METAS Time & Frequency Metrology Report

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***Abstract*— METAS is the Swiss Federal Office of Metrology and Accreditation, The METAS Time & Frequency Laboratory (T&F Lab) operates a cesium primary standard, maintains the Swiss national time scales, disseminates precise time and performs calibrations for customers. This paper reports current activities in the laboratory.**

I. Introduction

METAS is the National Metrology Institute (NMI) for Switzerland. The purpose of the METAS Time & Frequency Laboratory (T&F Lab) is to maintain the Swiss time & frequency metrology standards, to disseminate precise time in Switzerland and to perform calibrations for customers with delivery of official calibration certificates. The T&F Lab currently operates a laser cooled cesium fountain primary standard, a hydrogen maser and four commercial cesium beam frequency standards. Regarding time dissemination the T&F Lab offers both a phone/modem time service (European format ITU-R TF583.2) and a public NTP server. METAS also operates the HBG VLF time code transmitter (carrier frequency 75 kHz)located in Prangins, Switzerland. This paper reports current activities in the T&F Lab.

II. Time scales generation

The hydrogen maser and the four cesium beam frequency standards constitute the ensemble of atomic clocks used for the time scales generation. The clocks are continuously compared by means of a 5 MHz multi-channel digital phase comparator system. One of the cesium beam standards is used as the reference for the time difference measurements. Figure 1 is a simplified block diagram of the T&F Lab atomic clocks ensemble and reference signal distribution system. The national time scales TA(CH) and UTC(CH) are both paper clocks which are computed every day for epoch UTC 00:00 of the previous day. TA(CH) is a free running time scale while UTC(CH) is steered monthly to track UTC [2], [3]. The clocks results are sent monthly to BIPM and participate to the elaboration of TAI.

A real time realization of UTC(CH), called UTC(CH.R), is generated by a predictive steering of the free running hydrogen maser via a DDS (Direct Digital Synthesizer) [4], [5]. Every day a new rate correction is programmed, based on a prediction of UTC(CH) projected from the last computed epoch [3]. Figure 2 shows the daily values of UTC(CH).R)-UTC(CH) over an interval of 9 months. The deviation of UTC(CH.R) from UTC(CH) is 1.3 ns RMS.

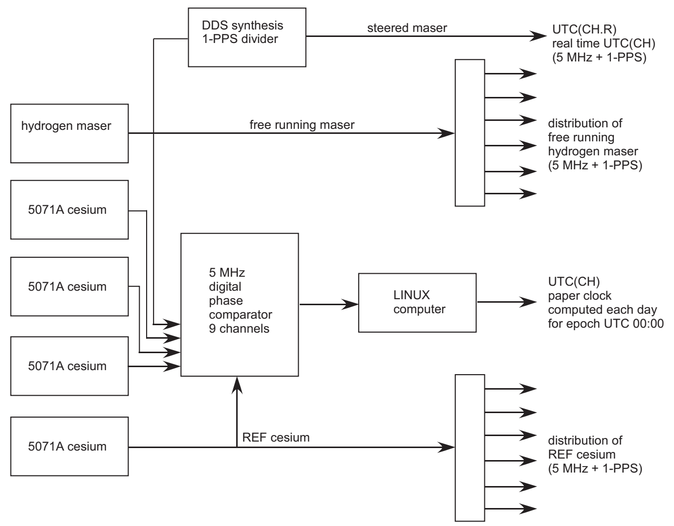

Fig. 1. Simplified block diagram of the T&F Lab atomic clocks ensemble and reference signals distribution system.

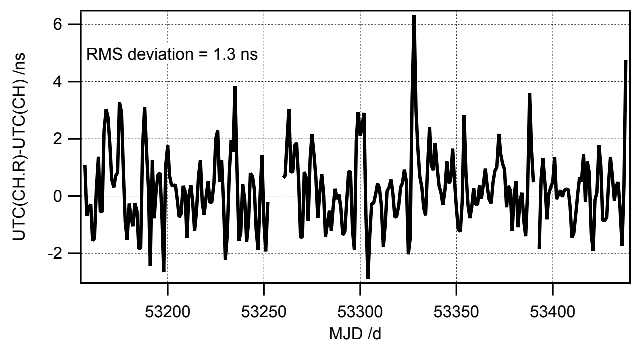

Fig. 2. Recording of UTC(CH.R)-UTC(CH) from MJD 53157 to MJD 53438.

