CALIBRATION OF THREE EUROPEAN TWSTFT STATIONS USING A PORTABLE STATION AND COMPARISON OF TWSTFT AND GPS COMMON-VIEW MEASUREMENT RESULTS

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Abstract

After a brief introduction and description of the portable station and a discussion of different approaches to use it for station calibration, the calibration trip is described and the results are presented. The calibrated TWSTFT measurements are compared with the GPS measurements calibrated by a GPS receiver trip carried out at the same time as the TWSTFT calibration and by previous GPS receiver trips. The findings are discussed and some envisaged activities using the portable station are mentioned.

INTRODUCTION

Since 1997 two-way satellite time and frequency transfer (TWSTFT) links are operated on a regular basis between six European laboratories and also between the European laboratories and two laboratories in the USA [1]. All links employ Ku-band channels of the same INTELSAT satellite positioned at 307° E and the measurement data are available in a format published in a draft revision of recommendation ITU-R TF.1153 [2]. This format minimizes the amount of data to be exchanged and allows easy computation of the results. The laboratories contribute to the international atomic time scale and carry out GPS observations according to the BIPM common-view schedules. Initially some of the TWSTFT links were calibrated using the difference between the respective time scales as published by the Bureau International des Poids et Mesures (BIPM) in Circular T. In order to obtain actual GPS calibrations which could also be used to calibrate the TWSTFT measurements, a series of GPS receiver transportations were organized by the BIPM, starting summer 1997. In June 1998 a calibration trip using a portable TWSTFT station developed at the Technical University Graz (TUG) was carried out between the Deutsche Telekom AG (DTAG), Darmstadt, the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, and the TUG to provide a calibration of the TWSTFT links independent of the GPS calibration. At the same time in the course of one of the GPS receiver trips, GPS calibrations were carried out between these laboratories, allowing a direct comparison of the performance of both techniques.

PORTABLE TWSTFT STATION

At the TUG in addition to the existing TWSTFT system, a second TWSTFT system has been developed to carry out common-clock experiments and for calibration purposes [3,4]. The system comprises a specially adapted VSAT-terminal (1.8 m antenna diameter, maximum EIRP of about 52 dBW, and a G/T of about 22 dB/K), a small 19" rack containing the measurement system designed to be operated with a SATRE-modem providing full frequency agility for the up- and down-link, a spectrum analyzer, a PC controlling the complete system including the spectrum analyzer, an uninterruptible power supply, and a cable drum containing the necessary cables to connect the satellite terminal and the measurement system allowing a maximum separation of 50 m. The system is designed for automated operation using a measurement software developed at the TUG, which allows, apart from other features, on-line monitoring of the measurements. Also available is the necessary software to get the results in both ITU-formats and to process the data [4]. The visited station has to provide a one pulse per second with known relationship to the local time reference and a 10 MHz signal to be connected to the measurement system. Figure 1 shows the satellite terminal. All necessary cable connections are done inside the cabinet at the right hand side providing protection from the environment. The complete measurement system is shown in Figure 2. Figure 3 provides a view into the interior of the trailer used for transportation of the complete TWSTFT system and Figure 4 shows the trailer with the antenna on top of it and the towing car ready to start the trip.

TWSTFT CALIBRATION TRIP

The calibration trip was arranged in a way to be able to make the calibration measurements during the satellite time available for the regular European TWSTFT measurements, trying to omit as few regular measurements as possible. To fit the adhered regular schedule also, the calibration measurements were done over two-minute intervals. The route of the calibration trip can be seen in Figure 5. The underlined dates indicate the days during which the measurements were performed. Depending on the location, two to three hours were needed to set up the station and to be ready for the measurements. In addition to the regular measurements most important with respect to the evaluation of the calibration, in all locations measurements were done between the transported and the local stations and the respective two other remote stations, allowing calculation of the calibration results in different ways. The usual approach is to carry out common-clock time transfer measurements at all sites between the transported station and the local station to get the differential delay between the portable station and the respective local station. Using this approach different signals are employed for the delay calibration and the actual time transfer and, therefore, for signal delays; depending on the received signal, the measured delay and the actual delay can differ from one another. Another approach is to perform a common-clock time transfer between the portable station and the local station at site A and after transporting the portable station to site B to perform a successive time transfer between the transported station and the station at site A and the local station and the station at site A. From the two time transfer results the differential delay of the local stations of site A and B can be calculated. In this case the actual delays are measured, but the stability of the clocks have to be considered, because the measurements are not performed at the same time.

