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PTB'S TIME AND FREQUENCY ACTIVITIES IN 2006: NEW DCF77 ELECTRONICS, NEW NTP SERVERS, AND CALIBRATION ACTIVITIES

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Abstract

The Physikalisch-Technische Bundesanstalt (PTB) maintains the German legal time scale, disseminates time and frequency for both business and the general public, and undertakes research to improve its capabilities. In this report, we focus on the new time dissemination installations for the general public, which is comprised of the new low frequency transmitter DCF77 electronics and the new NTP servers. We briefly discuss the calibration activities concerning PTB's external time links for the generation of International Atomic Time and report the result of the latest calibration of the link to the United States Naval Observatory.

INTRODUCTION

The Physikalisch-Technische Bundesanstalt (PTB) maintains the German national time scale, disseminates time and frequency for both business and general public, and undertakes research to improve its capabilities.

PTB's time scale UTC (PTB) is based on the primary clock CS2 and an associated phase micro stepper to keep the time scale in reasonable agreement with UTC. CS2 and the other primary standards CS1 **[1]** and CSF1 **[2]** are part of PTB's group of atomic clocks whose data are provided for the computation of TAI and in the near future for steering the Galileo System Time. PTB acts as one of the four so-called UTC (k) laboratories cooperating with the future Galileo Time Service Provider **[3]**. In this framework, its clock-monitoring and measurement systems are refurbished and upgraded.

PTB provides services to disseminate time and frequency within Germany, among which the low frequency transmitter DCF77 is the most prominent example. Other time services are the NTP servers, as well as the telephone time service to synchronize computer via Internet or modem connection, respectively. During 2006, completely new electronics for the signal generation of DCF77 and two new NTP-servers have been installed.

A broad range of satellite time-transfer equipment is being operated to enable time scale comparisons with other institutes in Europe, North America, and Asia. Single- and multi-channel GPS receivers, as well as so called geodetic receivers, enable redundant frequency and time transfer with state-of-the-art evaluation techniques (C/A code, P3, carrier phase). Two-way satellite time and frequency transfer

(TWSTFT) is being routinely performed with several European and US stations. On the initiative of NICT, a TWSTFT link was established between NICT and PTB in July 2005 **[4]**. Investigations of the link characteristics show a higher stability compared to GPS time transfer **[5]**. During the last 2 years, PTB has upgraded its TWSTFT and GPS capabilities in order to achieve better reliability and robustness against system failures. Several calibration campaigns have been performed, partly with substantial support of USNO and BIPM, which allowed verification of the uncertainty for time transfer using PTB's current equipment.

Here we present achievements and new developments concerning the new DCF77 electronics, the new NTP-server, and, briefly, the calibration of the international time links, i.e. the result of the latest calibration of the TWSTFT links to the USNO. Status of the primary fountain clock CSF1 and progress of the development of the new CSF2 **[6]**, as well as the status of the optical frequency standards and measurement techniques **[7]**, will not be addressed in this report.

DCF77 – NEW ELECTRONICS AND ADDITIONAL INFORMATION CONTENT

Legal time and standard frequency are disseminated via the low frequency transmitter DCF77 as an infrastructural service of the state. The service, with a standard frequency at 77.5 kHz, and coded time information has been broadcast via transmitter facilities operated by T-Systems Media Broadcast under contract. Time information is broadcast as amplitude modulation (AM) and phase modulation (PM). While the AM is widely used for applications with uncertainty requirements not below 1 ms, the PM code allows one to refer clocks to UTC (PTB) at the level of 10 µs. General information concerning DCF77 can be found in Ref. **[8]**, the PM modulation is described in detail in Ref. **[9]**, and for publications in German language one should see Ref. **[10]**.

A completely new electronic control unit was installed during summer 2006 and was put into routine operation in September. In Fig. 1, the new control unit is shown while under construction. The transmitted signal is generated, as in the previous setup, with three independent atomic clocks as inputs to three time code generators, from which one is chosen as the main source and one as a backup. In regular operation, the carrier phases of all outputs are kept in mutual agreement within a few tenths of a µs. However, in the case of a malfunction, a switch matrix discards the corresponding output or switches all outputs off if there is no coincidence between the two remaining generators in order to prevent a false transmission.

