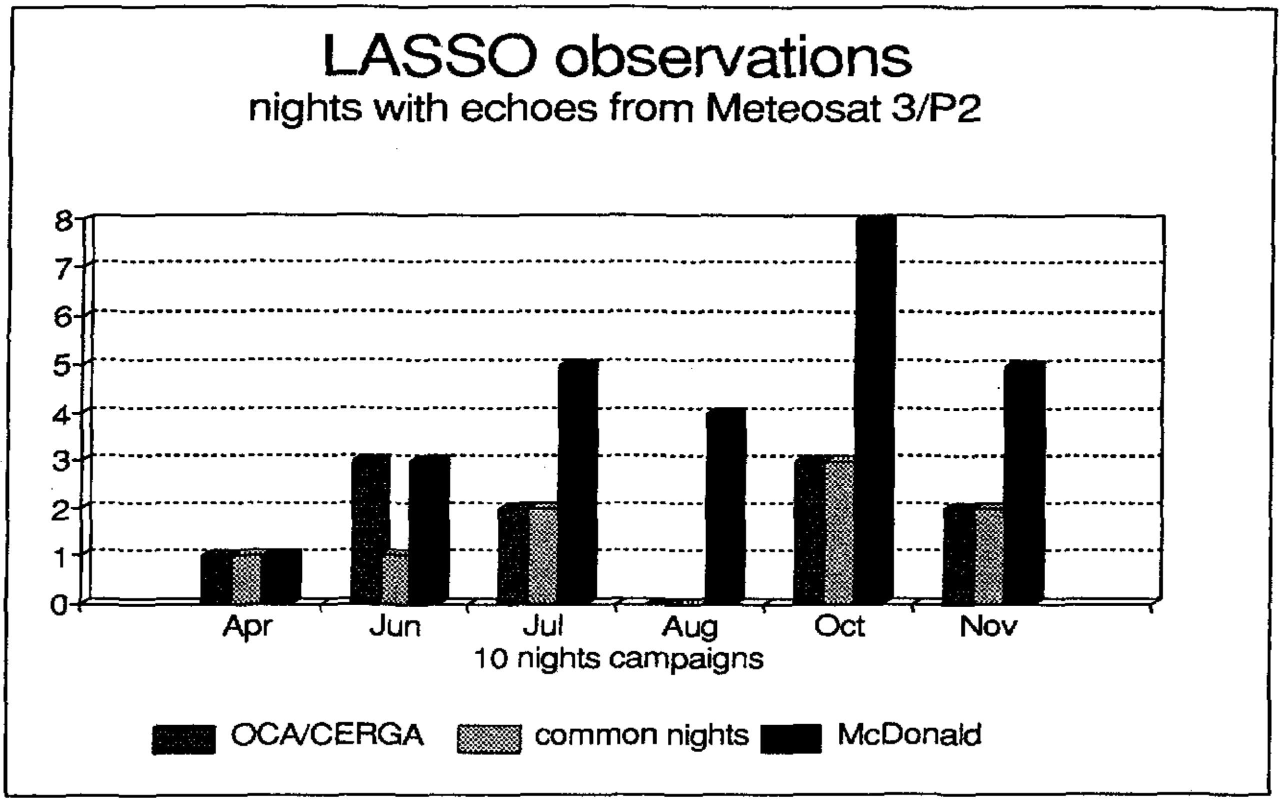
	Mc Donald	OCA/CERGA
Telescope diameter	75 cm	150 cm
Laser pulse length	200 ps	350 ps
Laser pulse energy	140 mJ	350 mJ
Laser repetition rate	10 Hz	10 Hz
MP2 elevation	26 °	14 °

The opposite table gives the main characteristics of the laser stations. The accuracy of the range measurement is directly related to the laser pulse length, as it is impossible to know if the detected photon comes from the beginning or the end of the laser pulse. The ability of the station to get echoes depends on the energy of the laser and the diameter of the telescope receiving the returning light.

4. The observations

At OCA, MP2 was continuously observed after its move (Oct 91), as it was before. The main difficulty is the clear weather needed in order to see the satellite at such a low elevation. At MLRS, the first echoes were obtained in April 92, and since then MLRS has been observing MP2 on a regular basis.

