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Current status of the UTC(NIM) and its application in metrology

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Abstract

The UTC(NIM) maintained by the National Institute of Metrology (NIM) in China is one of the physical realizations of Coordinated Universal Time (UTC) and serves as the foundation of China's time and frequency metrology. In recent years, due to the integration of higher-performance hydrogen masers into the clock ensemble, optimization of the UTC(NIM) prediction and steering methods, and enhancements in comparison link performance, the time difference between UTC(NIM) and UTC has reduced from ±5 ns to ±3 ns since 2020. This paper presents the current performance of UTC(NIM) and its application in time and frequency metrology.

1. Introduction

Time and frequency metrology forms the foundation of modern technology, communication, navigation, and scientific research. Coordinated Universal Time (UTC) is the global standard for time synchronization. UTC is a derived time scale based on the International Atomic Time (TAI), calculated monthly by the International Bureau of Weights and Measures (BIPM) using data from over 80 global time laboratories. The UTC(k) generally maintained by National Metrology Institutes (NMIs) can serve as a SI-traceable reference for time interval and frequency measurements. The time difference and frequency stability of UTC(k) relative to UTC are two key indicators used to characterize the its performance.

UTC(NIM) is one of the physical realizations of UTC and serves as China's national primary standard for time and frequency, maintained by the National Institute of Metrology (NIM) in China. As a cornerstone of time and frequency metrology system, the UTC(NIM) has significantly improved since the addition of higher-performance hydrogen masers into NIM's clock ensemble. Some improvements of time scale algorithm led to the better predictability of the hydrogen masers Additionally, the two Global Navigation Satellite System (GNSS) receivers developed by NIM are optimized to enhance the stability of time and frequency remote comparisons between UTC(NIM) with UTC.

This paper provides a brief overview of the current status of UTC(NIM) and its applications in metrology, while also looking ahead to its future development.

2. Current status of UTC (NIM)

The current time keeping clock ensemble maintained by NIM consists of 11 hydrogen masers and 1 cesium atomic clock. In 2014, the algorithm of UTC was modified that enhanced the influence of the hydrogen masers[1]. Then, an high-performance hydrogen maser is selected as the master clock in our laboratory. The laboratory temperature is controlled with in ±0.5℃ variation avoid the abnormal jump of the hydrogen clock. The clocks participating in UTC are linked by the GNSS time and frequency comparison link.

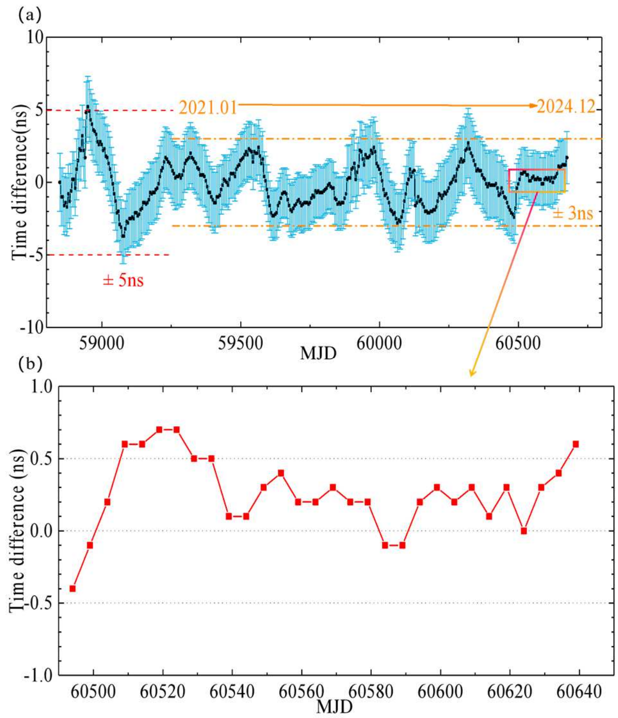

Figure 1. Time difference between UTC and UTC(NIM). (a) is the time of difference of [UTC-UTC(NIM)] form January 2020 to December 2024. (b) is the time difference of UTC-UTC(NIM) from July 2024 to November 2024, which continuously maintained at less than 1 ns level about 140 days.

The time difference between UTC(NIM) and UTC is controlled within the nanosecond level, as shown in Figure 1. From 2020 to 2024, the time difference decreased from ±5 ns to ±3 ns, and since 2021, it has consistently maintained a time difference of ±3 ns. In 2024, the sub-nanosecond level time scale accounted for 66% of the total, with a continuous stable period of over 140 days. During this time, the maximum time difference from UTC was 0.7 ns.

