Establishment of a TWSTFT link between Asia and Europe connecting NICT and PTB

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In this contribution we report on the installation of a two-way satellite time and frequency transfer link (TWSTFT) between NICT and PTB and discuss first observation results. Specific features of the architecture of the Earth stations are the use of the multi-channel time-transfer modems developed by NICT, which are also in operation in the Asia-Pacific TWSTFT network, and optical fiber connections for radio frequency transmission between indoor and outdoor equipment. Especially at PTB a distance of 1 km has to be bridged by that way. We have performed time transfer alternatively with two different reference sources, caesium standard based realizations of UTC and hydrogen masers (HM) at both sites, NICT and PTB. First results show Allan standard deviations at 10^4 s of 1×10^{-13} and 5×10^{-14}, respectively. This represents a significant improvement compared to the GPS based comparisons made hitherto. In a first approach towards an improvement of the TWSTFT stability we study the causes of diurnal variations appearing in the measurements.

1. INTRODUCTION

Two-way satellite time and frequency transfer (TWSTFT) is the leading technique for intercontinental comparisons of time scales. At present, two networks employing TWSTFT exist worldwide, the Asia-Pacific net which is operated by NICT and the Europe-USA net [1]. Following first TWSTFT experiments between Asia and Europe [2], a link between NICT and PTB was established to connect both networks by means of TWSTFT.

After a description of the installed hardware and the operation parameters we show first results of clock comparisons between NICT and PTB using TWSTFT. We investigated the stability of the link by using different frequency sources at both sites, caesium standards or hydrogen masers. Thereafter, routine operation was started comparing the local realizations of UTC at each laboratory. An analysis of four months data recording is presented. In a first approach to improve the stability of the link we investigate diurnal effects.

II. HARDWARE AND OPERATION

In addition to the existing TWSTFT systems for clock comparisons between institutes in the Pacific-Rim region [3], NICT initiated the establishment of a TWSTFT link between Asia and Europe. Two earth stations were designed and hardware was initially tested to be installed thereafter at PTB and NICT. Both stations consist of standard telecommunication up- and down-converters (UC, DC), solid state power amplifiers (SSPA), low noise amplifiers (LNA), and antennae. The modem is a 8-receive-channel modem developed at NICT [4]. In Fig. 1 a block diagram of the hardware is shown, and in Fig. 2 the earth stations of PTB and NICT for communication with the PAS-4 satellite is depicted. At both sites the modems, UC, and DC are located indoors in temperature stabilized environment (temperature variations < 1 K). Only SSPAs, LNAs and antennae are installed outdoors. The LNAs are mounted in temperature stabilized boxes. At PTB and NICT 2.4 m diameter Cassegrain and offset antennae have been installed, respectively. RF frequencies are transmitted from indoors to outdoors and vice versa via 40 m coaxial cables at NICT. At PTB the antenna is located at a distance of about 1 km from the time laboratory. To transmit the RF frequencies over that distance an optical fibre cable with electro-optical (E/O) and optical-electrical (O/E) converters have been installed indoors and outdoors. The separation in longitude between both sites is quite large which implies low elevation angles. Fortunately, the PAS-4 satellite is positioned such that a rather symmetrical signal path with elevation angles of 8° at PTB and 9° at NICT is feasible. At present, we use up- and down-link frequencies of 14.426250 GHz and 12.678250 GHz (14.426250 GHz and 11.465000 GHz) at NICT (PTB), respectively. The occupied bandwidth is 2.5 MHz.

After an initial performance evaluation and an up link access test (UAT), the first observation succeeded on July 22nd in 2005. Tentative operation started on that day. During August and September 2006 different test measurements were carried out (see Section III). The transponder frequency was changed to avoid interference problems on 18 October 2005. Regular operation started on 26 October 2005. Starting from 1 January 2006, data formatted according to the relevant ITU-R recommendation [5] are submitted to the BIPM on a weekly basis.