GPS CALIBRATION TRIPS

The GPS calibrations were carried out by means of a GPS receiver provided by the BIPM according to a schedule prepared by the BIPM and also the processing of the data was done at the BIPM. The fourth trip was arranged in a way that the TWSTFT calibrations and the GPS calibrations at DTAG, PTB, and TUG were performed at the same time. Unfortunately, this trip could not be finished as planned, because the receiver got lost and could only be recovered after one year. The detailed calibration results are given in reports published by the BIPM [5-8].

MEASUREMENT RESULTS

The results of the TWSTFT calibration trip are listed in Table 1 and plotted in Figure 6. The results of the TWSTFT calibrations are plotted after having subtracted the individual mean values for each laboratory in order to be able to show the results in one plot. For TUG the mean and standard deviation before the trip are 4.146 ns and 148 ps, after the trip 4.304 ns and 261 ps, and the overall figures are 4.209 ns and 204 ps. For DTAG and PTB the mean value and standard deviation are -277.974 ns and 28 ps, and -174.679 ns and 114 ps, respectively. An assessment of

LAB	CALIBRATION TIME MJD TIME	0.5*CALR / ns	MEAN / ns	STD.DEV. / ps
TUG (1)	50958 141100	4.052	4.146	148
	50958 141400	4.033		
	50958 141716	4.093		
	50958 142900	4.029		
	50960 141100	4.318		
	50960 141400	4.352		
DTAG	50967 141100	-277.955	-277.974	28
	50967 141400	-277.994		
PTB	50969 142329	-174.567	-174.679	114
	50969 142900	-174.529		
	50972 141100	-174.659		
	50972 141400	-174.727		
	50972 141700	-174.783		
	50972 142900	-174.807		
TUG (2)	50976 141100	3.961	4.304	261
	50979 141100	4.465		
	50979 141400	4.544		
	50981 141100	4.245		
TUG (1+2)			4.209	204

Table 1. Results of the TWSTFT calibration trip.

the calibration uncertainty by an error budget results in about 400 ps for the calibration at the TUG and at the PTB and about 1.7 ns at the DTAG. The greater uncertainty at DTAG is due to the greater uncertainty in the determination of the relationship between UTC(DTAG) and the time references used for the local and portable TWSTFT systems.

A summary of the relevant measurement results of the four GPS calibration trips is given in Table 2. The estimated uncertainty with respect to the receiver at the Paris Observatory (OP) given in the respective report is 3 ns for the first trip and 2 ns for the second and third trip. The standard deviations of the daily means range from 0.2 ns to 1.1 ns . For DTAG because of building construction work, no relevant data exist for the third trip [7]. Also for PTB, the results of the third trip have a higher uncertainty due to particularly poor measurement conditions [7].

TRIP No	CALIBRATION PERIOD	LAB	MEAN OFFSET BIPM3-LAB / ns
1	50624 - 50629	DTAG	-0.2
	50631 - 50635	PTB	-1.0
	50638 - 50643	TUG	-12.8
2	50757 - 50762	DTAG	+5.0
	50763 - 50769	PTB	+3.7
	50779 - 50783	TUG	-5.1
3	50878 - 50881	DTAG	-
	50884 - 50888	PTB	-7.5
	50891 - 50895	TUG	-7.6
4	50963 - 50966	DTAG	+64.48
	50967 - 50973	PTB	+2.55
	50974 - 50979	TUG	-5.99

Table 2. Results of the four GPS calibration trips.

Figure 7 shows for TUG - PTB the differences between the TWSTFT results and GPS results after having calibrated the TWSTFT data by the outcome of the TWSTFT calibration trip and after having calibrated the GPS data by the results of the individual GPS calibration trips. To calculate the differences for the GPS data, the result of a linear regression over one day centered at the TWSTFT measurements were used. Figure 8 shows the same for TUG - DTAG, apart from the fact that there are no DTAG data for the third GPS calibration trip. The corresponding numerical data are listed in Tables 3 and 4 using averages over the respective GPS calibration periods to calculate the differences between TWSTFT and GPS. Figures 7 and 8 and Tables 3 and 4 give the results using the first approach for the TWSTFT calibration (see Ch. TWSTFT CALIBRATION TRIP). Using the second approach for TUG - PTB, the results differ only by about 100 ps, but for TUG - DTAG the differences between TWSTFT and GPS become smaller by about 2 ns.

