PRECISE T & F INTERCOMPARISON BETWEEN NPL, INDIA AND PTB, FEDERAL REPUBLIC OF GERMANY VIA SATELLITE SYMPHONIE-1

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ABSTRACT

In this paper we report a T & F intercomparison experiment between the National Physical Laboratory (NPL), New Delhi, India and Physikalisch-Technische Bundesanstalt (PTB), Federal Republic of Germany, carried out from May 16 to June 29, 1979. The participating earth stations were New Delhi, India and Raisting, FRG. The NPL clock was placed at New Delhi Earth Station and the Raisting Clock was calibrated with PTB/ Primary standard via LORAN-C and travelling clocks. The random uncertainity of time comparisons, represented by two sample Allan Variance σ (30 seconds), was less than 10 nanoseconds. The relative frequency difference between the NPL and Raisting Clocks, $S_{NPL,RAIS}$, as measured over the 44 days period was found to be -15.7×10^{-13}. The relative frequency difference between PTB Primary Standard and Raisting Clock, $S_{PTB,RAIS}$, during this period, was measured to be -22.8×10^{-13}. The relative frequency difference between NPL clock and PTB Primary Standard, $S_{NPL,PTB}$, thus, is $+7.1\times10^{-13}$.

The clock rate (UTC, India) evaluated in the present work as $+7.1 \pm 0.5\times10^{-13}$, agrees very well with that obtained via VLF phase measurements over one year period described in a companion paper and with USNO travelling clock time comparisons made in September, 1980.

INTRODUCTION

The French-German Satellite Symphonie-1 was made available for Indian Telecommunication experiments from June 1977 to June 1979. It was parked over the equator at 49°E longitude. This group has earlier[1,2], in 10th and 11th PTTI Meetings, reported Clock Synchronisation and Time Dissemination Experiments in India by means of satellite Symphonie. In this paper we report a simultaneous two way mode time and frequency comparison experiment[3] by means of satellite symphonie between the atomic clocks at the National Physical Laboratory (NPL), New Delhi and the time scale of Physikalisch-Teschnische Bundesantalt (PTB), Federal Republic of Germany. This experiment was performed over a 44 days period, from May 16 to 23 and then again from June 28 to 29,1979. The main objectives were: to synchronise UTC (NPL) to that of UTC (PTB) and to find out the relative frequency difference of NPL clocks, $S_{NPL,PTB}$, with respect of PTB Primary Standard.

The earth stations which participated in the experiments were New Delhi earth station (DES) where one of the NPL cesium clocks, oscilloquartz Model 3200, hence forth called NPL-1, was kept and the Raisting earth station (RES). The other cesium clock at NPL, HP Model 5061A with option 004 hence forth called NPL-2 which participated in the experiments and was at a different location was intercompared with NPL-1 by regular rubidium clock transportations. The Cesium clock at Raisting earth station (HP Model 5061A with option 004) was calibrated with PTB, Primary Standard via LORAN-C and travelling clocks.

The theory and the measurement uncertainities of a simultaneous two way mode time transfer are well known[4] and will not be described. Only the experimental details and the results will be discussed.

DETAILS OF THE EXPERIMENTAL SET UP AT DES

The experimental set up at NPL is shown in Fig.1. It is similar to the one used by Hubner and Hetzel[5] for time comparisons performed by means of the satellite Symphonie between Raisting(FRG) and Pleumeur-Bodou (France). The 1 PPS pulse from NPL-1 was placed on TV synch pulse as the picture signal(wave form of the signal shown in Fig.1).To have identical signal pattern throughout the duration of

the experiment a perfect phase and frequency synchronisation between 1 PPS of Cs clock and TV sync pulse is required. To achieve this, frequency of TV synch pulse generator was locked to that of Cs clock and a definite phase relation with 1 PPS of Cs clock was maintained.

As is clear from Fig.1 the 1 PPS of NPL Cs clock was directly fed to "START" port of the time interval counter and the signal was received from Raisting (Similar type of pulse as shown in Fig.1) was directly used to "STOP" the time interval counter.

Initially the data was taken once every second with a time interval counter (HP 5248 L/M) of 10 nanoseconds resolution as it could be interfaced with the available printer(HP 5050B). Later, in view of the better measurement uncertainties, a counter (HP 5345A) with 2 nanoseconds resolution was used and the data was taken once every 30 seconds. The counter used at Raisting had a 1 nanosecond resolution.