The scheduling was made from OCA, in accordance with both ESOC (where the payload is activated) and MLRS. The night at both sites was imperative, as it is impossible to range MP2 without seeing it. With the



Moon too close to MP2 in the sky, it is impossible to distinguish MP2 against the illumated sky background. The period around new Moon was then chosen, and campaigns covering 10 nights every lunar month were organized. The figure above shows the amount of night where echoes were recorded at MLRS and OCA, together with the common nights, i.e. nights where LASSO data were acquired at both sites for a same LASSO session (1 hour duration).The data obtained in October are useless as MP2 was off during the sessions (Sun eclipses onboard).
A total of 7 nights over 9 months are up to now (end of November 1992) available for data processing.

Looking to the first echoes obtained at MLRS, it appeared that :
- the number of echoes from MLRS is generally small, yielding to few triplets for a session, and
- the sky is rarely clear enough at CERGA to get data from MP2 at 13°.

In order to extract the information with such poor conditions, we had to modify the data processing envisionned initially for LASSO.

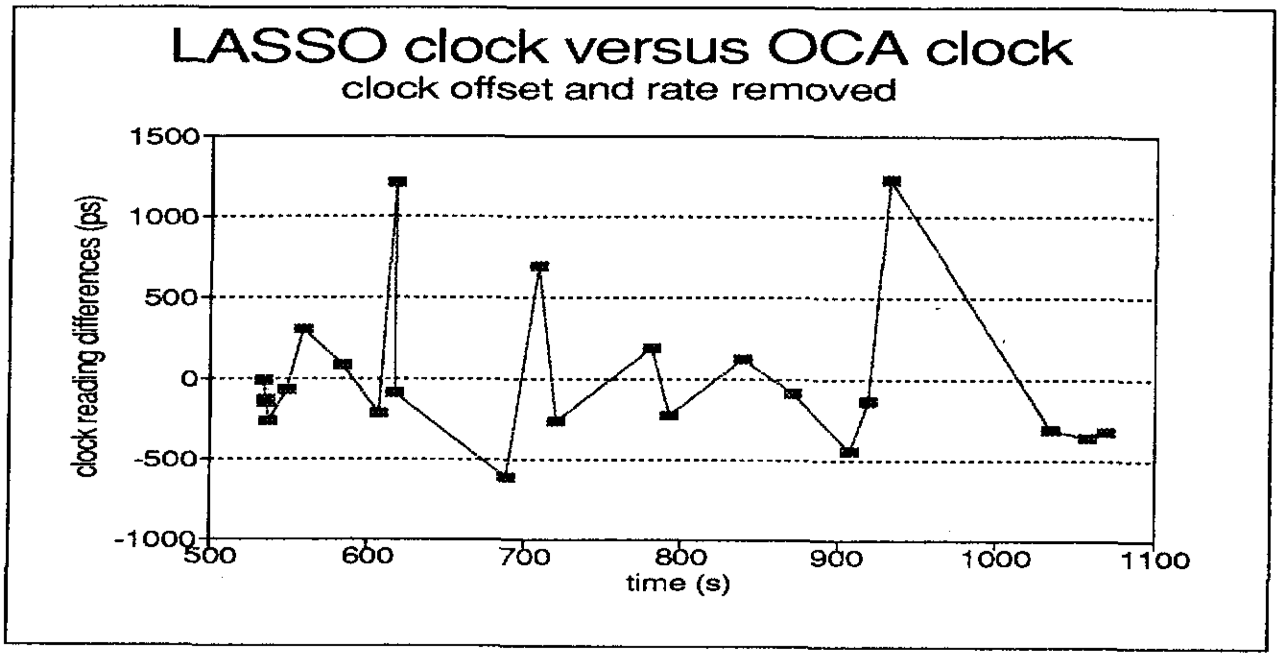
5. The analysis