TUG-PTB: TW-GPS			GPS CALIBRATED BY			
	TRIP No	CALIBRATION PERIOD	1st TRIP	2nd TRIP	3rd TRIP	4th TRIP
TW-GPS / ns	1	50631 - 50643	+0.563	-2.437	-11.137	-2.737
	2	50763 - 50783	+2.497	-0.503	-9.203	-0.803
	3	50884 - 50895	+3.976	+0.976	-7.724	+0.676
	4	50967 - 50979	+2.383	-0.617	-9.317	-0.917

Table 3. Differences between the independently calibrated TWSTFT and GPS measurements for TUG - PTB. (Lines give TWSTFT - GPS for the date of a specific trip; columns give TWSTFT - GPS for the dates of the different trips.)

TUG-DTAG: TW-GPS			GPS CALIBRATED BY			
	TRIP No	CALIBRATION PERIOD	1st TRIP	2nd TRIP	3rd TRIP	4th TRIP
TW-GPS / ns	1	50624 - 50643	-3.858	-5.858	-	+53.142
	2	50757 - 50783	-6.227	-8.227	-	+50.773
	3	50878 - 50895	+82.931	+80.931	-	+139.93
	4	50963 - 50979	+14.991	+12.991	-	+71.991

Table 4. Differences between the independently calibrated TWSTFT and GPS measurements for TUG - DTAG. (Lines give TWSTFT - GPS for the date of a specific trip; columns give TWSTFT - GPS for the dates of the different trips.)

DISCUSSION

The differences between TWSTFT and GPS for TUG - PTB show a kind of seasonal effect especially pronounced in the first part (see Figure 7). A closer investigation revealed that this effect was partly caused by the gradually breaking internal power supply of the GPS receiver used at the TUG, being replaced by an external one at MJD 50689. Apart from the third GPS trip, the differences between TWSTFT and GPS for the dates of the respective GPS calibrations making use of the different GPS calibration results, are below 1 ns. This agrees very well with the estimated TWSTFT and GPS calibration uncertainty (see Ch. MEASUREMENT RESULTS). The peak-to-peak difference is about 11 ns and can be assumed to be mainly due to delay variations of the GPS receivers at TUG and PTB. In addition, it should be mentioned that changing the TWSTFT calibration from the value obtained via the Circular T (see Ch. INTRODUCTION) to the one obtained by the TWSTFT calibration trip gives a step of about 18 ns and the average difference between TWSTFT calibrated by the TWSTFT calibration trip and the uncalibrated GPS data is about -9 ns (cf. [1]). The average correction for the GPS data calculated from the recent GPS calibration trips to be applied to get UTC(TUG) and UTC(PTB) is about -6 ns and 4 ns, respectively, and the corrections used to calculate Circular T are 12 ns and 0 ns, respectively [9].

The differences between TWSTFT and GPS for TUG - DTAG (see Figure 8) show a step after the second GPS calibration trip and another one after the third GPS calibration trip. These steps result from a problem with the GPS reference which is obtained by a divider chain separate from that providing the TWSTFT reference. Therefore, the TWSTFT measurements are not affected. The differences between the TWSTFT measurements calibrated by the TWSTFT calibration trip and the GPS measurements calibrated by the first and second GPS calibration trip are about -4 ns and -8 ns, respectively. Using the second approach for the TWSTFT calibration this becomes about -2 ns and -6 ns, respectively. An explanation for these larger values is the higher uncertainty (see Ch. MEASUREMENT RESULTS) in establishing the relationship between the different time references and UTC(DTAG).

It should also be mentioned that at the time of the TWSTFT calibration at TUG and at PTB SATRE-modems were used and at DTAG a MITREX 2500A modem was employed.

CONCLUSION AND ENVISAGED ACTIVITIES

The portable TWSTFT system worked without problems and is ready for further calibration trips. One problem occurred two weeks after the trip which turned out to originate from a poor soldering at one of the terminals of the switch used to switch between the internal and an external reference frequency. For TUG - PTB the average differences between the calibrated TWSTFT measurements and the GPS measurements for the dates of GPS calibrations were well below 1 ns. One can assume that the variation of the differences between the TWSTFT and GPS time transfer measurements is mainly caused by delay variations of the GPS receiving systems. To get more information about delay variations of TWSTFT systems, repeated TWSTFT calibration trips would be of interest.