No changes in the signal structure have been introduced. As published before **[11]**, the information content of 14 amplitude modulated bits, which are transmitted during the seconds 1 to 14, is no longer provided by PTB (see Fig. 2 for the current coding scheme and Ref. **[12]** for a detailed description). Under responsibility of the Federal Office of Civil Protection and Disaster Relief (the German Bundesamt für Bevölkerungsschutz und Katastrophenwarnung, BBK), warnings to the population can be transmitted using these 14 bits. Negotiations are still ongoing and at present no decision has been made as to whether DCF77 will be used for that purpose or not. As a further extension of the information content transmitted by DCF77, weather information has been provided under responsibility of Meteo Time GmbH since November 2006 **[13]**. The same 14 bits are employed in a way that ensures compatibility with the transmission protocols of the warning messages. The Meteo Time service is also available on the Swiss low frequency transmitter HBG **[14]**.

Figure 1. New electronic control during construction. As a detail, one can see in racks 1 to 3 the three signal generators and temporarily only two atomic frequency standards.

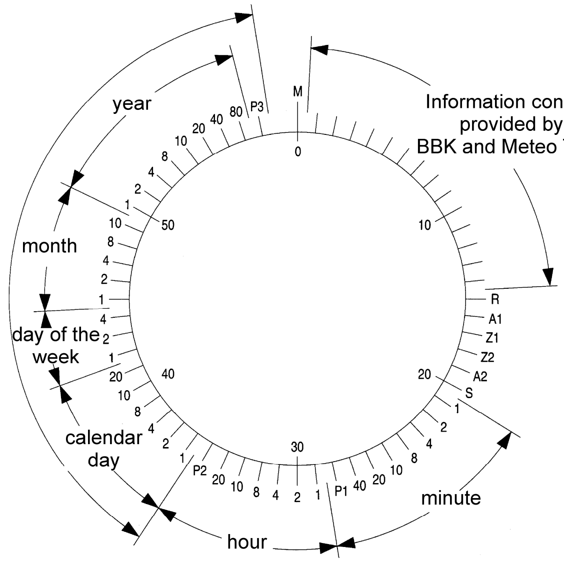


Figure 2. Current coding scheme of the DCF77 time code frame. For a detailed description, see Ref. **[8]**, **[12]**, or, in the German language, **[10]**.

NTP – NEW SERVERS

Two new NTP servers (see Fig. 3) were put into operation in early 2006 to replace the ones which were in use since April 1999. As before, UTC (PTB) can be obtained at *ptbtime1.ptb.de* or *ptbtime2.ptb.de*. UTC (PTB) is fed into the servers by time code generators and direct 1pps inputs. For control purposes, UTC (PTB) can be received from a DCF77 radio clock (ptbtime1; see Fig. 4), and the NTP servers use each other as an additional backup reference. ptbtime1 (ptbtime2) is equipped with a Pentium Mobile 1600 MHz (600 MHz) processor, respectively, handling 700 (300) queries per second at present. One of the old NTP servers is still in use, answering 250 queries per second.

Figure 3. New NTP servers ptbtime1 (lower) and ptbtime2 (upper).