The improvement in the performance of UTC(NIM) can be attributed to the following factors. Firstly, the addition of high-performance hydrogen masers has significantly boosted the system's performance. The stability of the hydrogen masers now reaches the E-16 level, offering excellent predictability. Secondly, random pursuit strategies for clock difference prediction, and multi-source-driven time scale control methods have been integrated into the timekeeping process. These approaches have strengthened the inter-comparison between clocks, enhanced clock anomaly detection, and greatly improved the accuracy and real-time performance of the local atomic clock ensemble[2, 3]. Thirdly ,We used the self-developed domestic GNSS receivers for the link calibration and the stability of the comparison link has been greatly improved .The A-class uncertainty of the time and frequency transfer comparison link has reached 0.2ns from 1ns. More stable transfer links have reduced the occurrence of abnormal clock deviation data, further enhancing the overall performance of UTC(NIM). Additionally, the frequency stability of UTC(NIM) has reached the E-16 level as shown in Table1, with the optimal frequency stability in 2024 achieving 3.8e-16 over a 5-day period.

Table 1. time and frequency stability of UTC(NIM) from 2020 to 2024

Time	Time stability/5d	Frequency stability/5d
2020	0.32 ns	1.28e-15
2021	0.14 ns	5.67e-16
2022	0.16 ns	6.83e-16
2023	0.23 ns	9.44e-16
2024	0.13 ns	5.27e-16

3. Application of UTC (NIM) in metrology

3.1 NIMDO Assistance in Realizing Traceability of UTC(NIM)

In conjunction with the GNSS transfer link, NIMDO has successfully realized the traceability of UTC(NIM) to provincial-level metrology testing institutions. NIMDO enables the comparison of remote time-frequency sources with the atomic time reference standard UTC(NIM) through GNSS. It facilitates the real-time calibration of remote time-frequency sources, ultimately achieving real-time synchronization with UTC(NIM). When using UTC(NIM) as the reference time, the remote end can replicate UTC(NIM) with a certain deviation (better than 10 nanoseconds in 90% of cases) and an associated uncertainty level (the deviation combined standard uncertainty is better than 5 nanoseconds).

NIMDO supports global navigation systems such as the Global Positioning System (GPS), GLONASS (Global Navigation Satellite System), BeiDou Navigation Satellite System (BDS), and Galileo. It also supports both code and carrier-phase measurements. The system can generate receiver-independent exchange formats (Rinex) and the International Committee for Time and Frequency Transfer (CGGTTS) time transfer standard format, along with real-time data (one data file is generated every 16 minutes). Additionally, it enables automatic upload and download of local data to and from remote servers, and facilitates comparison with other observation stations via real-time interactive data.

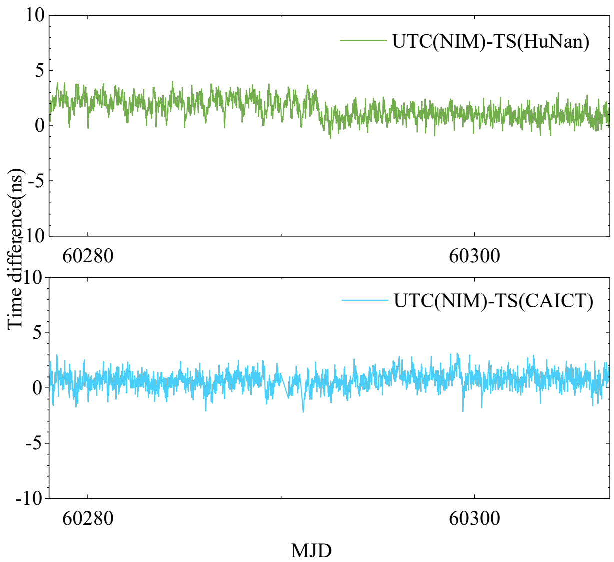

Figure 2. Time difference between UTC(NIM) and 2 demonstration points from November 30, 2023, to December 29, 2023.