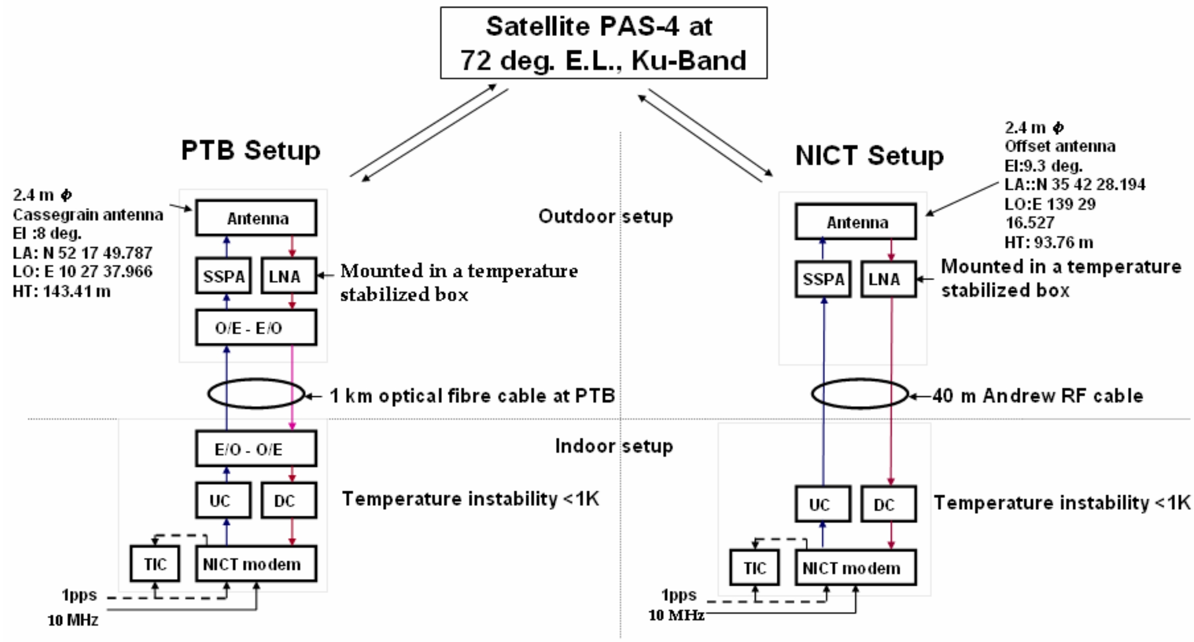
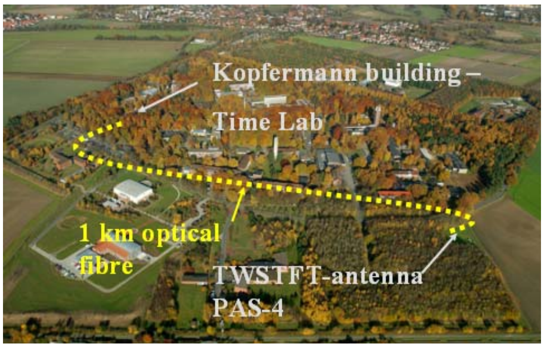


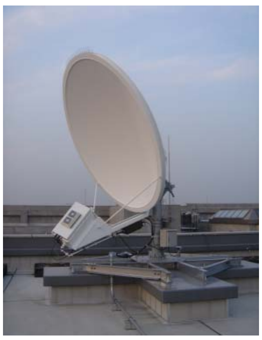
Figure 1. Block diagram of NICT-PTB Link

PTB Antenna of 2.4m

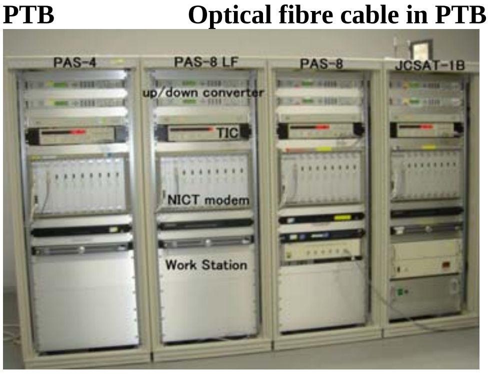
Equipment in PTB



Optical fibre cable in PTB



NICT Antenna of 2.4m



Equipment in NICT

Figure 2. Earth station for PAS-4 satellites of PTB and NICT

III. Short Term Stability

During the first operation phase we changed the frequency references from caesium standards based local realization of UTC (CS) to hydrogen masers (HM) of the modems to investigate the achievable short term frequency stability. Two measurement series were recorded, one with CS connected to the modems and the other with HM as the source for the frequency reference. The series consist of six and nine days continuous recordings of one second measurements UTC(NICT) – UTC(PTB) and HM(NICT) – HM(PTB), respectively. In Fig. 3a and b the results of Allan standard deviation analysis are shown for both cases, respectively (dots). The slope reveals white phase noise up to $\tau = 10^4$ s, and values of $1\text{x}10^{-13}$ and $5\text{x}10^{-14}$ at $\tau = 10^4$ s are reached. Reducing measurement noise by reducing the one-second-data to 5 minute averages results in a lower noise level (line). The dominant noise type changes to white frequency noise for CS, proving that 5 minutes averaging is sufficient. However, in the case of HM the noise type at 5 min is still white phase and a small bump at about $\tau = 4\text{x}10^4$ s may indicate diurnal effects superposed to the time transfer information.

