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Ensuring a Reliable National Time Scale UTC(KZ) as Critical Infrastructure of Kazakhstan

KazStandard modernized the state primary standard of the units of time and frequency and of the national time scale of the Republic of Kazakhstan, based on three passive hydrogen masers with automated UTCr-based steering

*KazStandard
Kazakhstan (KZ)*



The Challenge

Kazakhstan's critical infrastructure – telecommunications, energy grids, financial transactions, and transport systems – depends on precise time synchronization traceable to Coordinated Universal Time (UTC). As GNSS timing signals grow increasingly vulnerable to jamming and spoofing, a sovereign and resilient national time scale has become a strategic necessity. As a member of COOMET and a participant in the CCTF-K001.UTC key comparison, Kazakhstan needed a cost-effective solution to maintain UTC(KZ) within single-digit nanoseconds of UTC.

During an earlier period (2008–2018) in Kazakhstan's time metrology history, the national time scale UTC(KZ) relied on aging cesium clocks and deviated from UTC with an RMS of 832 ns and peak excursions exceeding 2.5 μ s. In December 2018, a power cable fire disabled the standard entirely, forcing Kazakhstan to suspend its contribution to international comparisons and data submissions to the International Bureau of Weights and Measures (BIPM). This compromised Kazakhstan's ability to provide a reliable national time reference, affecting sectors that require sub-100-nanosecond synchronization: 5G/LTE base stations (ITU 5G target: ± 30 ns), power-grid phasor measurement, GNSS validation, and financial timestamping.

The Solution

After 3 years of suspension of its time metrology activities, in 2021, the state primary standard of the units of time and frequency and of the national time scale of the Republic of Kazakhstan (hereafter, the Kazakhstan standard) was updated with a new time-and-frequency reference complex based on three passive hydrogen masers, including VCH-1008 (manufactured by Vremya-CH, Russia), thereby realizing the national time scale UTC(KZ). A novel automatic steering algorithm – a proportional-integral (PI) controller that approximates optimal linear-quadratic-Gaussian (LQG) control at a fraction of the computational cost – was developed and implemented to correct UTC(KZ) on a weekly basis using Rapid UTC (UTC_r) data published by the BIPM. The system is illustrated in **Figure 1**. This includes: (1) continuous phase comparison via the VCH-315M comparator at 1 Hz; (2) daily CGGTTS / RINEX data transmission to the BIPM via the GTR-55 multi-GNSS receiver; (3) automated weekly frequency correction of the VCH-317 synthesizer; (4) a custom monitoring software stack (UTC(KZ) Monitoring System v3.4) providing a real-time web dashboard, Telegram bot alerts, automated climate journals and PDF reporting. UTC(KZ) is the first national time scale fully based on passive hydrogen masers with automated UTC_r-based steering.

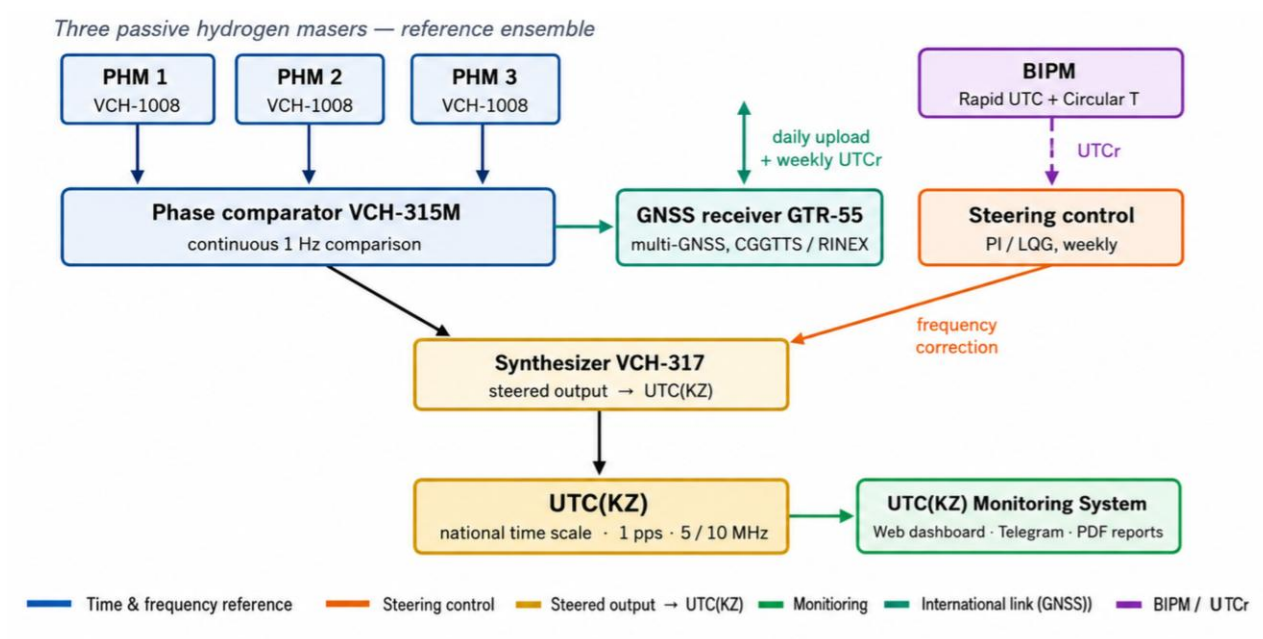


Figure 1. Functional schematic of the Kazakhstan standard for the realization of UTC(KZ).