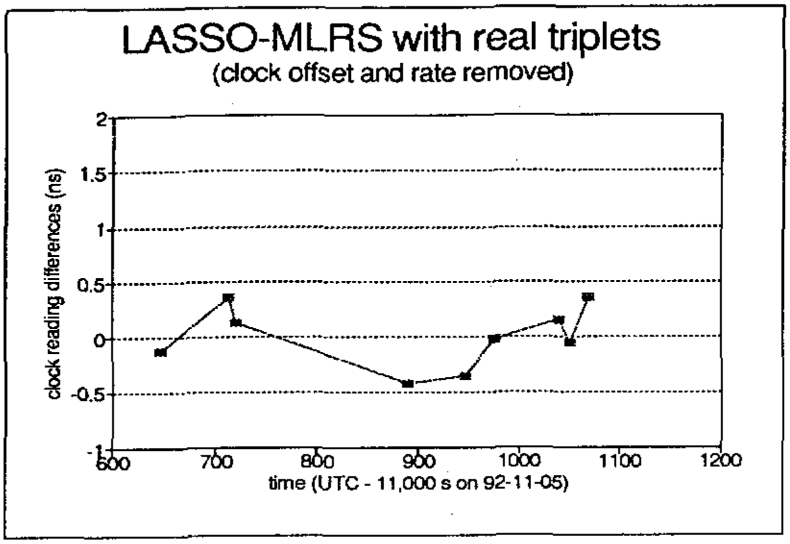
5.1 How to deal with so few data ?

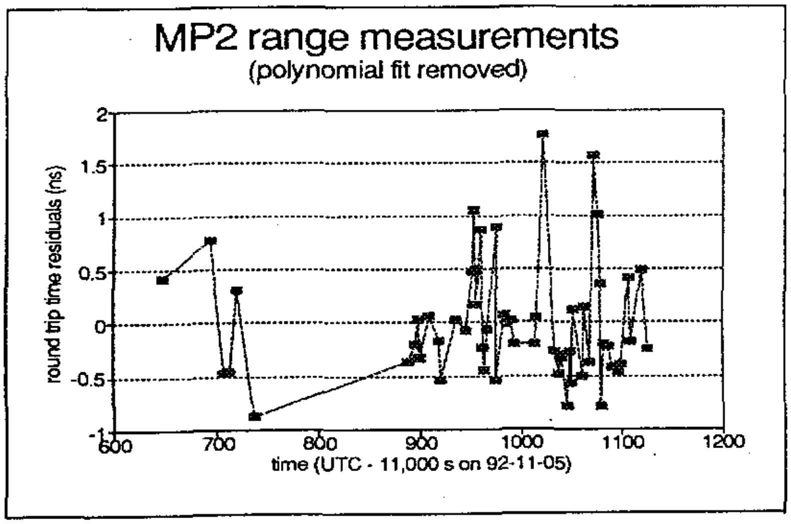
The original data processing was as follows : The firing times of the laser at every participating station, here MLRS and OCA, are scheduled in such a way the pulses arrive on board a few milliseconds apart, for example from MLRS 4 ms before the pulse from OCA. As the onboard oscillator is designed to be stable enough, the direct difference between these arrival times is small enough to be interpreted as the difference on any of the station time scales.The ground clocks can be linked with only a pair of such triplets, the LASSO oscillator vanishing. As MP2 is spinning at 100 rpm, the scheduling is uneasy as one needs to know the rate and phase of the satellite rotation for determining when the laser pulses should start from the ground to hit the LASSO detector. Rate and phase can be determined at OCA from laser observations prior to a LASSO session, but have to be sent to the other participating stations. The European phase demonstrated how ackward is this process. Even with a correct scheduling, the statistics is very poor, and it is extremely rare to have a pair of pulses providing a triplet. Another data handling has to be used for MLRS-OCA time transfer through LASSO.