Extensive common-clock experiments between the local TWSTFT station and the portable one are planned to investigate the stability of the signal delays of the stations and the possible improvements by using corrections derived from satellite simulator measurements. The portable station may also be used for extended common-clock experiments at remote sites (comparisons with TWSTFT systems or other time transfer systems). Operating two TWSTFT stations at the TUG allows the simultaneous use of two different satellites and, therefore, would enable the TUG to perform simultaneous TWSTFT measurements with stations in the eastern and western parts of the world.

ACKNOWLEDGMENTS

The authors wish to thank all colleagues who helped to perform the measurement and especially for the help carrying heavy equipment on top of the roofs of terribly high buildings. The Austrian participation has been supported by the Austrian Academy of Sciences and the Jubilee Fund of the Austrian National Bank.

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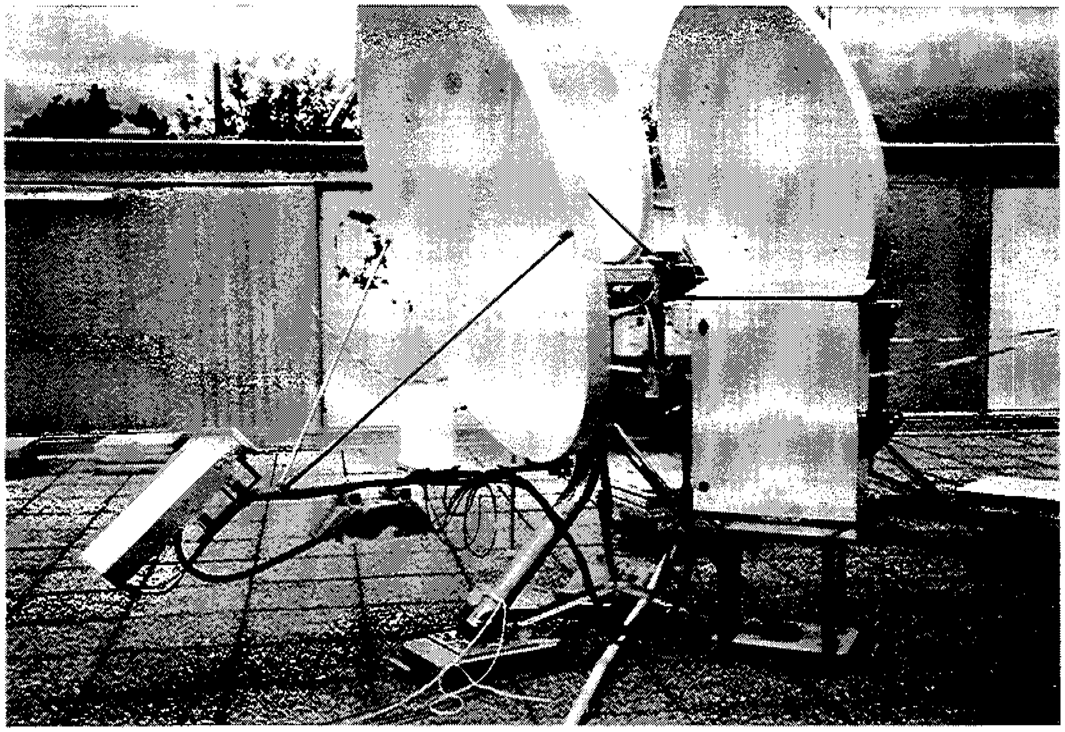

Figure 1. Satellite terminal of the portable TWSTFT station.