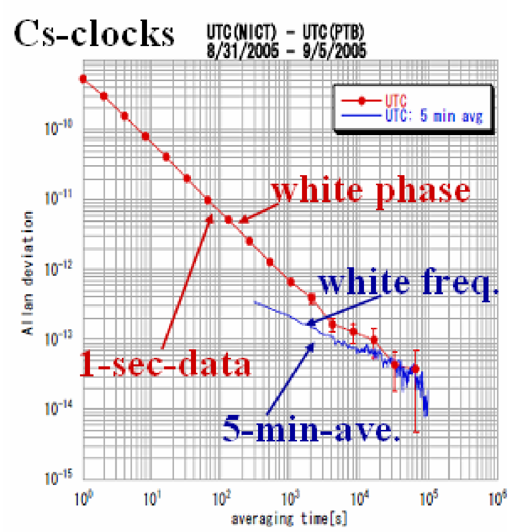


Figure 3a. Frequency stability of time transfer UTC(NICT) – UTC(PTB).

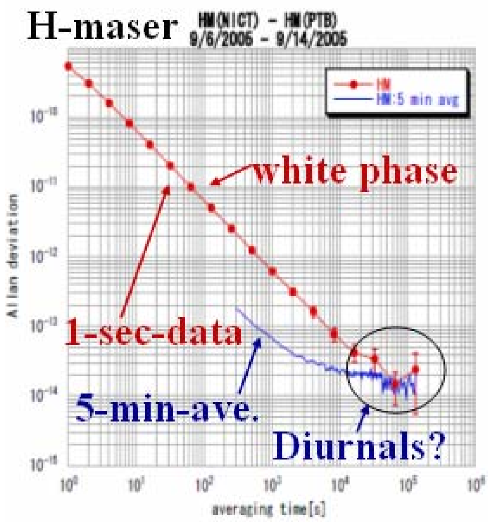


Figure 3b. Frequency stability of time transfer HM(NICT) – HM(PTB).

IV. FOUR MONTH OBSERVATION RESULTS

Since Nov 2005 the TWSTFT link is routinely operated. The one second data are reduced to one value per hour. The first 300 data points taken every hour are fitted with a quadratic function, and the midpoint is reported in the file format according to the well-known ITU-R recommendation [5]. Additionally, the link was calibrated using GPS P3 time transfer data provided by the BIPM [7]. The estimated uncertainty for a time comparison is thus $u_B = 5.0$ ns due to the uncertainty of the GPS link calibration. A comparison of the TWSTFT and the GPS P3 link is shown in Fig. 4. The red line represents GPS P3 data while the blue line represents the TWSTFT measurements. The course of both time series data show good agreement. In Fig. 5 the corresponding Allan deviations are displayed in the same colors. TWSTFT shows a significant improvement of the time-transfer stability compared to GPS P3. The noise level and slope of the Allan deviation plot at long averaging times is typical for Cs standards which were the frequency sources connected to the modems during this period of time. A change of the UTC(NICT) generation from a CS clock ensemble to a HM steered in frequency happened on 7 Feb 2006. Data taken afterwards (black crosses) reveal a reduced noise, and one can see the typical shot-noise limited frequency stability of PTB's primary standard CS2. Additionally, the Allan deviation of one year (starting in Feb 2005) CircT data are shown as black dots.

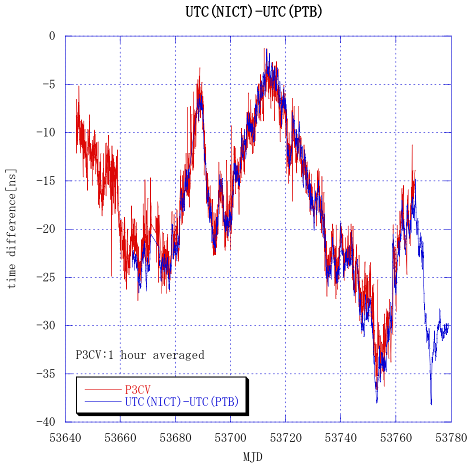


Figure 4. Time difference of UTC(NICT)-UTC (PTB)

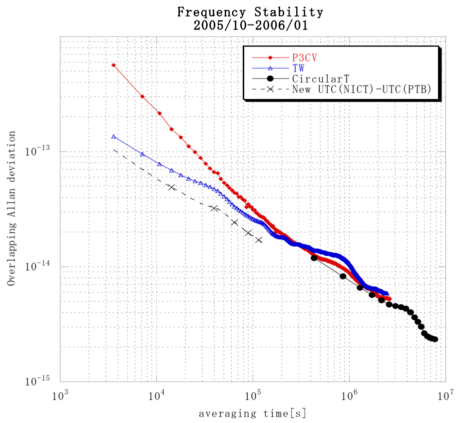


Figure 5. Frequency stability.