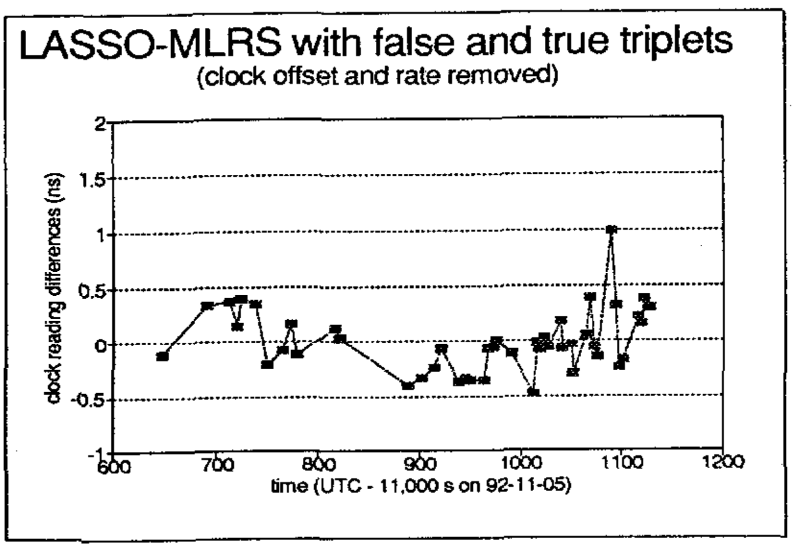
For ten minutes, a station ranging at 10Hz (as MLRS and OCA) transmits to MP2 6000 laser pulses. As the satellite is rotating at 100 rpm, and the retroreflector array has an angle of view of 60°, one shot over six can be reflected and sent back to the station. It means that the maximal return rate is one per 600 ms. With a very clear sky, such a rate can be obtained at OCA. As the telescope is smaller and the laser less powerful at MLRS, the rate is lower. The angle of view of the LASSO laser detector is smaller than for the reflectors, and only one laser pulse over ten can be detected on MP2. As its sensitivity is not very large, the statistics is lower. As a result of these considerations, we observe that :
- the number of echoes is generally larger at OCA than at MLRS
- the number of LASSO detections is larger for OCA pulses than for MLRS ones.
- the number of triplets for ten minutes sessions is varying from nothing up to 100, depending on the station involved and on the meteorological conditions.

If we suppose that we have some triplets from a given station over ten minutes, we can assess the behavior of the onboard oscillator against the station clock. From observations made at OCA, the oscillator has been found performing well : the offset and rate of the LASSO clock can be determined accurately. The opposite figure below shows the LASSO clock versus OCA clock, an offset and rate being removed. The formal uncertainty on the offset is around 50 ps, and on the rate below 5.10^{-13}. Comparing the offset and rate versus OCA clock to the same parameters seen from MLRS provides a link between the station clocks. Again, the onboard oscillator vanishes, but now through a determination of its characteristics over a 10 mn time span.









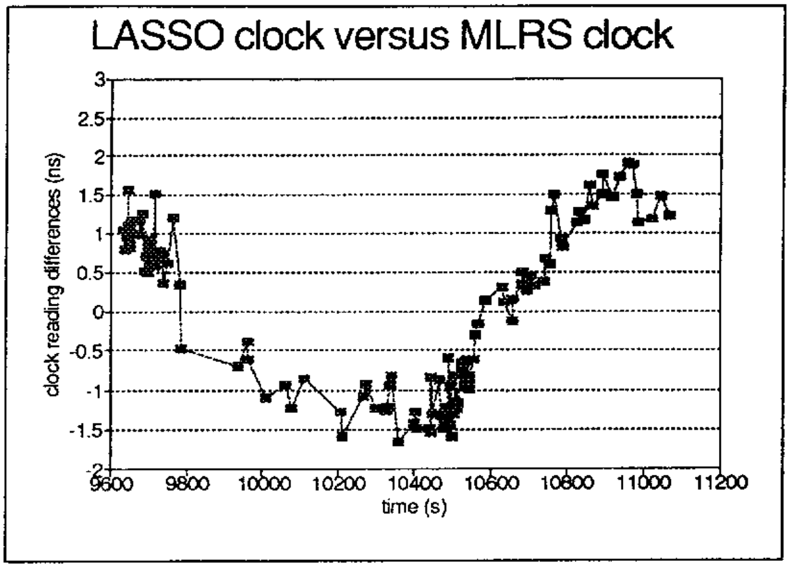
Unfortunately, many sessions give only a short number of triplets for a given station, and the observation of the LASSO clock is very poor. The opposite figure shows an example with 9 triplets determined for 300 seconds. It is sometimes worst, with only two or three triplets identified over the same time span ! In such cases, the determination of the LASSO clock offset and rate is not precise enough for a good comparison of the station clocks. However, one can observe for such a session many echoes, and also many LASSO detection times, which can be used for improving the LASSO clock observation.