RESULTS

Fig.2 shows a 30 minutes section of measurement values, as obtained once every 30 seconds in New Delhi and Raisting. The data was taken once every 30 seconds for about an hour on each day. In Fig.2 the satellite motion has been eliminated by plotting first difference and only the deviations from the straight line have been shown.

The random uncertainty for the upper curve, which is the half difference of the measured values at New Delhi and Raisting is $\pm$ 4 nanoseconds. The mean half difference of the measured values at New Delhi and Raisting along with standard deviation and Allan Variance (σ =30 seconds) are given in Table 1. Typical values of random uncertainties are in the range of $\pm$ 3 to $\pm$ 10 nanoseconds. In two cases, values of even about $\pm$ 70 nanoseconds were found. The reasons for this large uncertainty could not be ascertained.

The NPL-1, which was used in direct measurements with Raisting, experienced a phase angle shift during the two sets of data in May and June and a phase shift correction of 564 ns with an estimated uncertainty of 20 ns, based on the relative frequency difference of two NPL cesium clocks, $S_{NPL-1, NPL-2}$, was applied to the second set data of June. $S_{NPL-1,NPL-2}$, measured by regular rubidium clock transportations during the experiment was found to be 22 ns/day, with NPL-2 running faster than NPL-1.

The daily mean half difference of the measured values at New Delhi and Raisting T (NPL-1 -Raisting) are plotted in Fig.3. The slop of this curve gives the relative frequency difference between NPL-1 and Raisting clock, $S_{NPL,RAIS}$, as measured over the 44 days period. The value in this case is found to be $-15.7 \pm 0.4 \times 10^{-13}$. In Fig.3 an expanded view of first set of data is shown. The uncertainity shown is the uncertainity of the slope of inclination of the regression line through the two sets of data points. The time comparisons T(Raisting-UTC,PTB) between Raisting clock and PTB primary standard during the above measurement period is plotted in Fig.4. The slope of the curve gives the relative frequency difference $S_{PTB,RAIS}$. The data for this curve was made available through the courtesy of PTB and is tabulated in Table 2. Points on Fig.4 represent measurements via LORAN-C and points with circle represent measurements via travelling clock. $S_{PTB,RAIS}$ from Fig.4 is found to be $-22.8 \pm 0.3 \times 10^{-13}$. From Figs. 3 and 4 the relative frequency difference between NPL clock and PTB primary standard SNPL,PTB (SNPL,RAIS-SPTB,RAIS), thus, is $+ 7.1 \pm 0.5 \times 10^{-13}$.

CONCLUSIONS

The time comparison made with U.S. Naval Observatory travelling Clock brought to New Delhi in September 1980 agreed with the initial NPL-1 clock setting with respect to PTB to within a small fraction of a microsecond and with the NPL-PTB relative frequency difference, $S_{NPL,PTB}$, of $\pm 7.1 \times 10^{-13}$ to within few parts in 10^{-14}, with those measured by means of satellite symphonie.

Similarly, $S_{NPL,PTB}$ reported in this paper is in good agreement with the relative frequency difference $S_{NPL,PTB}$ $7.0 \pm 0.1 \times 10^{-13}$ evaluated from VLF phase measurements over one year period and described in a companion paper.

With this paper we conclude a series of time transfer and time comparison experiments by means of satellite symphonie which were initiated in April 1978 and were reported in tenth and eleventh PTTI Meetings. The future plans on time dissemination via satellites include some more experiments with Indian experimental satellite APPLE (to be launched in mid 1981), a time dissemination service via operational Indian demostic satellite INSAT to be launched in late 1981, involvement in LASSO/SIRIO-2 experiments and possibilities of international time comparisons via some common view satellites.

The intercalibrations between PTB and Raisting clocks were made via LORAN-C and travelling clocks. Four time comparisons were made during this period via travelling clocks with an estimated uncertainty of ± 50 ns. The LORAN-C measurements were more uncertain than these.

A basic limitation, contributing maximum uncertainity, of a two-way time transfer via satellite is the precise measurement of individual path delay of transmitter and receiver. At New Delhi no attempts were made to measure individual path delay of transmitter and receiver. Only combined loop delay consisting of transmitter, test loop translator (a replica of transponder on satellite) and receiver was measured. This gave a value of 1900 ± 10 nanoseconds. PTB has communicated separate measurements on path delay of transmitter and receiver at Raisting earth station. These, including filter delays, are :

Transmitter (Raisting)	: 956 ns
Receiver (Raisting)	: 954 ns
Total	:1910 ns

It may be seen that total path delays encountered at New Delhi and Raisting are same with transmitter and receiver contributing half of the total delay.