This passive-maser configuration is unique. Out of 91 laboratories that contribute clocks to TAI (BIPM clock database, 2026), only two operate a passive H-maser as their sole primary reference – KazStandard (KZ) and the Danish Fundamental Metrology Institute (DFM, Denmark). Of these, KZ is the only one whose national time scale is realized by an ensemble of three passive masers with automated weekly UTCr-based steering (**Figure 2**).

A Quantifiable Impact

With the modernized Kazakhstan standard and BIPM Circular T data through 29 May 2026, several metrological milestones have been achieved (**Figures 3 and 4**): UTC(KZ) deviates from UTC with RMS = 2.44 ns and a maximum absolute time difference of 8.9 ns; this corresponds to an approximately 341-fold RMS reduction compared with the legacy cesium configuration. The realization and dissemination of the national time scale UTC(KZ) have continued without interruption since the restoration of BIPM Circular T reporting in June 2021. All three masers receive weight in the TAI computation, the combined KZ weight reaching 0.13 % in November 2025 (more than double its 2022 level) – a level sustained by only three of the thirteen passive-maser realizations worldwide. Even without external reference data, UTC(KZ) holds within 10 ns of UTC for up to three weeks, providing resilience against GNSS or UTCr outages – a critical property for national infrastructure.

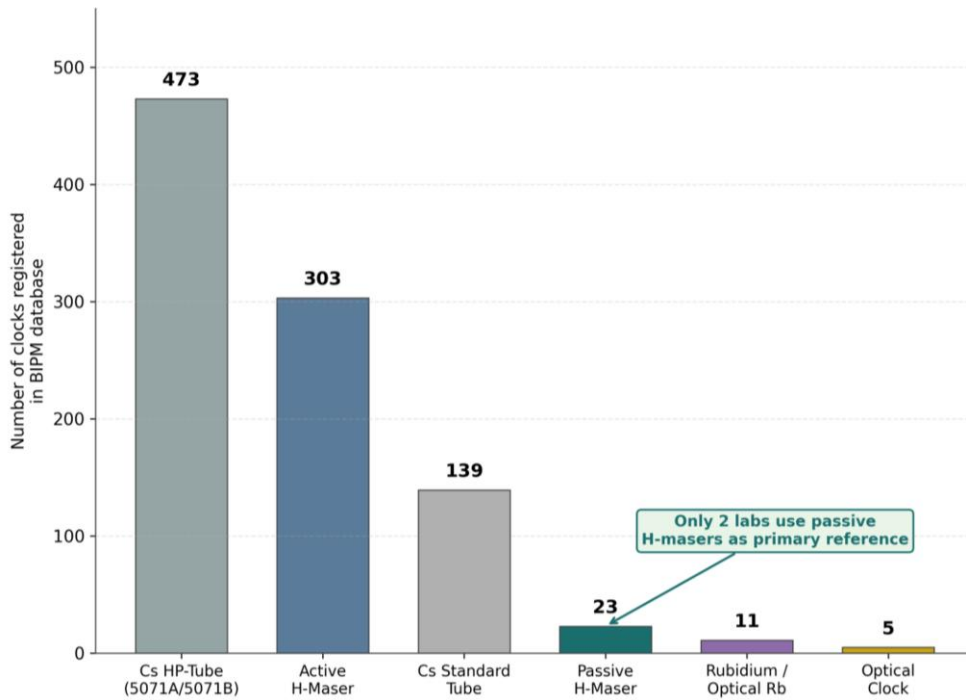


Figure 2. Clock inventory across 91 TAI contributing laboratories (BIPM clock database, 2026). Only two laboratories use passive H-masers as their sole primary reference: KazStandard (KZ, 3 × VCH-1008 Passive H-Masers) and DFM Denmark (DE, 1 × T45 pHMaser 1008 Passive H-Maser). KZ is the only one with an ensemble of three passive H-masers under automated UTCr-based steering. (Source: BIPM clock database (clocklab.csv, 2026); 91 laboratories contributing to TAI.)