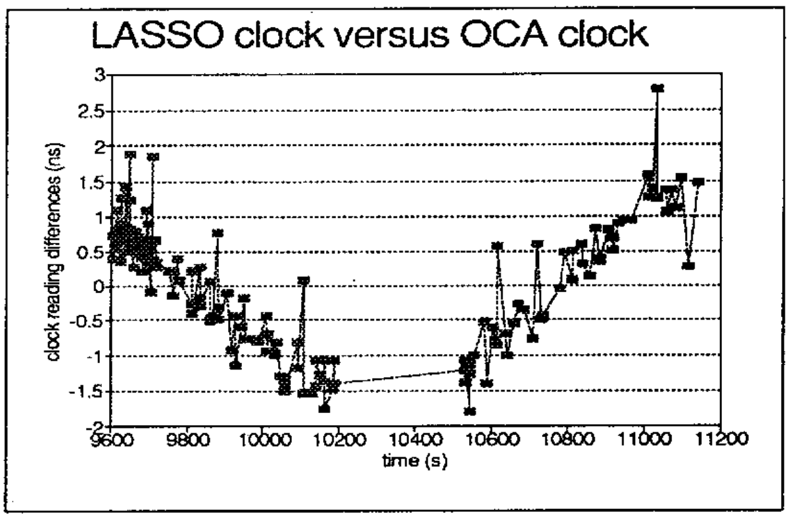
The opposite figure shows for the same session as before the range measurements. Each point corresponds to an observed return time. Most of the laser pulses did not provide any detection time on LASSO. Only nine of them did, as seen with the previous figure.The LASSO detections not associated to a return time come from a laser pulse for which it is possible to determine a return time by using the echoes obtained around. A polynomial fit is computed from all the returns for the considered session, and used for assessing the return time which could have been obtained for all the pulses without echo. The paires [start time - LASSO detection time] obtained through this process are now "false" triplets, using all the information from the echoes observed, and all the detection times onboard MP2.

The opposite figure shows the result of this process. It is a mixing of true triplets (already seen on the first plot above), and false triplets combining a real LASSO time and a recomputed echo time. All the data for common sessions have been treated using this *true-false* combination.

5.2 The results...

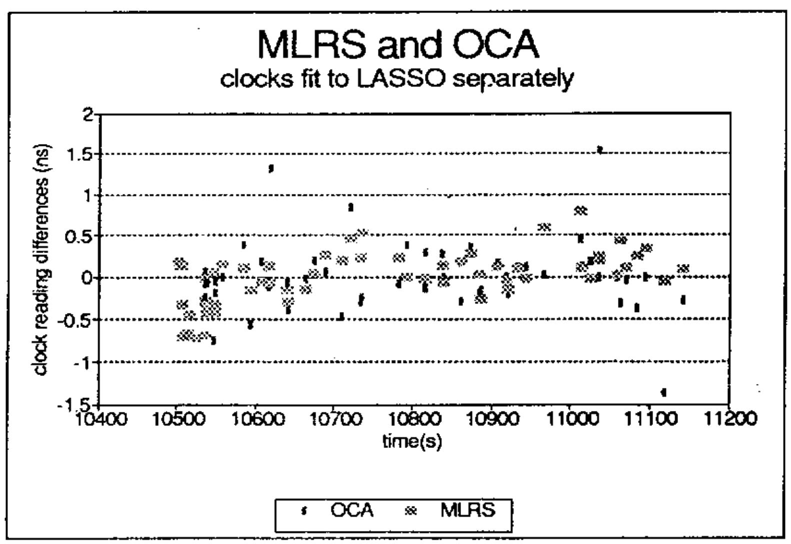
All the common sessions have been processed in a preliminary step. The echoes have been filtered, in order to eliminate the noise in the laser data. The LASSO epochs have been matched to laser pulses from one of the stations (the process is not easy, but details on it are beyond the scope of this paper). After the identification of the real triplets, false ones were obtained. The OCA and MLRS clocks have then been compared to the LASSO time scale. The opposite figures show the LASSO clock seen from the two sites for a given session. It covers 1200 seconds, and the behavior of the LASSO oscillator is clearly seen from both MLRS and OCA. A linear term has been removed independently for each station. Using only the data from one station could have been confusing, as the curve exhibits a non-linearity which can be interpreted as a frequency change of the LASSO oscillator, or as a problem in the laser ranging measurement (calibration change, ...). The agreement of the plots from both the stations allows us to assess that we really see the frequency changes of the onboard oscillator.