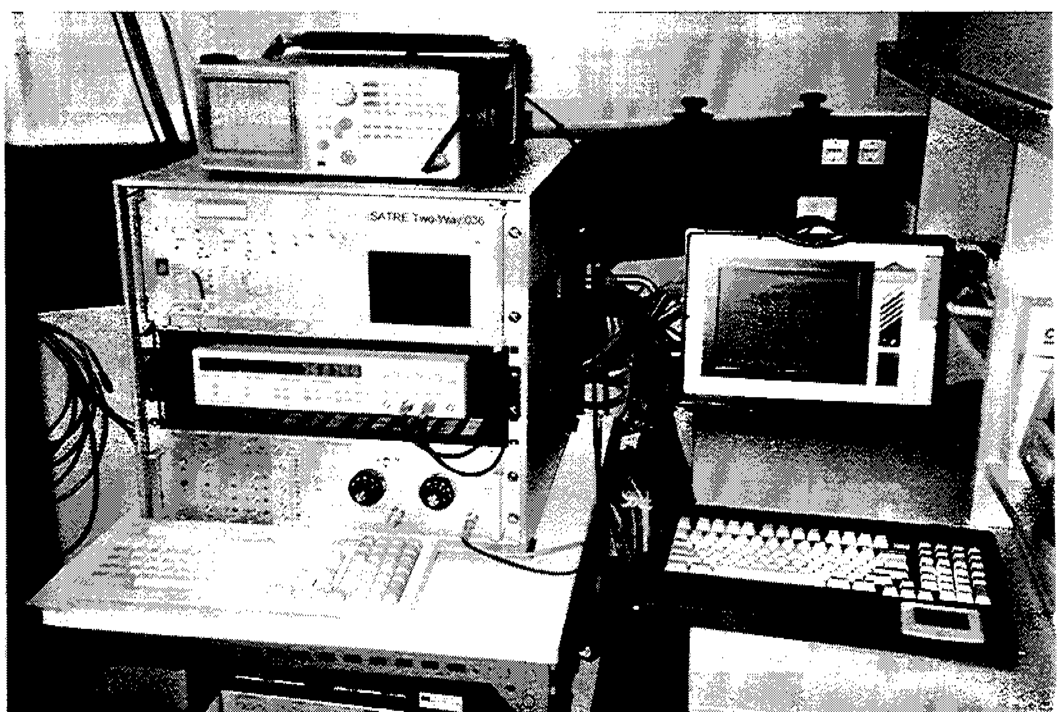

Figure 2. Measurement system of the portable TWSTFT station.

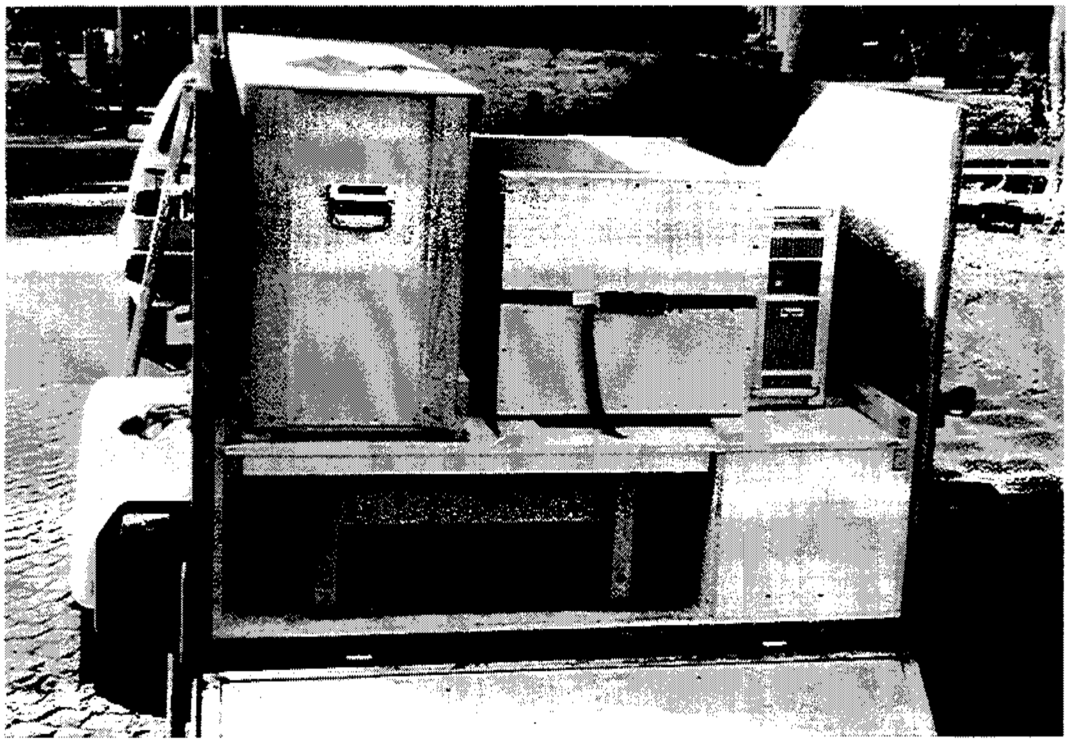

Figure 3. View into the interior of the trailer used to transport the TWSTFT system.

