Austrian contributions to the realization of time systems

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Abstract

The realization of accurate time scales is an important task for a country and worldwide because it is needed for many applications, such as financial transactions or positioning. The Federal Office of Metrology and Surveying (BEV) is in charge of the realization of the Coordinated Universal Time (UTC) for Austria and it is contributing to the realization of UTC globally. On the other hand, TU Wien and BEV are involved in the determination of UT1 with Very Long Baseline Interferometry (VLBI) observations. UT1 corresponds to the Earth rotation angle and is indispensable for any kind of satellite-based positioning and navigation. The difference between both time scales does not exceed 0.9 second because leap seconds are introduced in UTC to keep the difference below one second.

Keywords: Atomic Time, Universal Time, Earth Rotation

Kurzfassung

Die Realisierung von Zeitsystemen ist eine wichtige Aufgabe für ein Land und weltweit, da eine genaue Zeit für viele Aufgaben gebraucht wird, wie zum Beispiel Finanztransaktionen oder Positionierung. Das Bundesamt für Eich- und Vermessungswesen (BEV) ist mit der Realisierung der Coordinated Universal Time (UTC) für Österreich beauftragt und das BEV trägt auch zur globalen Realisierung von UTC bei. Andererseits sind die Technische Universität Wien (TU Wien) und BEV involviert in der UT1-Bestimmung mit dem Verfahren der Very Long Baseline Interferometry (VLBI). UT1 ist mit dem Winkel der Erdrotation verknüpft und unabdingbar für satellitenbasierte Positionierung und Navigation. Die Differenz zwischen diesen beiden Zeitskalen wird nicht größer als 0.9 Sekunden, weil immer rechtzeitig vorher eine Schaltsekunde bei UTC angebracht wird.

Schlüsselwörter: Atomzeit, Universalzeit, Erdrotation

1. Introduction

For a long time only astronomic observations to stars, planets, and the Moon could provide sufficient accuracy for forming accurate time scales. Then in the middle of the 20th century, the technical progress of the development of frequency standards, which are based on atomic physics processes (atomic clocks), gave a good precondition for a new quality of time scales and could reveal the irregularity of Earth rotation. By this new quality of time measurement, the definition of the second in the International System of Units (SI) could be revolutionized in 1967 on one hand and on the other hand, a uniform stable time scale, the International Atomic Time (TAI), could be launched in 1971. Additionally, the Coordinated Universal Time (UTC) has been implemented as new time scale. It guarantees the stability of an atomic time scale and is adjusted to the rotating Earth. In irregular intervals leap seconds are added according to the difference between the Earth rotation angle as defined with Universal Time (UT1) and UTC, so that the difference between these two amounts to a maximum of 0.9 s.

In this paper, we present Austrian contributions to the realization of UTC and UT1. In particular, Section 2 describes the observation of UT1 with geodetic Very Long Baseline Interferometry (VLBI) observations, and Section 3 provides an overview of the Austrian contribution to the national and international realization of UTC. Finally, we provide some information on leap seconds.

2. Observation of UT1 with Very Long Baseline Interferometry (VLBI)

The Universal Time 1 refers to the Greenwich hour angle of the mean Sun plus 12 hours corrected for polar motion (see Figure 1). Since the movement of the mean Sun in the equator with respect to the stars is exactly known, stars could be observed instead of the Sun.

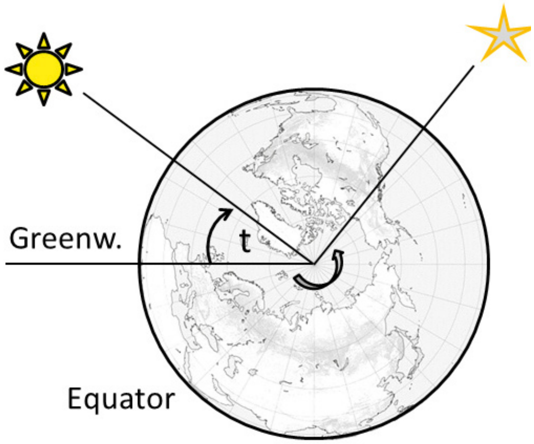

Fig. 1: UT1 refers to the Greenwich hour angle t of the mean Sun plus 12 hours. "1" denotes the correction for polar motion. Since the right ascension of the mean Sun with respect to the stars is exactly known, stars could be observed instead of the Sun.

