A resilient secondary realization of UTC(PTB) using a passive hydrogen maser

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***Summary*—This paper describes the design and operation of an additional, autonomous implementation of UTC(PTB). The realization of this time scale is set-up geographically separated from the primary UTC(PTB) realization. It is based on a passive hydrogen maser, steered via a custom algorithm by either the PTB's caesium fountains or the BIPM product UTCr. Using a multi-site approach increases the resilience of UTC(PTB) in case of a major accident and allows for additional testing possibilities.**

***Keywords*—time scale; UTC; passive hydrogen maser; steering**

I. INTRODUCTION

Critical infrastructure such as telecommunications, broadcasting, energy and finance all rely on accurate timing based on a national standard time scale. In Germany this time scale is provided by the Physikalisch-Technische Bundesanstalt (PTB) and is an implementation of the Coordinated Universal Time (UTC) called UTC(PTB). Since 2010 UTC(PTB) has been realized using an active hydrogen maser (AHM) steered in frequency via a phase micro stepper based on the signal of PTB's primary caesium fountain clocks [1,2]. This realisation is made in duplicate based on two different AHMs which are located in the same building. To improve the resilience of UTC(PTB) a backup time scale is implemented, called UTC2(PTB), which is generated in a laboratory in a separate building, roughly 300 m from the UTC(PTB) lab. This time scale is realized using a passive hydrogen maser (PHM), which is also steered by a microstepper. During normal operation, this steering process is based on the PTB's caesium fountain clocks [2]. However, to achieve fully autonomous operation from the UTC(PTB) lab, steering can also be based on the BIPM product UTCr [3].

II. UTC2(PTB) TIME SCALE GERNEATION SETUP

Both laboratories are temperature and humidity controlled and are connected via optical fibre and coaxial RF cables. The masers and microstepper have backup batteries to ensure operation in case of a blackout.

The latest PHM by Vremya-CH, the model VCH-1008M, is used as a basis for the time scale. Typical for a hydrogen maser, it provides good short-term stability. Additionally, this model shows a very stable frequency drift even over months of operation. The maser is regularly compared to various atomic clocks via a time interval counter (TIC). One of these atomic clocks is the AHM driving UTC(PTB), whose frequency is compared to the PTB's caesium fountain clocks. For steering the PHM, a SDI Spectra Dynamics HROG-5 phase and frequency offset generator is employed. The 1PPS output of the HROG-5 is called UTC2(PTB). UTC(PTB) is transferred to the UTC2(PTB) laboratory via a calibrated optical fibre connection. This allows for continuous comparison of the two time scales via a TIC. UTC(PTB) and UTC2(PTB) are both steered towards UTC, which prevents them from drifting apart over long time periods.

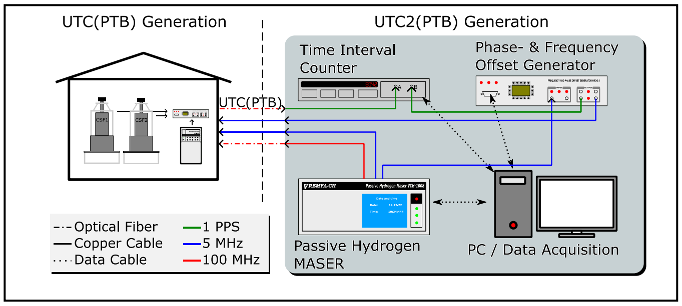

Figure 1. Setup of the UTC2(PTB) time scale generation

STEERING ALGORITHM

To generate the time scale a steering value Δf is applied to the 5 MHz signal from the base clock via the microstepper. This steering value is calculated as the sum over multiple fractional frequency deviations as

$$\Delta f = \Delta f_{Ref} + \Delta f_d + \Delta f_{Offset} + \Delta f_{Drift}.$$

The individual contributions account for the frequency difference to a reference clock, the difference between EAL and TAI, the phase offset of the timescale to UTC and the frequency drift of the PHM [1], respectively.

The role of the reference clock can e.g. be filled by one or multiple primary clocks in the laboratory, or the latest UTCr release. Differentiating the phase between the reference and the base clocks, gives the fractional frequency deviation Δf_{Ref}. In case UTCr is used as a reference the steering contribution is calculated as

$$\Delta f_{Ref} = \frac{d}{dt}(Ref - Base).$$

Here, the phase values are not available immediately. The fractional frequency deviations computed from the latest UTCr publication are therefore averaged to produce the final Δf_{Ref} value, used for the steering algorithm.