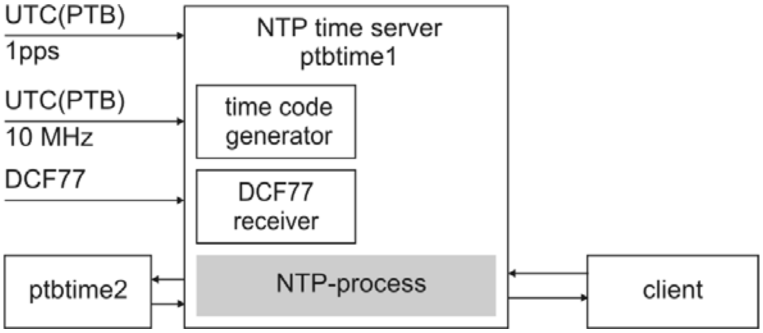
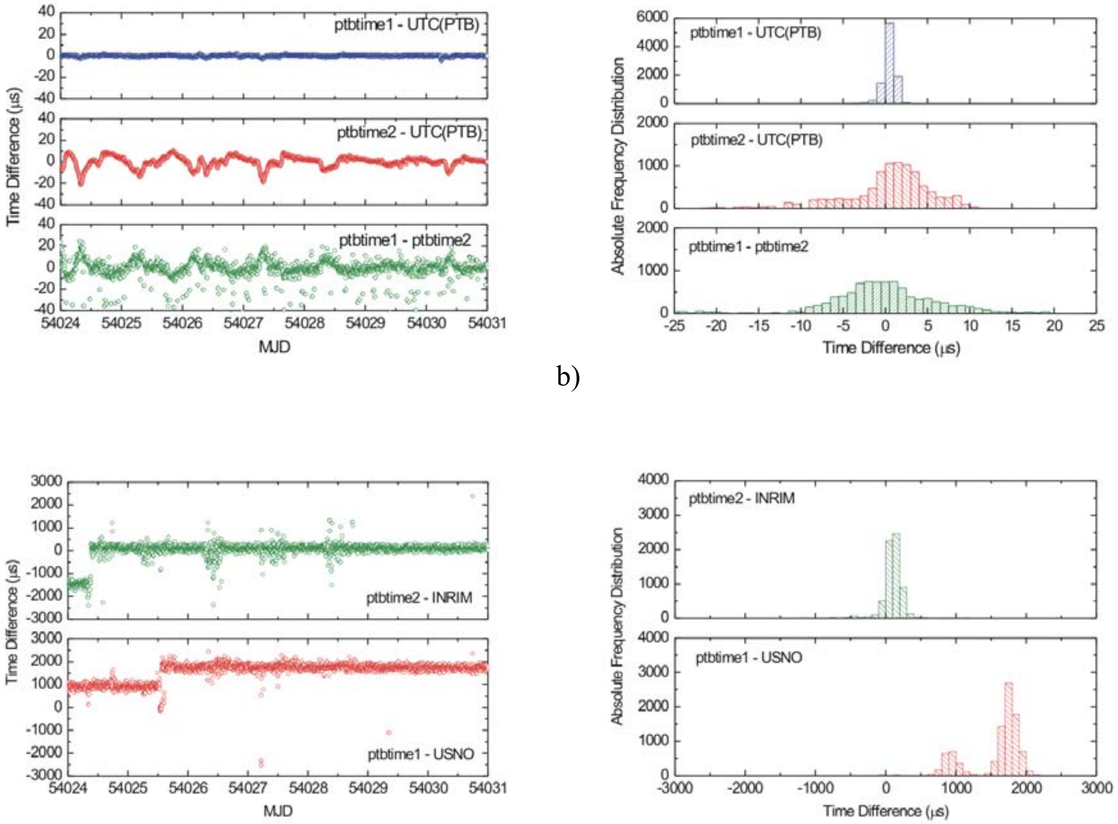


Figure 4. Connection of ptbtime1 to UTC (PTB).

In Fig. 5, one week of time stamp records from October 2006 of the NTP servers with different sources (October 2006) is depicted. Time of arrival measurements of different remote sources with respect to the respective internal server system clock of ptbtime1 and ptbtime2 are recorded. ptbtime1 has a significant smaller phase fluctuation than ptbtime2 (Fig. 5 a). The absolute frequency distribution of the phase (Fig. 5 b) of ptbtime1 does not exceed 5 µs, although ptbtime2's phase shows variations up to 20 µs and a diurnal component. This has a significant impact on the absolute frequency distribution shown in Fig. 5 b). The distribution flattens further if we compare both servers via the PTB intranet. For a comparison with remote NTP servers, we chose INRIM (*ntp1.inrim.it*) as a European reference and USNO (*ntp0.usno.navy.mil*) for an intercontinental connection. Comparisons with external NTP servers (lower graph) show significantly larger scatter than the internal synchronization data through the PTB intranet. One can identify two kinds of features in the time difference comparisons (Fig. 5 c): There are time jumps on the order of 1 ms, which may be due to changes of the delay asymmetry of the transmission path through the Internet, and a diurnal increase of the data scatter during working days (MJD 54024 to 54028, inclusive).