III. Calibration of remote comparison links

Two GPS geodetic time receivers (Ashtech ZXII3T) are in operation at antenna sites WAB1 and WAB2 located on the roof of the new METAS building. The WAB1 receiver is driven by the reference cesium beam clock while the receiver WAB2 is driven by the free running hydrogen maser.

A simplified block diagram of the T&F Lab remote comparison links is shown on Figure 3 with mention of the site name and of the reference atomic clock for the TWSTFT station and for each GPS receiver.

The RINEX files from both receivers are processed by

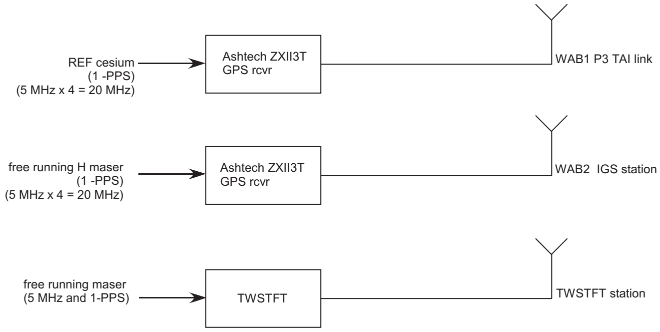

Fig. 3. Simplified block diagram of T&F Lab international remote comparison links.

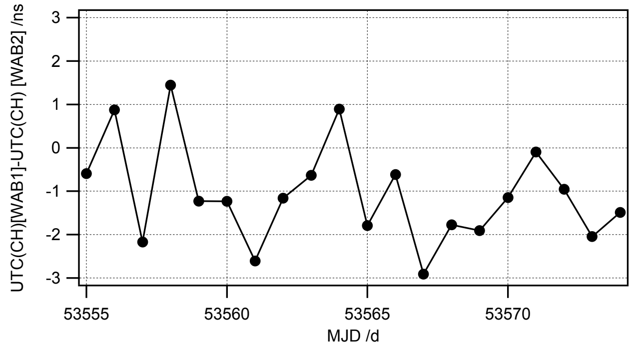

Fig. 4. Comparison of WAB1 vs WAB2 via P3 common view processing after independent differential calibration of each GPS receiver in collaboration with BIPM. The discrepancy between the two independent calibrations is 1 ns.

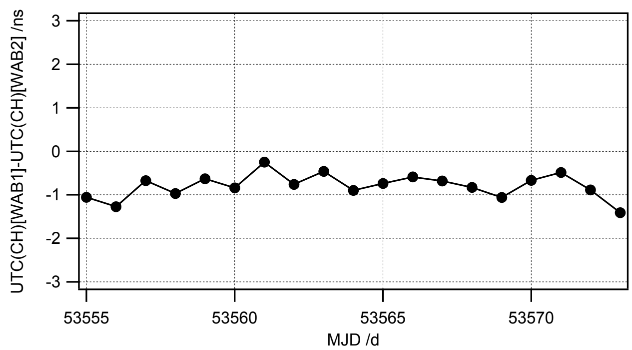

Fig. 5. Comparison of WAB1 vs WAB2 via geodetic carrier phase processing. A calibration constant of +77 ns is added to match the P3 differential calibration.

the CODE geodetic processing center of the Astronomical Institute of University of Bern (AIUB) [1]. In addition WAB2 has been recently declared official IGS geodetic station. In the near future, therefore, WAB2 will be included in the standard IGS time products.

In parallel to the geodetic processing, the RINEX files are translated into CGGTTS files and sent to BIPM for the P3 GPS common-view processing and the elaboration of TAI.

At the end of 2004 both WAB1 and WAB2 receivers were calibrated in the course of a differential calibration trip organized by BIPM for TAI P3 common-view time comparisons. In a zero baseline measurement, the discrepancy between the two links is 1 ns with a 1 ns standard deviation as shown on Figure 4. This result is interesting because the discrepancy between two co-located and independently calibrated GPS receivers can be viewed as a good estimation of the uncertainty associated with the calibration procedure.