V. DIURNAL EFFECTS

A small bump in the Allan deviation at τ ≈ ½ day visible in Fig. 5 indicates a diurnal effect superimposed to the time transfer. These variations were also observed by BIPM [6]. The correlation of these diurnals to the outdoor temperatures at both earth stations is analysed in the following. In Fig. 6, a five-days excerpt of the double differences GPS P3 - TWSTFT from the data shown in Fig. 4 is displayed together with records of the outdoor temperatures at PTB (upper graph) and NICT (lower graph). The GPS P3 analysis shows clear diurnals, so we attribute most of the effect visible in the double differences to the TWSTFT link. The correlation coefficient between the temperature records at PTB and NICT and the double differences are 0.26 and -0.57, respectively. The diurnal variation seems to be related to the temperature at NICT. In fact, the course of the temperature at NICT shows a strong day-to-day periodicity, which makes an analysis of the correlation much easier than in case of PTB. The main difference between the NICT setup and the PTB setup is the use of optical fibres at PTB instead of coaxial cables at NICT to connect indoor and outdoor equipment. However, the E/O and O/E mounted in an outdoor box have only minor temperature coefficients (overall < 25 ps/K) of the group delay. The source of the diurnals should be analysed in more detail in future investigations.

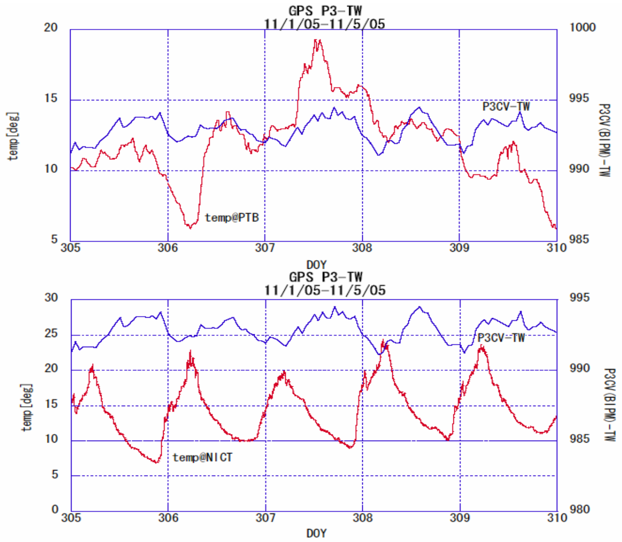


Figure 6. Double difference (ns) between P3CV and TWSTFT (blue) and local temperature (°C) at PTB (upper graph) and NICT (lower graph).

VI. CONCLUSION

On initiative of NICT, a TWSTFT link between NICT and PTB was established. This link has a baseline of about 10,000 km. This is the longest baseline in the world wide network of TWSTFT links used in the production of TAI. The time transfer is regularly performed and hourly data are reported to the BIPM. The observed diurnal variations are an important issue to be understood and its analysis will continue. Furthermore, in a cooperation between NICT, TL, USNO, and NIST a construction of an earth station at Hawaii is planned to expand the Asia-Pacific TWSTFT network to USA. Once this project is completed, an around the world TWSTFT network will be in operation.

Acknowledgements

We would like to express our thanks to T. Leder, C. Richter, J. Becker, and T. Polewka in PTB, and T&F members in NICT for their support during the installation of the link.

REFERENCES

[1] B. Guinot and E. F. Arias: “Atomic time-keeping from 1955 to the present”; *Metrologia*, Vol. **42**, No. 3, pp. S20-S30, 2005.
[2] H. T. Lin, W. H. Tseng, S. Y. Lin, H. M. Peng, C. S. Liao, G. de Jong, E. Kroon, M. J. Brakel: “The first two-way time transfer link between Asia and Europe”; *Proc. 35th PTTI*, 2-4 Dec 2003, San Diego, USA, pp. 71-79 (2004).
[3] H. Maeno, M. Fujieda, M. Aida, L. Q. Tung, R. Tabuchi, F. Nakawa, T. Suzuvama, Y. Takahashi: “TWSTFT plans for the Pacific-Rim region and Europe link”; *Proc. EFTF 2005*, pp. 459-463 , 2006.
[4] M. Imae, T. Suzuyama, T. Gotoh, Y. Shibuya, F. Nakagawa, Y. Shimizu and N. Kurihara: “Two Way Satellite Time and Frequency Transfer”; *Journal of the NICT*, Vol. **50**, No. 1/2, pp. 125-133, 2003.
[5] Recommendation ITU-R TF.1153-2: “The operational use of two-way satellite time and frequency transfer employing PN time codes”; Geneva, last update 2003.
[6] Z. Jiang and G. Petit, “BIPM first analysis of NICT-PTB TW link and comparison with GPS CV-AV P3 links BIPM”; *TM144*, 2006.
[7] Z. Jiang: private communication