a)

b)

c)

d)

Figure 5. One week (MJD 54025 corresponds to 17 October 2006) of time stamp records with different sources. Time series plot (a) and histogram (b) of comparisons of the internal clock of ptbtime1 and ptbtime2 with the 1pps input UTC (PTB) and ptbtime2 as it is received via the PTB intranet by ptbtime1. Comparison of PTB's NTP server with external servers (c) and (d).

A summary a time deviation (TDEV) analysis of the data displayed in Fig. 5 a) and c) is shown in Fig. 6. For the remote connections, the data base was shortened to the period MJD 54026.0 to 54030.0 to exclude the jumps from the analysis. This may reduce the weight of the diurnal scatter during working days, but gives a realistic estimate for the necessary stability of the PTB time servers. The TDEV values for internal measurements (ptbtime1 – UTC (PTB), ptbtime2 – UTC (PTB), ptbtime1 – ptbtime2) are well below 10^{-5} s at all computed averaging times. At the same time, the instability of the answers of remote NTP servers are at the 10^{-4} s level or even below.

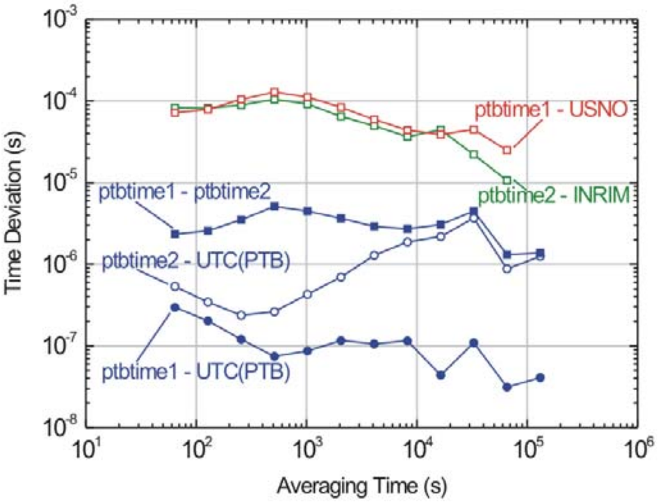


Figure 6. Time deviation (TDEV) plot of the data displayed in Fig. 4. For details, see the text.

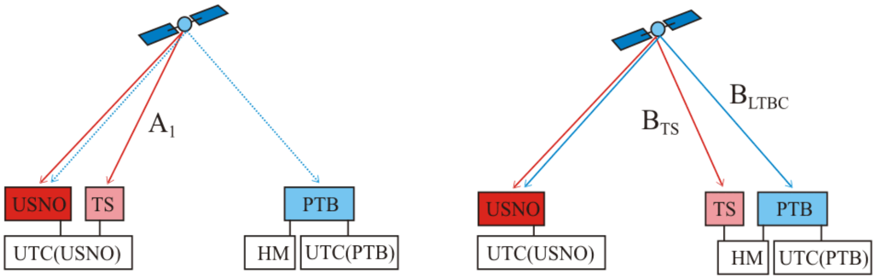
PARTICIPATION IN INTERNATIONAL CALIBRATION CAMPAIGNS

During the last 2 years, PTB participated in several international calibration campaigns to determine internal delays of the time transfer equipment, for both TWSTFT and GPS, which is needed for the contribution to International Atomic Time. In Table 1, the 2005/2006 activities in which PTB participated are summarized. As a result, uncertainties (u_B) of about 5 nanoseconds were commonly achieved for GPS C/A time transfer techniques **[15]** and uncertainties around 1 ns were achieved in TWSTFT calibration campaigns **[16,17]**. In the following, the results of the latest calibration of the TWSTFT link between the USNO and PTB are reported.