Note that WAB1 and WAB2 are driven by two independent atomic clocks which implies that the comparison of Figure 4 is actually given by

$$[(C_1 - G_1) - (C_1 - H)] - [(C_2 - G_2) - (C_2 - H)] \quad (1)$$

where C_1 is the clock driving WAB1, C_2 is the clock driving WAB2, G_1 is GPS time as seen through the calibrated link WAB1, G_2 is GPS time as seen through the calibrated link WAB2, and H is the paper time scale UTC(CH). Therefore the calibration bias and the measurement noise shown on Figure 4 include not only the uncertainty on the differential calibration of the receivers and the noise of the remote comparison via GPS, but also the noise and calibration bias associated with the coaxial cables, the signal distribution electronics, the multi-channel time comparison system and the UTC(CH) time scale computation algorithm that generates the differences $C_1 - H$ and $C_2 - H$.

On the other hand the geodetic processing time transfer (GeTT) processing is not calibrated for absolute time. Figure 5 shows the zero-baseline comparison WAB1 vs WAB2 via GeTT processing after calibration against the P3 link. The comparison of Figure 4 versus Figure 5 shows that the GeTT processing is significantly less noisy than the P3 processing. Note however that our in house P3 processing is not optimal and the noise could be reduced if a better filtering of the GPS noise were applied.

On the other hand the new TWSTFT station, reported below, has not yet been calibrated for absolute time. METAS intends to participate to the TWSTFT European calibration campaing planned for the end of 2005.

IV. TWSTFT LINK

In 2004 a Two Way Satellite Time and Frequency Transfer (TWSTFT) station was built at T&F Lab. The station became fully operational at the end of 2004 and now participates on a regular basis in the measurement sessions of the TWSTFT community. Figure 6 shows the TWSTFT antenna located on the roof of the new METAS building.

The validation phase of the TWSTFT-setup started at the beginning of 2005. Figure 7 shows a preliminary calibration obtained by comparing the UTC(CH)-UTC(PTB) experimental TWSTFT data with the time scale data published by BIPM in Circular T.

The TWSTFT-station is based on a two-channel *SATRE* modem from *TimeTech* with an internal time interval counter. This part of the station is kept in an environment where the temperature is stabilized to better than 1 K. The cable length for the IF signals from the *SATRE* modem to the up/down

Fig. 6. Photograph of the TWSTFT antenna located on the roof of the new METAS building.

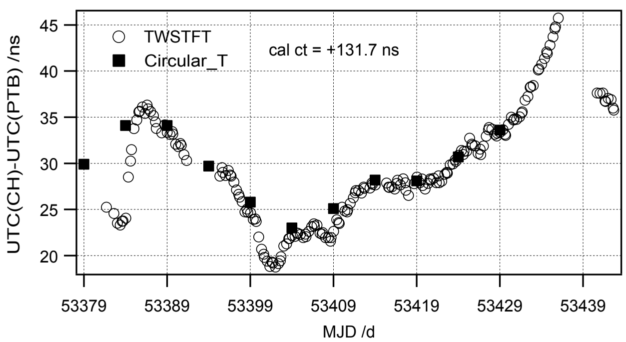

Fig. 7. Preliminary calibration of the TWSTFT link obtained by comparison of the UTC(CH)-UTC(PTB) TWSTFT data with the UTC(CH)-UTC and UTC(PTB)-UTC data computed by BIPM and published in Circular T.

converter is 30 m and lies entirely inside the building. The up/down converter is installed under the roof of the building, only a few meters apart from the antenna dish. This setup has the advantage that neither the cables for the IF signals, nor the converter are exposed to major temperature variations. The antenna dish (Figure 6) has a diameter of 1.8 m and a gain of 45 dBi.

The nearby *Gurten* hill limits the visibility of satellites at low elevation angles as illustrated schematically on Figure 8. Until recently the transatlantic TWSTFT measurements were carried out over the *IntelSat 903* satellite (orbit longitude 34.5° W). Since May 5, a new satellite is used: *IntelSat 707* (orbit longitude 53° W). With an azimuth of 247.5° and an elevation angle of 11.5° the local direction of the new satellite is at the limit of visibility as shown on Figure 8.