III. SYSTEM PERFORMANCE

A. TIME SCALE SIMULATION

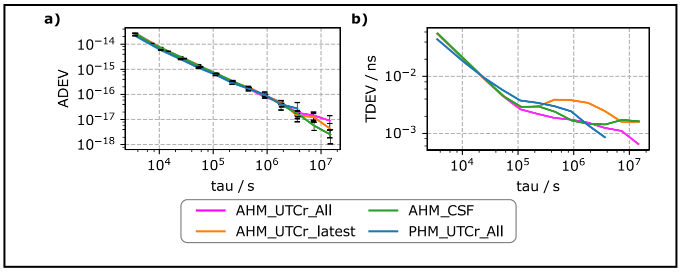

Figure 2: Time scale simulation results for steering with UTCr and the PTB's CSFs. The TS represented by the magenta and blue curves are steered towards UTCr, using all available data points from the latest UTCr release while the TS represented by the orange curve

To evaluate the performance of the UTCr steering algorithm, timescales were simulated using historical clock data. The development of a time scale TS_{Sim} towards a comparison time scale TS_C can be calculated by first determining the fractional frequency offset f_C of TS_C to the base clock. The steering values Δf are then added and the sum multiplied by a time-step ΔT. The phase difference $TS_C - TS_{Sim}$ at the time i can be calculated by performing multiple steps j.

$$(TS_C - TS_{Sim})_i = (TS_C - TS_{Sim})_0 + \sum_j \left(f_{C,j} + \Delta f_j\right) \cdot \Delta T$$

$(TS_C - TS_{Sim})_0$ is the phase difference at time 0.

Figure 2 shows the results of a 790 d simulated time scale based on the AHM H9, driving UTC(PTB), compared to UTC as published in the Circular T. The historical data are from the time span between the MJDs 59000 and 59790. Also shown are results from a TS based on the PHM H13 and steered towards UTCr.

B. RUNNING THE TIME SCALE

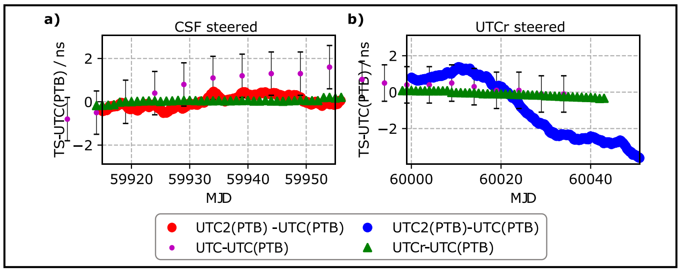

Figure 3: Timeline of the phase differences between UTC2(PTB) and UTC(PTB), measured via TIC every 20 s. The red and blue data points are one hour averages of UTC2(PTB) steered with via the CSFs and UTCr respectively.

The UTC2(PTB) was run first with steering by the PTB's CSF Clocks and later by steering towards UTCr. The CSF steering setup was run between MJDs 59915 and 59955 and the UTCr steering setup from MJD 60000 until 60050. The phase timelines and the time and frequency statistical analysis results of these setups are shown in figures 3 and 4.

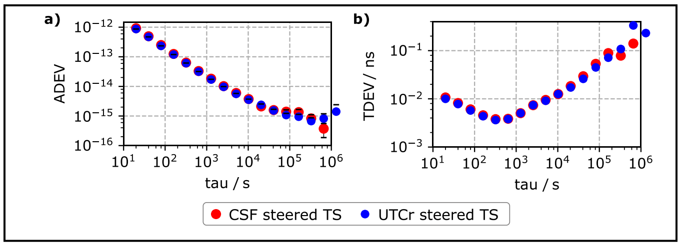

Figure 4: Allan deviation and time deviation calculated from the phase data shown in figure 3.

IV. CONCLUSIONS

The new UTC2(PTB) timescale is currently running fully autonomous from UTC(PTB) as intended. The performance when steering the TS towards UTCr is comparable to the steering using the PTB's CSFs and to the calculated data. An increasing offset of UTC2(PTB) compared to UTC(PTB) can be observed in figure 3 b). This was most likely caused by an error in the steering algorithm script which caused Δf_{Drift} to be overestimated. This resulted in an over-steering of the TS. Since the script has been corrected the offset is decreasing.

Going forward, additions such as an GNSS receiver could form the new laboratory into a complete and independent time lab.

REFERENCES

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