Today, we do not observe stars but we use VLBI with radio telescopes to observe quasars, extragalactic radio sources billions of light years away. This measurement technique is a thousand times more accurate than the classical observations to stars. Essentially, geodetic VLBI is based on the observation of the difference in arrival time of signals from quasars at two sites which are equipped with atomic clocks ([1], Schuh and Böhm, 2013).

Internationally, geodetic VLBI activities are organized by the International VLBI Service for Geodesy and Astrometry (IVS; [2], Nothnagel et al., 2017), a Service of the International Association of Geodesy (IAG) and the International Astronomical Union (IAU). The Federal Office of Metrology and Surveying (BEV) and TU Wien are forming a joint analysis center of the IVS, and they are involved in scheduling observations, correlation, and the analysis of VLBI observations to determine geodetic products (see Böhm et al, this issue). The IVS organizes two different types of observing session. On the one hand, there are about three 24 hour sessions per week with six to eight stations participating to derive various geodetic parameters like Earth orientation parameters (nutation, polar motion, UT1-UTC) or station coordinates with highest accuracy and a latency of 10 to 14 days. UT1-UTC, which is essentially the difference between the Earth rotation angle and atomic time, can be derived with an accuracy of about 5 microseconds from these sessions, which corresponds to about 2-3 millimeters at the Earth surface.

Then, on a daily basis, there are 1 hour long so-called Intensive sessions with two or three stations, ideally with a long east-west baseline. UT1-UTC can be derived with an accuracy of about 20 microseconds (less than one centimeter at the Earth surface) from these sessions and is already available one or two days after the observation. This aspect is important because UT1-UTC cannot be predicted with sufficient accuracy over longer time spans and Global Navigation Satellite Systems (GNSS), such as GPS and Galileo, require exact information about UT1-UTC from VLBI for positioning and navigation purposes. Thus, it is essential that VLBI delivers these parameters with high accuracy and short latency.

As IVS analysis center, BEV and TU Wien are analyzing VLBI sessions from the IVS, thereby routinely providing UT1-UTC next to other parameters. We submit our estimates to the International Earth Rotation and Reference Systems Service (IERS) for combination. Additionally, we are developing and organizing special Intensive sessions such as European Intensives on the baseline Wettzell (Germany) to Santa Maria (Azores) and we are scheduling INT9 sessions between Wettzell and AGGO in Argentina.

3. Austrian realization of UTC at BEV

The Bureau International des Poids et Mesures (BIPM) in Sèvres close to Paris organizes the international network of time links to compare local realizations of UTC in contributing laboratories and uses them in the calculation of TAI and UTC. This network of time links used by the BIPM relies on observations of GNSS satellites and on two-way satellite time and frequency transfer (TWSTFT). TAI and UTC are formed monthly by a combination of data from about 500 atomic clocks operated by more than 80 timing centres which maintain a local UTC(k). BEV participates in these comparisons with its three atomic clocks (two caesium standards and one hydrogen maser, see Figure 2) and realizes UTC(BEV) valid as official time scale for Austria.

Most time links are based on GPS satellite observations and the data from multi-channel dual-frequency GPS receivers are regularly used in the calculation of time links, in addition to that acquired by a few multi-channel single-frequency GPS time receivers. For those links realized using more than one technique, one of them is

Fig. 2: Laboratory with atomic clocks at BEV

considered official for UTC and the others are calculated as back-ups. GPS links are computed using the method known as "GPS all in view", with a network of time links that uses the *Physikalisch-Technische Bundesanstalt (PTB)* as a unique pivot laboratory for all the GPS links. GPS data are corrected using precise satellite ephemerides and clocks produced by the International GNSS Service (IGS). The links between laboratories equipped with dual-frequency receivers providing Rinex format files are computed with the Precise Point Positioning (PPP) method. GLONASS links are computed using the "common-view" method. GLONASS data are corrected using the IAC ephemerides SP3 files and the CODE ionospheric maps. A combination of individual TWSTFT and GPS PPP links and of individual GPS and GLONASS links are currently used in the calculation of TAI and UTC.

Once a month the BIPM informs the individual institutes in the publication *Circular T* about the deviations of UTC(k) to UTC (see Figure 3). By occasional corrections the deviations of UTC(BEV) to UTC are always kept smaller than 100 ns.

Additionally the weekly rapid solution UTCr is published by the BIPM. It allows weekly access to a prediction of UTC for about 50 laboratories which also contribute to the regular monthly publication. However, the final results published in *Circular T* remain the only official source of traceability to the SI second for participating laboratories.