Figure 4. Trailer with the antenna on top of it and the towing car.

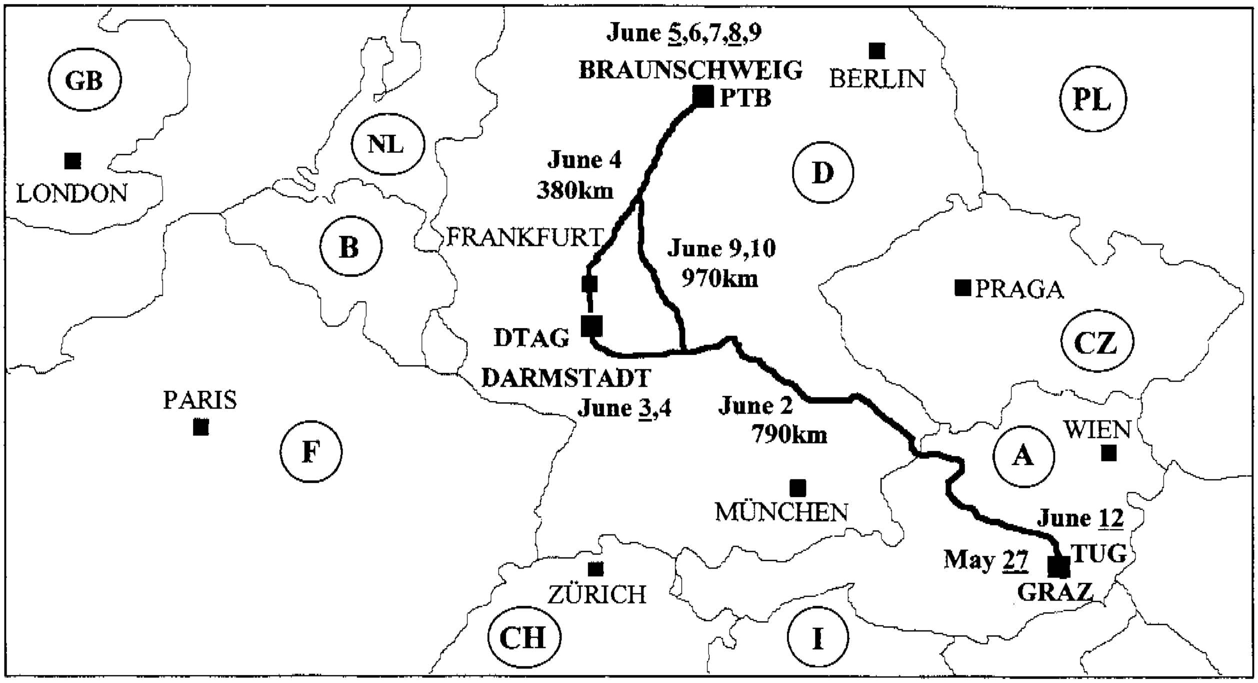

Figure 5. Route of the TWSTFT calibration trip.