A clock transport between NPL and PTB during the experiment was not possible for financial reasons and the uncertainity of time comparisons could not be ascertained. However, based an equality of path delays at Raisting and New Delhi, with transmitter and receiver delay being almost equal, one could infer 100 nanoseconds as the upper limit for accuracy uncertainty of time comparisons. These include time transfer uncertainity between PTB and Raisting (~50 ns), time transfer uncertainity between NPL-1 and NPL-2(~20ns) and uncertainity in path delays (~100 ns).

The Relativistic Correction[6] due to earth's rotation for the NPL-PTB time comparison experiment is calculated to be + 179.5 ns. This value should be added to column 3(mean value) of Table 1 to get the true value for the time difference between Raisting and NPL. It is a significant contribution in view of the precision of less than 10 ns achieved in the experiment. However, in absence of traveling clock time comparison, this could not be verified.

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Table 1

TIME COMPARISONS BETWEEN RAISTING'S CLOCK AND UTC(PTB) VIA LORAN-C AND TRAVELLING CLOCK.

Date	MJD	T(Raisting-UTC (PTB) by clock transportation (us)	T(Raisting-UTC (PTB) via LORAN-C (us)
14.05.79	44007	0,367	
16.05.79	44009		0,060
17.05.79	44010		0,304
18.05.79	44011		0,497
21.05.79	44014		1,092
22.05.79	44015		1,415
23.05.79	44016		1,527
30.05.79	44023		2,955
31.05.79	44024		3,034
01.06.79	44025		3,350
06.06.79	44030	4,118	4,136
07.06.79	44031		4,342
08.06.79	44032		4,709
09.06.79	44033		4,752
18.06.79	44042		6,519
19.06.79	44043	6,638	6,680
20.06.79	44044		6,903
21.06.79	44045		7,153
28.06.79	44052		8,469
29.06.79	44053	8,705	8,730

Table 2

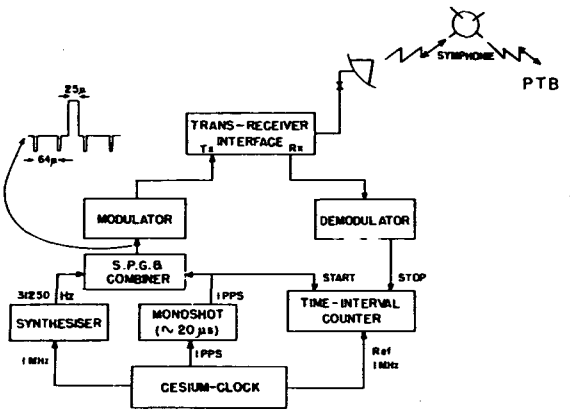
TIME COMPARISONS, STANDARD DEVIATION AND ALLAN VARIANCE BETWEEN RAISTING'S CLOCK AND NPL-1 VIA SATELLITE SYMPHONIE

Date	MJD	Mean Value * **	Standard Deviation	Allan Variance = 30 Sec. ***
May 16'79	44009	- 6.0 ns	20.2 ns	4.4 ns
May 17'79	44010	+104.7ns	10.96 ns	10.6 ns
May 18'79	44011	+263.7ns	7.92 ns	10.3 ns
May 21'79	44014	+698.8ns	4.24 ns	3.8 ns
May 22'79	44015	+746.9ns	62.52 ns	65.1 ns
May 23'79	44016	+951.5ns	7.91 ns	2.8 ns
June 28'79	44052	+5067.0 ns	88.4 ns	60.5 ns
June 29'79	44053	+5401.2 ns	3.5 ns	4.78ns

* Positive sign indicates Raistings 1 PPS coming earlier than NPL 1 PPS.

** NPL Time was off by 436.2943 us and was set after the experiment on May 16'79.

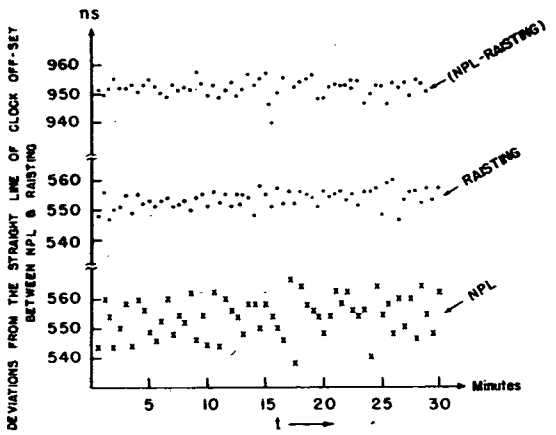
*** For limited number of observations.