The TWSTFT-station at METAS was designed for fully automated operation in order to allow unattended participation to the scheduled measurement sessions. Automation encompasses the control of the hardware, the acquisition of the raw-data and the data processing. The SATRE-modem takes care of the control of the main part of the hardware, the data processing and archiving are controlled by separate pieces of equipment.

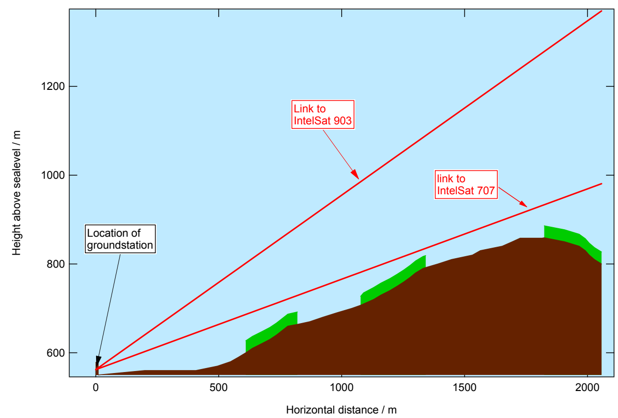

Fig. 8. Schematic view of the Gurten hill (860 m) that limits the observable satellite elevation angle at the antenna location.

The 1-s raw-data, as measured by the modem, are buffered in a *National Instrument* real time module. The same device is also responsible for collecting and buffering meteorological data. From this temporary buffer, both measured time delays and environmental parameters are transferred to the TWSTFT server, where they are archived in a SQL data base. Storage of the huge amount of raw data in a data base structure offers the advantage that the results from previous sessions can easily be retrieved by simple SQL requests. Regarding compilation of the results to the ITU format, the TWSTFT server fetches input data from the database and publishes the ITU formatted file on a public FTP-server.

V. New NTP Stratum 1 Server Setup

Up to now the NTP public server *ntp.metas.ch* was not located in the METAS building, for network security reasons, and its time source was a HBG radio controlled clock. This NTP server setup was not convenient because of unreliable radio reception at the server location.

In the new NTP server setup the NTP servers and the time sources are both located in the METAS buildings. However network security rules oblige the servers to be located a secure room located a hundred meters away from the T&F Lab which provides the time sources. To bridge the gap it was decided to send an IRIG-B signal from the T&F Lab to the server room via coaxial cables.

At the T&F Lab location, three independent IRIG-B Accurate Time Sources (IATS) are operated. Each IATS contains a computer, a quartz master clock locked to the reference 1-PPS signal of an atomic clock, an IRIG-B 1 kHz AM time code generator, and a HBG radio-synchronized time receiver. The IRIG-B time code output is generated from the master clock. The time offset between the atomic clock 1-PPS and the master clock 1-PPS is programmable. This makes possible the calibration and the adjustment of the master clock outputs (1-PPS and/or IRIG-B code) versus UTC(CH).

The HBG time receiver is necessary to acquire calendar time after a reset of the system because the 1-PPS from the atomic clock contains the precise fractional second time information but lacks the calendar time information. Moreover, the HBG time receiver is used as a surveillance clock. An alarm is generated if the difference between the master clock and the surveillance clock is larger than a preset limit. The accuracy of the HBG surveillance clock is $\pm$ 1 ms.

At the server location, on the other hand, each NTP server contains an IRIG-B receiver with a 1-PPS calibration output. The programmable time offset of each IATS time source is adjusted so that the 1-PPS calibration output of the corresponding NTP server matches UTC with a $\pm$ 1 μs accuracy. This calibration procedure compensates both the code delay and the coaxial cable delay. For better reliability each stratum 1 NTP server is peered with the other two.