4. Leap seconds

Due to tidal friction, Earth rotation is slowing down. As a consequence, leap seconds have to be inserted in UTC to keep the difference between UTC and UT1 smaller than one second. The last leap second had to be set at the end of 2016 (see Figure 4). In general, leap seconds cannot be predicted, but UT1-UTC needs to be observed with VLBI. It should be mentioned that there is an ongoing discussion about the abolition of leap seconds, but no decision has be taken.

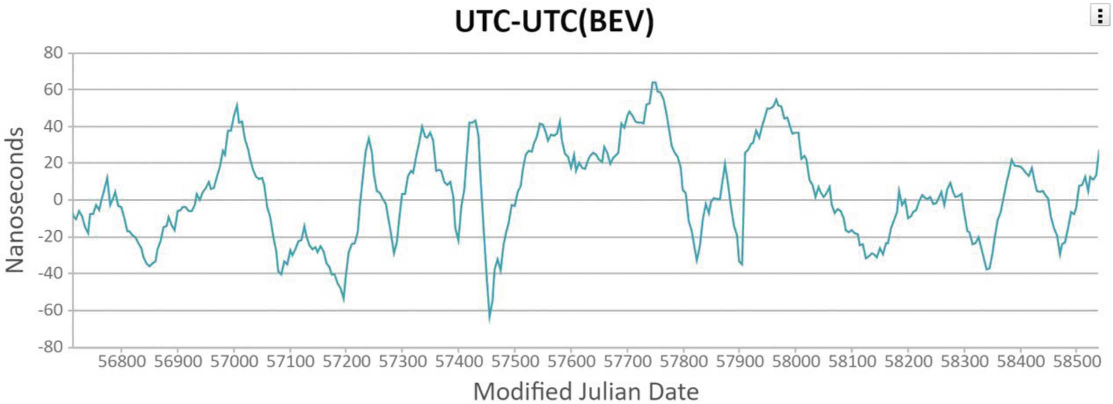

Fig. 3: UTC minus UTC(BEV) in nanoseconds as provided in Circular T *over the past five years (2014 - 2019) [from https://www.bipm.org/en/bipm-services/timescales/time-ftp/Circular-T.html]*

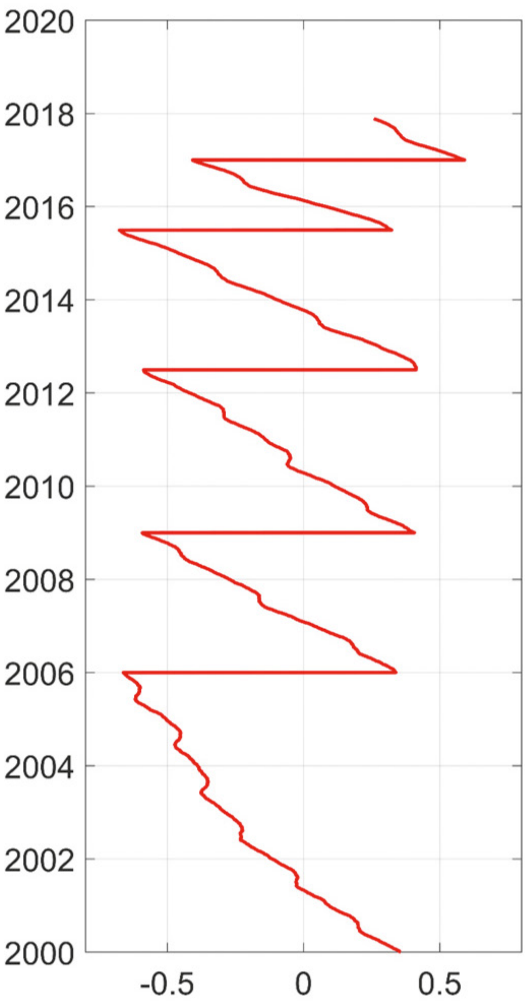

Fig. 4: UT1-UTC in seconds as observed with VLBI and leaps seconds since 2000.

5. Summary and outlook

BEV and TU Wien are making very valuable contributions to the realization of UTC and UT1, at a national and an international level. The reliable realization of those time scales is indispensable for a large variety of tasks. In future, it will certainly be important to also follow modern developments such as new optical clocks or new VLBI observing scenarios.

References

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