EXPERIMENTAL SET-UP OF NPL-PTB CLOCK SYNCHRONISATION EXPERIMENT (MAY - JUNE, 1979)

S.P.G. = Synch pulse generator

Fig. 1



NPL-PTB CLOCK SYNCHRONISATION EXPERIMENT MAY-JUNE, 1979.

Fig.2 : Deviations from the straight line of Clock off-set between NPL and Raisting.

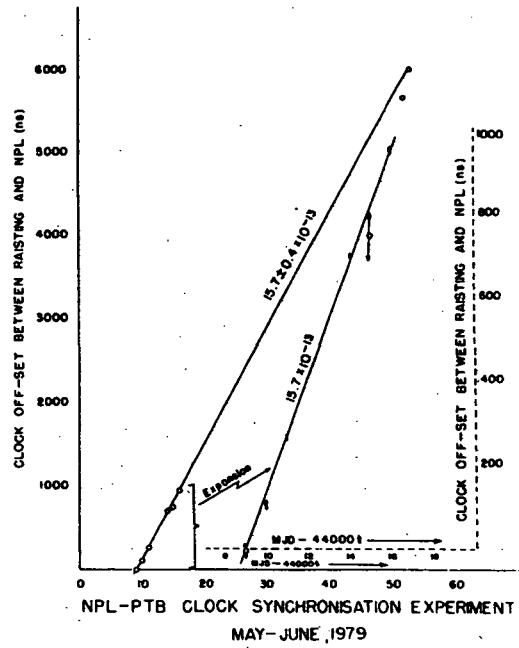


Fig.3 : Clock off-set between NPL and Raisting ($S_{NPL,RAIS}$).

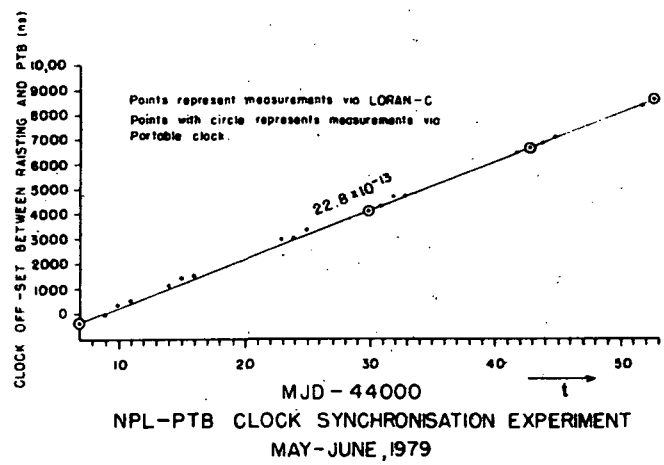


Fig. 4: Clock off-set between PTB and Raisting ($S_{PTB,RAIS}$).

S.No.	Date	Mean Julian Day MJD	Mean Value	Standard Deviation	Allan Variance τ = 30 Sec.
1.	MAY 16'79	44009	−6.0 ns ✱ ✱✱	20.2 ns	4.4 ns ✱✱✱
2.	MAY 17'79	44010	+104.7 ns	10.96 ns	10.6 ns
3.	MAY 18'79	44011	+263.7 ns	7.92 ns	10.3 ns
4.	MAY 21'79	44014	+698.8 ns	4.24 ns	3.8 ns
5.	MAY 22'79	44015	+746.9 ns	62.52 ns	65.1 ns
6.	MAY 23'79	44016	+951.5 ns	7.91 ns	2.8 ns
7.	JUNE 28'79	44052	+5067.0 ns	88.4 ns	60.5 ns
8.	JUNE 29'79	44053	+5401.2 ns	8.5 ns	4.78 ns

✱ Positive sign indicates Raistings 1pps coming earlier than NPL 1pps.

✱✱ NPL Time was off by 436.2943 μs and was set after the experiment on May 16'79.

✱✱✱ For limited number of observations.

Figure 5. NPL (New Delhi)--PTB (West Germany) Clock Synchronization Experiments via Satellite Symphoney-I