Table 1. Participation in calibration campaigns.

Date	Technique	Organizer/Participants	Reference
May 2005	TWSTFT	USNO, PTB	**[16]**
October 2005	GPS C/A	BIPM	-
November 2005	TWSTFT	PTB, SP, VSL, NPL, OP, INRIM	**[17]**
January 2006	TWSTFT	USNO, PTB	this report
May 2006	TWSTFT	TUG, PTB, METAS	to be published
June 2006	GPS TAIP3	BIPM	-
September 2006	GPS C/A	BIPM	-

As in previous years, USNO has conducted the calibration of the time transfer link USNO – PTB by operating a pre-calibrated traveling station (TS) at PTB. By this means, a temporary TWSTFT link between USNO and PTB was established. The calibration requires two steps, which are depicted in Fig. 7. The TS station was operated first at USNO to determine the common clock difference (measurement A, Fig. 6) and then second at PTB performing a true time transfer (measurement B, Fig. 6) in parallel to a time link to be calibrated (LTBC). In Fig. 6, LTBC is a link using the same satellite. This is not mandatory. In the series of calibration exercises, both existing TWSTFT links to the USNO were calibrated, one in the X-band, using the same satellite as TS, and one in the Ku-band. Measurement A was repeated after finishing the calibration trip, to estimate the stability of the TS during the whole trip. Different hardware configurations were employed to ensure redundancy in case of the operation failure of single components.



Measurement A$_1$
Common Clock Difference

Measurements B$_{TS}$, B$_{LTBC}$
True Time Transfer

Figure 7. Schematic of the setup of the traveling TWSTFT station (TS) sequentially operated at USNO and PTB.

At the time of the calibration experiment, both routinely operated links, in Ku-band and X-band, respectively, had already been calibrated. The time transfer data are depicted in Fig. 8 as blue squares and red diamonds, respectively. The results of the true time transfer using the TS are shown as orange or yellow diamonds, representing the main and the backup TS setup, respectively. Differential calibration corrections were calculated by subtracting every TS data point from the interpolation of the two close-by data points of the regular TWSTFT sessions. Differential corrections of -2.0 ns (-1.4 ns) for the Ku-band (X-band) link were determined using the main TS setup. The results using the backup setup perfectly agree within 0.1 ns. Combined uncertainties of 0.9 ns were estimated for both links, following the same procedure as employed in previous calibration campaigns **[16,17]**. The overall uncertainty of the calibration constants can be calculated using the following equation:

$$U = \sqrt{u_{A,1}^2 + u_{A,2}^2 + u_{B,1}^2 + u_{B,2}^2 + u_{B,3}^2}\ , \qquad (1)$$

where $u_{A,1}$ reflects the statistical uncertainty of the common clock determination; $u_{A,2}$ is the statistical uncertainty of the measurements at the remote site B$_{TS}$ and B$_{LTBC}$. The systematic contributions reflect the stability of the TS as well as the stability of the home station of USNO and are contained in $u_{B,1}$. The connection to the local time scale UTC requires one time interval measurement. We have to account for this by applying $u_{B,2}$ = 0.5 ns according to the time interval counter specifications. $u_{B,3}$ reflects all other systematic errors, e.g. the stability of the connection to the local UTC (0.1 ns), Tx/Rx-power, and C/N$_0$ (overall 0.1 ns). The results are summarized in Table 2. The corrections are applied to the TWSTFT time transfer data rounded to one decimal.