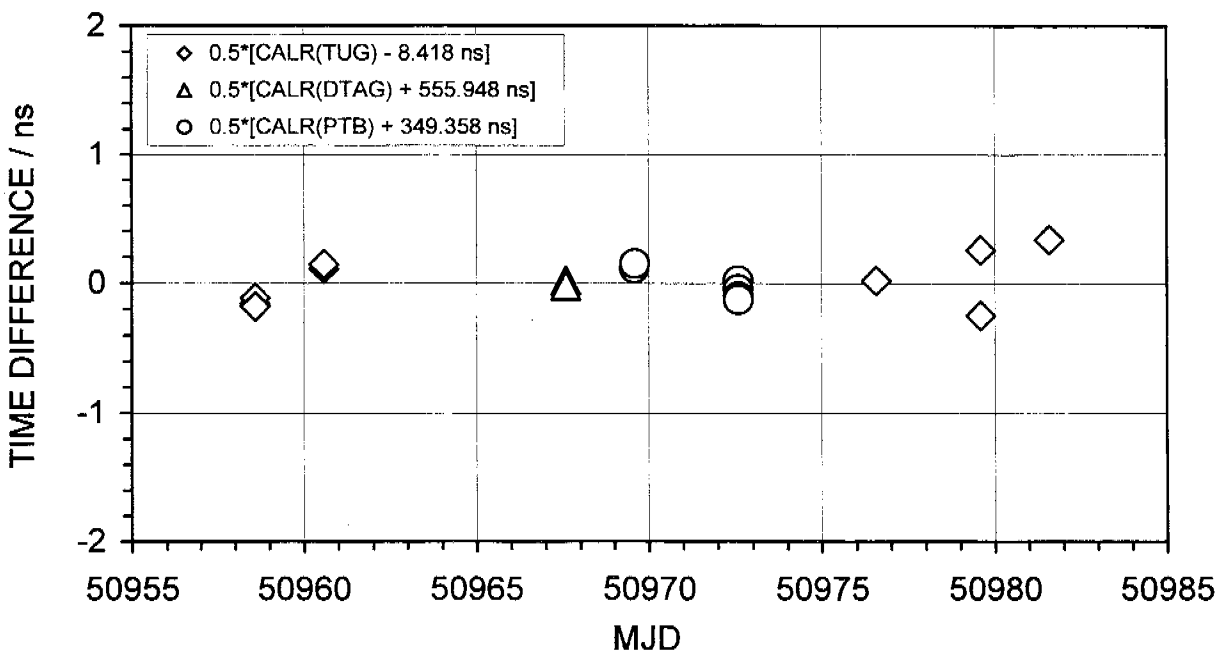

Figure 6. Results of the TWSTFT calibrations.

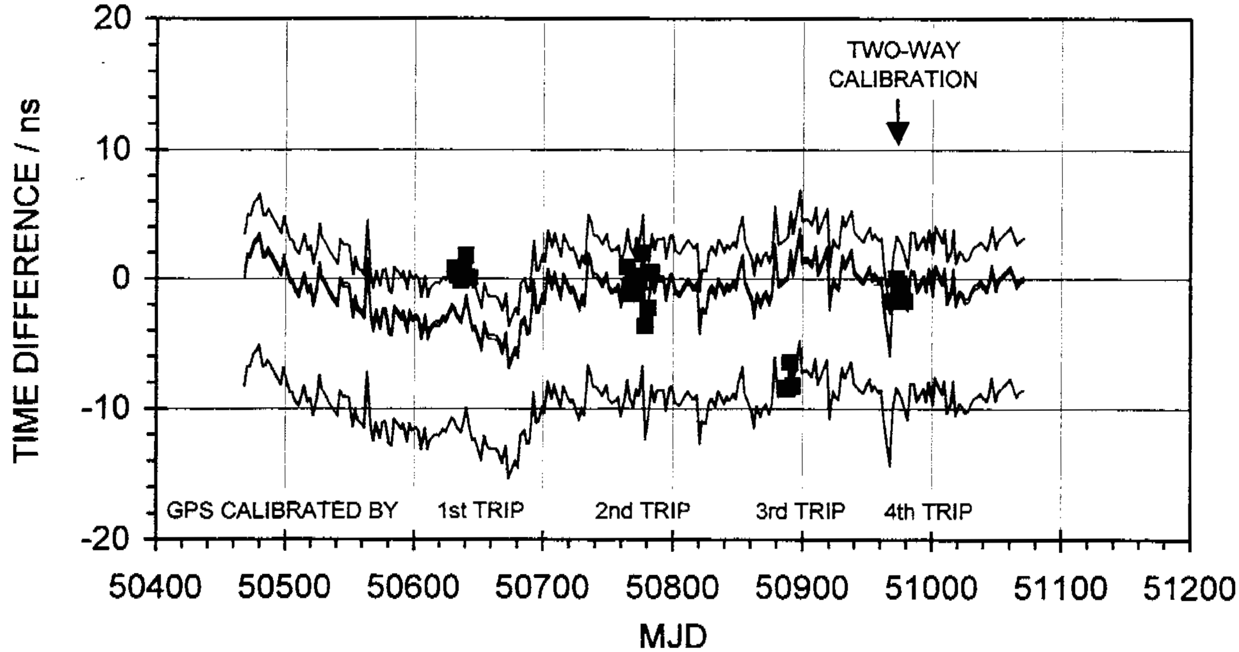

Figure 7. Differences between the independently calibrated TWSTFT and GPS measurements for TUG - PTB.