The new setup is presently under test in the T&F Lab. Figure 10 shows typical NTP server download outputs in answer to a *ntpd peers* request. The column *offset* indicates the time offset of each server in ms as compared to the local clock of the server that sent the *ntpd peers* request. The upper table shows the response of the 3 IATS controlled servers as seen from the T&F Lab local server. The IATS NTP servers bear the *.GPS. refid* even though they are actually driven by an IRIG-B signal because of the reference clock driver used. The 3 IATS servers agree within a 15 μs interval however the dispersion does not reflect the accuracy of the IATS servers. As a matter of fact the dispersion stems from the local clock stability of the T&F Lab server. The lower table, on the other hand, shows 2 IATS servers as seen from the third IATS server. In this case the two IATS servers agree within the stated $\pm$ 1 μs accuracy because the third IATS server is stable enough to compare accurately the other two. On the other hand the IATS server sees the other two with a 21 μs offset. These typical examples show that although it is possible to calibrate the hardware reference clock inside each IATS locked stratum 1 NTP server with an accuracy of $\pm$ 1 μs, the actual accuracy of the software time distributed by each server across the network depends strongly on the jitter and asymmetries of the network transmission. The new NTP server setup will be commissioned later this year and made available on the existing domain name *ntp.metas.ch*.

VI. Calibration and Measurement Capabilities

On April 22nd 2005 EUROMET has published the Calibration and Measurement Capabilities (CMC's) declared by 10 countries (Austria, Germany, Hungary, Italy, The Netherlands Sweden, Slovenia, Switzerland, United Kingdom). The declaration of CMC's by NMI's is part of the implementation of the Mutual Recognition Arrangement (MRA) set up by the CIPM (*Comité International des Poids et Mesures*). The goal is to establish an equivalence between the calibration certificates issued by different NMI's and to make possible the mutual recognition of the certificates. The MRA has now been

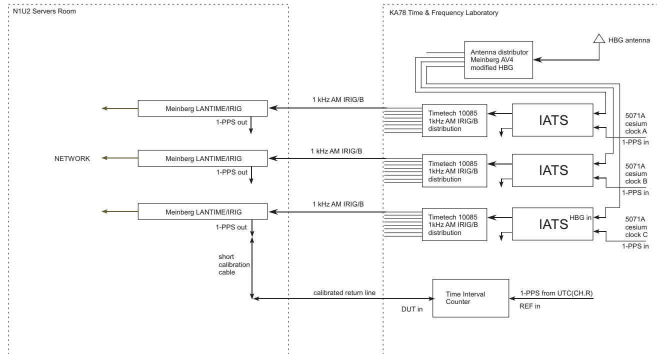

Fig. 9. Block diagram of the new NTP server setup.

remote	refid	st	t	when	poll	reach	delay	offset	jitter
*GENERIC(0)	.HBG.	0	l	22	64	377	0.000	-0.015	0.105
ACTS_PTB(0)	.TDS.	0	l	6	36h	376	0.000	1.320	0.033
+GENERIC(1)	.DCF.	0	l	34	64	377	0.000	0.939	3.474
-u-216-39-01.met	.GPS.	1	u	44	64	377	0.512	0.875	0.070
+u-216-39-02.met	.GPS.	1	u	42	64	377	0.518	0.799	0.110
-u-216-39-03.met	.GPS.	1	u	13	64	377	0.503	0.852	0.078

remote	refid	st	t	when	poll	reach	delay	offset	jitter
LOCAL(0)	LOCAL(0)	12	l	27	64	377	0.000	0.000	0.004
+GENERIC(0)	.GPS.	0	l	4	64	377	0.000	-0.026	0.040
oPPS(0)	.PPS.	0	l	61	64	377	0.000	-0.023	0.037
-blg-ka78-3.meta	.HBG.	1	u	62	64	377	0.525	-0.730	0.141
+u-216-39-02.met	.GPS.	1	u	56	64	377	0.826	0.021	0.036
+u-216-39-03.met	.GPS.	1	u	14	64	377	0.831	0.021	0.027

Fig. 10. Typical NTP server tabular outputs in answer to a *ntpd peers* request. The upper table shows the stability of the three IATS servers as seen from the T&F Lab local server. The lower table shows the stability of two IATS servers as seen from the third IATS server.

signed by the representatives of 64 institutes from 45 Member States, 17 Associates of the CGPM, and 2 international organizations and covers a further 96 institutes designated by the signatory bodies. The CMC's are published by BIPM on *http://kcdb.bipm.org/appendixC/*.

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