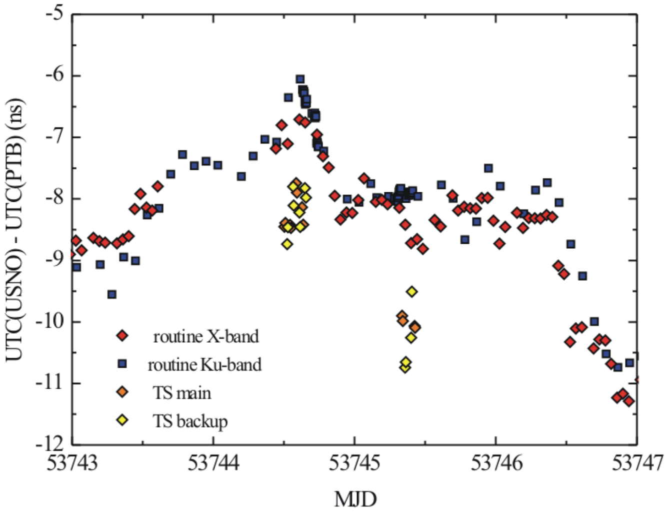


Figure 8. Comparison of the time scales UTC (USNO) and UTC (PTB) using three TWSTFT links established during the calibration campaign in January 2006: routine Ku-band (blue squares) and routine X-band (red diamonds), TS X-band (yellow and orange diamonds).

Table 1. Uncertainty budget (1-sigma) of the calibration of the two TWSTFT links between USNO and PTB. The corrections are applied to the TWSTFT data rounded to one decimal.

Link	$u_{A,1}$	$u_{A,2}$	u_A	$u_{B,1}$	$u_{B,2}$	$u_{B,3}$	u_B	U
Ku-band	0.103	0.196	0.221	0.670	0.5	0.141	0.849	0.877
X-band	0.103	0.171	0.200	0.670	0.5	0.141	0.849	0.872

In Fig. 9, the long-term records of the differential corrections of the TWSTFT links UTC(PTB) – UTC(USNO) are depicted. The graph is an update to the results published in 2005 **[16]**. The error bars of the differential corrections to be applied to the TWSTFT links reflect the estimated uncertainty of the calibration. The gray bars represent the estimated uncertainty of the link at the day of calibration, including uncertainties due to data bridging. The differential correction of the January 2006 calibration is relatively large compared with older results, which justifies the motivation to conduct calibrations once or twice per year.

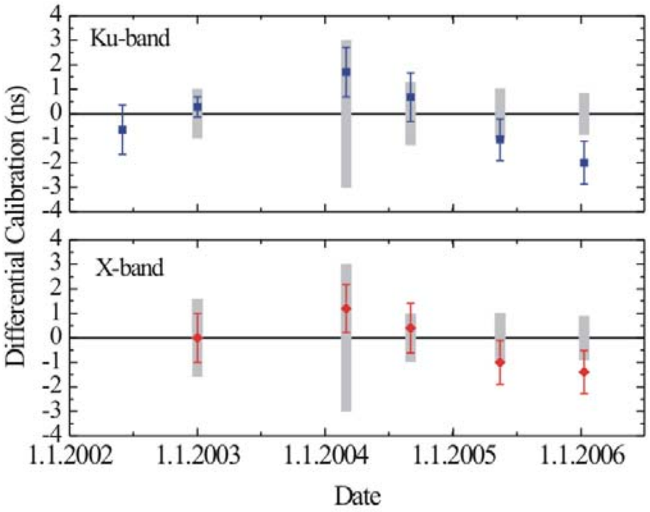


Figure 9. Differential corrections applied to the routine TWSTFT links. The error bars reflect the estimated uncertainty of the link at the day of calibration, including the uncertainty due to data bridging.

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DISCLAIMER

The Physikalisch-Technische Bundesanstalt as a matter of policy does not endorse any commercial product. The mentioning of brands and individual models seems justified here, because all information provided is based on publicly available material or data taken at PTB and it will help the reader to make comparisons with his own observations.

REFERENCES

[1] A. Bauch, 2005, *"The PTB primary clocks CS1 and CS2,"* **Metrologia, 42,** S43-S54.

[2] R. Wynands and S. Weyers, 2005, *"Atomic fountain clocks,"* **Metrologia, 42,** S64-S79.