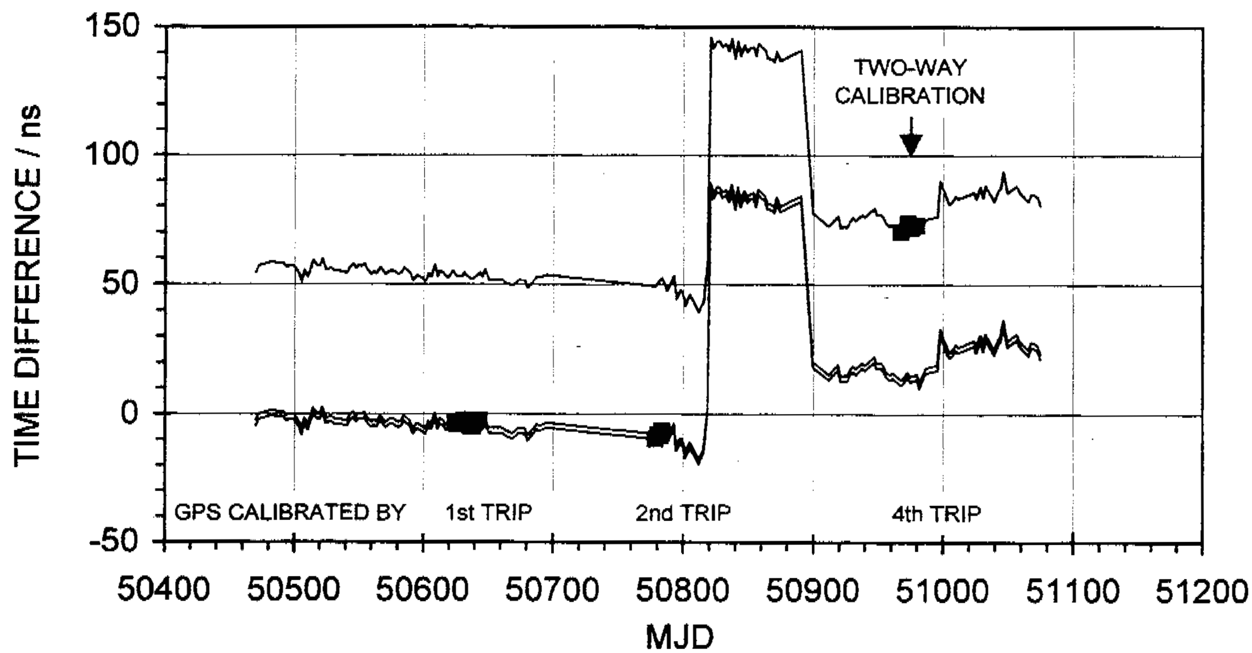

Figure 8. Differences between the independently calibrated TWSTFT and GPS measurements for TUG - DTAG.

Questions and Answers

DEMETRIOS MATSAKIS (USNO): Dieter, I think that your talk is an excellent case for using two-way on the basis of the fact that common-view GPS is not, in the end, for one reason or another, calibrated correctly in the short run. I am very curious about the fact that you had a slowly dying GPS receiver. I wonder if there was some indication that people should be looking for in their own receivers.

DIETER KIRCHNER (TUG): Yes, I can tell you the real problem. It was an eight-volt power supply in a NBS GPS receiver, and the voltage slowly decreased. It took weeks before it really failed. The GPS receiver was still working with eight volts, decreasing to 7.5 and so on, until reaching six volts, then it really stalled. You can only detect this by comparing your data with another GPS receiver. I have plotted it down here. You can see it here. This is a comparison between our two on-site GPS receivers. This extra effect here is coming from the slowly dying power supply. After replacing the power supply, you have a change here of three nanoseconds, back to nearly the old figure.

It is dangerous to simply correlate things with temperature because, if it had not really failed, we would say it is a large seasonal effect.

DEMETRIOS MATSAKIS: There is a health or status indicator or some way that you could watch the decay happen?

DIETER KIRCHNER: No. Now we are using an external power supply. We are already experienced in substituting an extra power supply to NBS receivers. So it takes only half an hour to do it. It is easily done.

To give the difference between two-way and the GPS receiver delay variation – this is the delay variation of our on-site two-way station measured by a satellite simulator. There are some problems with these measurements. You see a rapid change here – the scatter is higher and the number changed. This was because we are also receiving using our satellite simulator. We are also receiving the signal back from the satellite. If you have interfering signals from the satellite at the same frequency band, you can have problems.

So, we have to look for a gap in the band. This will not be the case with your simulator.