SOME PRELIMINARY RESULTS OF THE FAST CALIBRATION TRIP DURING THE INTELSAT FIELD TRIALS

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Abstract

At the beginning of 1994, field trials for an international two–way time transfer experiment using the INTELSAT V-A(F13) satellite at 307oE were started. The experiment was set up to last one year and involved six European time laboratories and two North–American time laboratories. Three times a week, 5–minute time transfer sessions were scheduled. At each of these laboratories, GPS common–view time observations were also performed.

From September 22 to October 22, 1994 a calibration trip which visited participating laboratories in Europe was organized. It involved a portable Vertex 1.8 meter two–way station (Fly Away STation [FAST]), belonging to USNO, and a portable GPS time transfer receiver, belonging to BIPM. The *calibration trip was conducted by members of the staff of USNO and Observatoire de la Cote d'Azur (OCA). It provided differential delays of the satellite Earth stations and GPS receivers. The initial analysis of this calibration campaign are reported here.*

I. Introduction

The TWSTT technique has developed the reputation of being one of the most accurate and precise methods for time transfer[1,2]. One of the goals of the FAST Calibration Trip was to evaluate the quality of this measurement technique. While quality implies a somewhat nebulous expression, attempts can be made to quantitatively express the quality of the technique as a function of its capability. Its capability being defined in terms of its accuracy and precision. Obviously, a technique, where the accuracy is identical to the precision of measurement, is a technique which has reached its full capability. This relation can be shown as:

FULL CAPABILITY   Accuracy = Precision

If the accuracy of a measurement process is significantly less than its measurement precision than systematic errors are still affecting the process. The technique is, then, not yet of high quality.

In regard to TWSTT, estimates for the inherent precision of measurement for this technique range from 100–500 ns.[3]. It is possible to adopt 250 ps. as the current level of precision. Various estimates for the achievable accuracy range from 25 to 1 ns. This means that significant systematic errors are still affecting the results of TWSTT. It is the reason for undertaking this FAST Calibration Trip. It is hoped that, by careful measurements, more insight into the errors affecting TWSTT will be gained. It is assumed that one of the factors contributing to this error is our inability to measure the delays that signals undergo as they pass through the spacecraft. This thought to be one of the greatest contributors to the systematic errors affecting the measurement process.

II. FAST Calibration Trip

With regard to calibrating or determining delays through a system, there are three approaches. One is to design and develop equipment which will inject a signal into the system and consequentially trace its path throughout the station. This is the approach of Gerrit de Jong at VSL[1]. One can then take this calibration station around to different laboratories and measure the delays through other similar stations. This procedure could be called absolute calibration (AC).

Another approach would be to measure the delays throughout a small portable station and then transport this station to other laboratories in order to make side–by–side measurements with the station to be calibrated. This approach could be called absolute system calibration (ASC).

Still another approach would be to carry a transportable station around to different laboratories and make side–by–side measurements and refer all measurements to one primary reference station. This is the approach adopted for this experiment since operational absolute calibration equipment has not yet been fully developed. This approach could be called relative system calibration (RSC)

Planning for the FAST calibration started at the Second Meeting of the CCDS Working Group on TWSTT held at NPL on 22 October 1994[5].

III. Observational Plan

The plan for RSC is rather simple. One makes initial measurements of the calibration station with respect to one fixed base station. A record of the difference is made. Similar measurements will be made at subsequent base stations and the differences also noted. At the same time, measurements are also made with respect to all other base stations participating in the experiment. Then, relative calibration with regard to any base station can be deduced.

The observation sequence followed at each laboratory visited by the FAST Team consisted of making side–by–side measurements between the FAST and visited laboratory for at least half an hour. Next, the FAST and laboratory base station each did time transfers with all other participating labs. This observation period usually spanned several hours. Finally, The FAST made side–by–side observations with the visited laboratory base station before going on to the next laboratory.

Also, at each base station, sufficient documentation of known, measured delays were made in order to correct for as many systematic offsets as possible.

IV. Data Analysis

The observed data obtained at VSL are presented in Tables 1, 2 and 3. Several consistency checks can be performed with this data. Because the FAST had not yet returned to its initial starting point at the time of the writing of this paper, a closure error or verification that nothing happened to the FAST during the trip has not yet been performed.

An initial analysis that can be done is to set up a three cornered hat method to see if there is consistency among the readings [6]. By differencing the data in Tables II and III, one can compute a value for the time difference between the FAST at VSL and the base station at VSL [FAST(VSL)–VSL(Base Station)]. These differences are given in Table IV. Next, one can compute the differences between the observed values for FAST(VSL)–VSL(Base Station) and the computed one. This is given in Table V. The data in Table V indicates that the two procedures agree to within about a nanosecond.

V. Discussion

The consistency check performed in Section IV points to another fact that has been the subject of some speculation. The data in Table I was obtained by going through the spot transponder on INTELSAT V–A (F13) which covers Europe. The data exhibited in Tables II and III was obtained through the transponder which connects Europe to North America. Since the data measured for the difference between the FAST located at VSL and the VSL Base Station and the data computed from the set of measurements obtained using USNO as an intermediary is so close together, it seems that the delays through the different transponders are not that much different. This is not conclusively proven by this procedure. In any event, this is a notable observation. Once a permanent routine evolves in TWSTT, it is easy to visualize that data exchange may not always occur through the same transponders of the satellite being used. This observation merits further corroboration because it is a possible source contributing to the systematic errors of the measurement process.

VI. Conclusions

Preliminary analysis of some of the data obtained during the FAST Calibration Trip to Europe indicate that the equipment performed reasonably well. After additional data is obtained when the FAST is returned to USNO, it will be possible to verify this conclusion. It will also then be possible to establish a calibrated path between the stations which participated in the experiment. This will be an essential step to precede the next round of international time transfers.

References

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[5] Minutes of the Meeting of the BIPM Working Group of the CCDS on Two–Way Satellite Time Transfer, 20–21 October 1993.

[6] Winkler, G.M.R. *"Intermediate Term Frequency Measurements with the HP Computing Counter in the USNO Time System"*, Proceedings of the 4th Annual PTTI Planning Meeting, 152–167, 1972.

Table I Observed Time Differences [FAST(VSL)–VSL(Base Station)]		
MJD	49625.52419	49626.35815
Observed (FAST–VSL)	-667.28 ns	-669.31 ns.

Table II Observed Time Differences [USNO(Base Station) – VSL(Base Station)]		
MJD	49624.62534	49626.48090
Observed (USNO-VSL)	122.13 ns.	130.32 ns.

Table III Observed Time Differences [USNO(Base Station) - FAST(VSL)]		
MJD	49624.62327	49626.46942
Observed (USNO-FAST)	790.14 ns.	797.97 ns.

Table IV Computed Time Differences [FAST(VSL)–VSL(Base Station)]		
MJD	49625	49626
Computed (FAST-VSL)	668.01 ns.	667.65 ns.

Table V Observed–Computed Time Differences of FAST(VSL)- VSL(Base Station)		
MJD	49625	49626
(O-C) FAST-VSL	0.73 ns.	-1.67 ns.