[3] R. Hlaváč, M. Lösch, F. Luongo, and J. Hahn, 2006, *"Timing Infrastructure for Galileo System,"* in Proceedings of the 20th European Frequency and Time Forum (EFTF), 27-30 March 2006, Braunschweig, Germany, pp. 391-397.

[4] H. Maeno, M. Fujieda, D. Piester, A. Bauch, M. Aida, Q. T. Lam, T. Gotoh, Y. Takahashi, 2006, *"Establishment of a TWSTFT link between Asia and Europe connecting NICT and PTB,"* in Proceedings of the 20th European Frequency and Time Forum (EFTF), 27-30 March 2006, Braunschweig, Germany, pp. 575-579.

[5] M. Fujieda, T. Gotoh, M. Aida, J. Amagai, H. Maeno, D. Piester, A. Bauch, and S. H. Yang, *"Long Baseline TWSTFT Between Asia and Europe,"* in Proceedings of the 38th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 5-7 December 2006, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 497-508.

[6] R. Wynands, D. Griebsch, R. Schröder, and S. Weyers, 2006, *"Current status of PTB's new caesium fountain clock CSF2,"* in Proceedings of the 20th European Frequency and Time Forum (EFTF), 27-30 March 2006, Braunschweig, Germany, pp. 200-202.

[7] C. Tamm, B. Lipphardt, H. Schnatz, R. Wynands, S. Weyers, T. Schneider, and E. Peik, 2006, "$^{171}Yb^{+}$ *single-ion optical frequency standard at 688 THz,"* in Proceedings of the 20th European Frequency and Time Forum (EFTF), 27-30 March 2006, Braunschweig, Germany, pp. 293-297.

[8] F. Riehle, 2004, **Frequency Standards; Basics and Applications** (Wiley-VCH, Weinheim).

[9] P. Hetzel, 1988, *"Time dissemination via the LF Transmitter DCF77 using a pseudo-random phase-shift keying of the carrier,"* in Proceedings of the 2nd European Frequency and Time Forum (EFTF), March 1988, Neuchâtel, Switzerland, pp. 351-364.

[10] D. Piester, P. Hetzel, and A. Bauch, 2004, *"Zeit- und Normalfrequenzverbreitung mit DCF77,"* **PTB-Mitteilungen, 114**, 343-366.

[11] D. Piester, A. Bauch, J. Becker, and T. Polewka, 2005, *"Time and Frequency Activities at the Physikalisch-Technische Bundesanstalt,"* in Proceedings of the 36th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 7-9 December 2004, Washington, D.C., USA (U.S. Naval Observatory, Washington, D.C.), pp. 179-188.

[12] ITU-R Recommendations: TF-583-6 "*Time Codes*" and TF.768-6 "*Standard frequency and time-signals*" (ITU, Geneva); see: *http://www.itu.int/ITU-R/Study-Groups/rsg7/index.asp*

[13] *http://www.meteotime.ch*

[14] *http://www.metas.ch*

[15] B. Guinot and E. F. Arias, 2005, *"Atomic time-keeping from 1955 to the present,"* **Metrologia, 42,** 2005, S20-S30.

[16] D. Piester, A. Bauch, J. Becker, T. Polewka, A. McKinley, L. Breakiron, A. Smith, B. Fonville, and D. Matsakis, 2005, *"Two-Way Satellite Time Transfer between USNO and PTB,"* in Proceedings of the 2005 Joint IEEE International Frequency Control Symposium and Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 29-31 Aug 2005, Vancouver, Canada, pp. 316-323.

[17] D. Piester, J. Achkar, J. Becker, B. Blanzano, K. Jaldehag, G. de Jong, O. Koudelka, L. Lorini, H. Ressler, M. Rost, I. Sesia, and P. Whibberley, 2006, *"Calibration of Six European TWSTFT Earth Stations Using a Portable Station,"* in Proceedings of the 20th European Frequency and Time Forum (EFTF), 27-30 March 2006, Braunschweig, Germany, pp. 460-466.