6. What about the precision ?

From the current analysis, the precision of LASSO time transfer is clearly better than 100ps. The number of data which can be acquired for 10 mn, using the concept of true and false triplets, is good enough to compensate the relatively long pulse length from OCA. The opposite figure shows the second linear part of the above figure. The formal uncertainty of the mean clock offset is 40 ps. The frequency drift (MLRS versus OCA) is determined with an uncertainty better than 2.10^{-13}.



These uncertainties are much better than the anticipated ones. Two reasons for that : the laser pulses currently used are much shorter than those used at the time of the LASSO preparation, and the observation procedure as well as the data processing now used yield to much more data than originally planned. But uncertainty does not mean accuracy. For achieving an accuracy better than 100ps, we need to calibrate both the stations at the same level, and every station has to take care of the link between its own time scale and its ranging equipment, again at the 100ps level. This last point is not very easy to achieve. The beginning of 1992 should give an answer on how accurate can LASSO really be. But we can be sure right now that the LASSO equipment is suitable for time transfer at better than 100ps.

7. The future

After the calibration of MLRS and OCA stations, it will be possible to achieve one of the goals of LASSO: the comparison between two different time transfer techniques, GPS and LASSO, at the nanosecond level.

LASSO will move with its carrier Meteosat 3/P2 in Februray 1993 up to 75°W. The experiment will no longer be used from Europe (below the horizon !), but could be used by the US stations interested in LASSO, with the scheduling, data gathering and processing made from OCA. MLRS and GSFC laser stations could participate, in order to take benefit from this unique experiment still available for one or two years more.

The next step is to build a next generation LASSO, using the modern technology. To reach a 10ps precision seems easily feasable, looking back to what has been obtained from the existing LASSO. To keep the time metrology at a station at the same level is clearly not very easy, but it can be achieve through serious efforts. Such a new LASSO could fly for time transfer, and also other time-related experiments (relativistic tests, dynamics,...).

8. Conclusion

The preliminary analysis of common sessions of LASSO between MLRS and OCA shows that time transfer between remote sites through LASSO can be achieve with a precision better than 100ps. The only requirement for the station is to range to the satellite (10 shots per second) in the same 10mn time span. This result has been obtained thanks to a simplification of the observation scheduling and improvements of the data processing. A complete analysis of the LASSO data using the calibration results should provide a comparison between LASSO and GPS.

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QUESTIONS AND ANSWERS

H. Peters, Sigma Tau Standards: How much would the precision, accuracy and coordination improve if you could maintain one to two picoseconds stability in your standards at the station over periods up to 10,000 seconds?

C. Veillet: I am not sure I understood the question. It is clear that what we do in such a method is that we have over a few minutes an instantaneous comparison between two clocks; one is for example, our cesium and the other one is a cesium in Texas. That is what we have from the experiment. If you want to compare with GPS it means that GPS is not exactly at the time we hope for, but as you know with GPS you have time measurements, for example, for a few minutes, so you need to have some interpolation in a program. Their is also stress when you compare GPS and Two-Way Time Transfer. As long as that is a concern, the goal is to provide a clean time transfer to be compared with another technique. Therefore our goal for the next two months is to compare GPS with LASSO. For the rest if we want, for example, to compare LASSO with two way time transfer, it will be very difficult to have a time transfer session at exactly the same time we have a LASSO observation. For that we have a maser at our place, and it was planned to also have a maser moved in Texas along with a two way time transfer station. So that we can really compare the two techniques and to avoid this problem of instability of clocks. As long as we know there is no "two way" there, probably it is sufficient just to have the clock there and work compared to the GPS time schedule because of goal is to compare GPS and LASSO.