The goal of NIMDO is to address the lack of time standards (time-keeping systems) in most local regions of China. Additionally, 15 demonstration points have been deployed, further extending the reach and application of UTC(NIM) in time frequency metrology. We chose 2 points Hunan Institute of Metrology and Testing, and the China Academy of Information (HuNan) and Communications Technology(CAICT) as the demo. As shown in Figure 2, from November 30, 2023, to December 29, 2023, NIMDO successfully calibrated the time scale of the observation stations, maintaining the time difference within ±10 ns relative to UTC(NIM).

3.2 Digital Metrology

With the digital transformation in the field of metrology, traditional calibration certificates are gradually being replaced by Digital Calibration Certificates (DCC). Nowadays，NIM has leveraged its existing time-keeping resources to establish a cloud platform for remote transmission and online traceability. By developing data communication protocols between time-frequency benchmarks and end applications, the Institute has built an integrated database for time-frequency value transmission and traceability. The system also supports the development of an online calibration method and application service system for time-frequency values, based on a specialized database. DCC certificates are generated using trusted and accurate timestamps (Time Stamp Authority, TSA) and digital certification (Certificate Authority, CA) technologies.

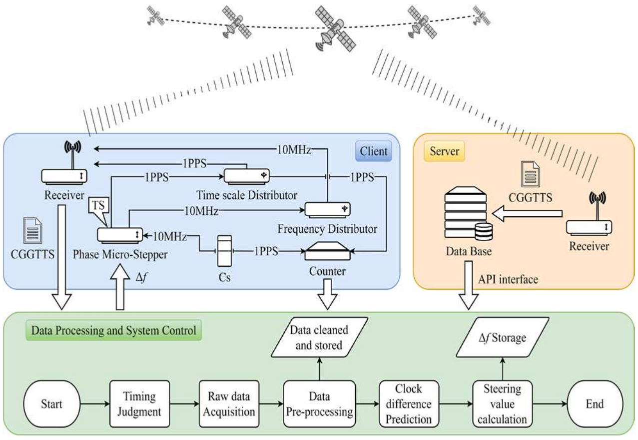

Figure 3. Time frequency remote traceability and online calibration system.

The time-frequency remote traceability and online calibration system is shown in Figure 3. The digital metrology system automatically compares the CGGTTS files uploaded by users (either manually or automatically) with the reference receiver CGGTTS files located at NIM[4]. It then calculates the time deviation between the user's time and the standard time UTC(NIM) and generates a DCC certificate that includes time deviations (both daily averages and 16-minute averages). Users can promptly download the corresponding certificate through the digital metrology system. This digital time-frequency metrology system improves the efficiency of metrology management and promotes data sharing and application.

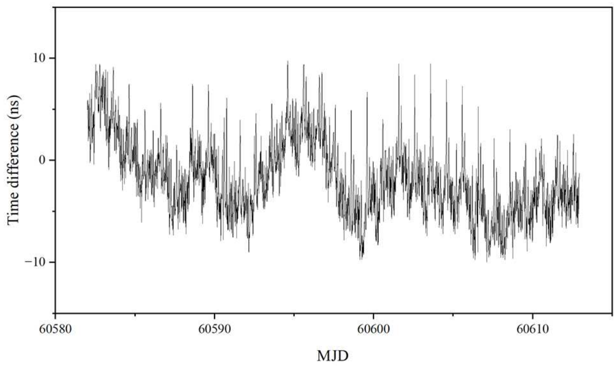

Figure 4. Time difference between UTC(NIM) and TS(FuJian) from DCC certificates

We have established a demonstration site for digital time-frequency metrology in Fujian Province. The Fujian Institute of Metrology and Testing used a receiver CGGTTS file to calibrate the local time scale TS(FuJian) with UTC(NIM) and generated DCC certificates . From September 29 to October 29, 2024 (MJD60582 to MJD60612) , the time difference ,as Figure 4 shown ,was maintained within ± 10 ns, and the local time scale remained stable at 1.7E-14 over a 1-day period.

4. Conclusion

UTC(NIM), as the core reference standard for time-frequency metrology in China, has gradually reduced the time deviation from UTC to within ± 3ns through optimization of clock group prediction and control algorithms, as well as improvements in receiver and comparison link methods. The next phase will focus on further enhancing the accuracy and real-time performance of atomic clock group analysis, expanding high-precision time-frequency links, and achieving comparisons between UTC and high-precision time-frequency links (such as fiber optics or GNSS).

With the promotion and application of NIMDO and digital time-frequency metrology, UTC(NIM) will play an even greater role in higher-precision and broader-range time-frequency metrology.

5. Acknowledgement

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