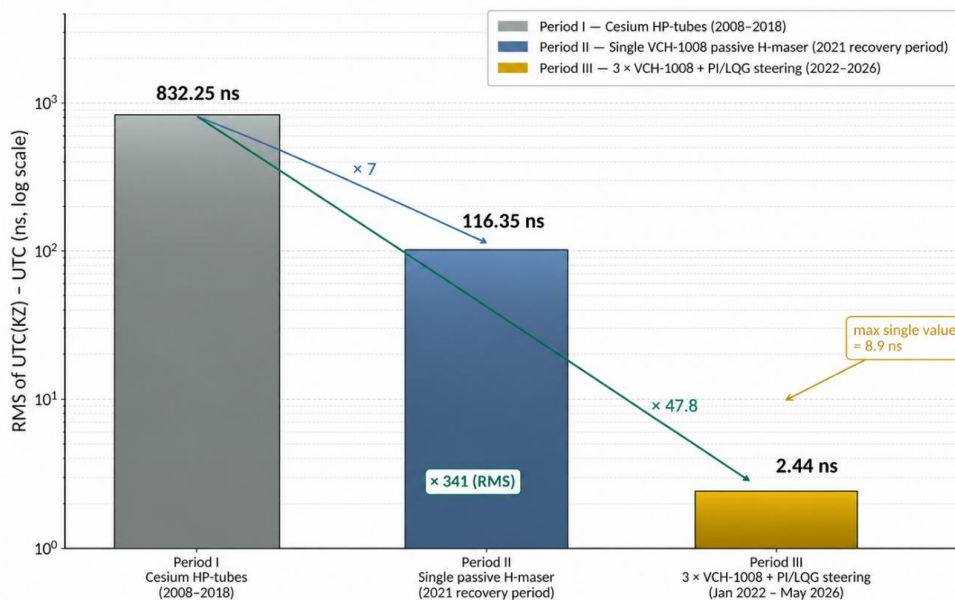


Figure 3. RMS reduction of UTC(KZ) across three operational periods of the Kazakhstan standard. Period I corresponds to the legacy cesium-clock configuration (2008-2018); Period II corresponds to the 2021 recovery period with a single VCH-1008 passive hydrogen maser; Period III corresponds to three VCH-1008 passive hydrogen masers with automated PI/LQG steering, with Circular T data through 29 May 2026. (Source: KazStandard/BIPM Circular T.)

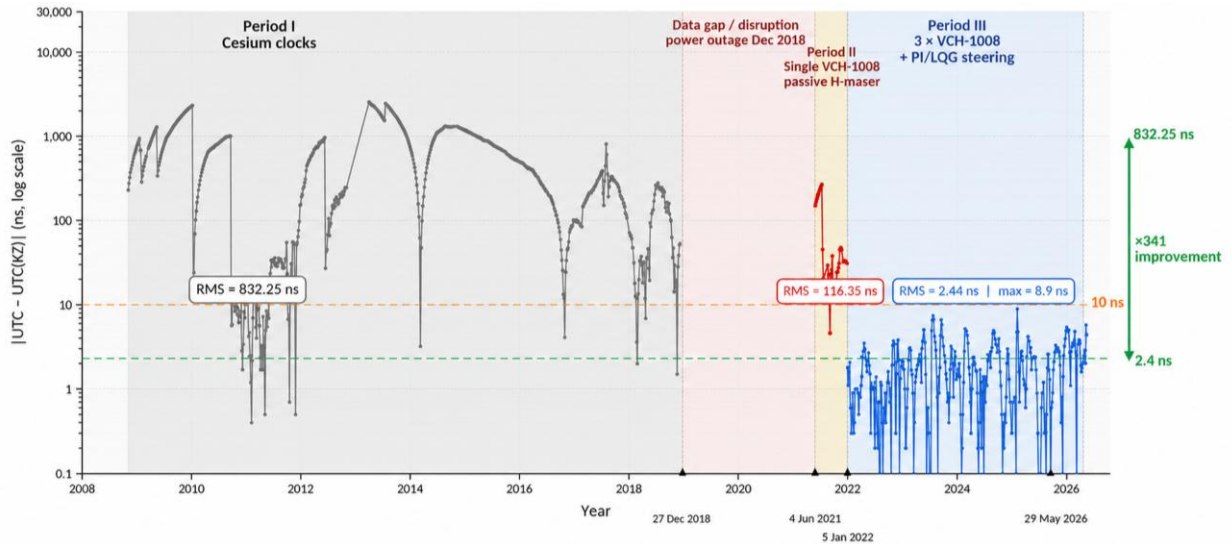


Figure 4. Absolute time difference $|UTC - UTC(KZ)|$ across KazStandard’s operational periods on a logarithmic scale, from 2008 to 29 May 2026. Data are based on BIPM Circular T values. Data are presented as Period I: Cesium clocks (---), Period II: Single VCH-1008 passive H-maser (---), and Period III: 3 × VCH-1008+PI/LQS steering (---). The pink shaded 2018–2021 interval without data between Period I and Period II illustrate the disruption and recovery following the December 2018 power cable fire. The updated data show an improvement from RMS = 832.25 ns with cesium clocks (Period I, 2008–2018) to RMS = 2.44 ns with three passive hydrogen masers and automated PI/LQG steering (Period III, 2022–2026), corresponding to an approximately 341-fold RMS reduction.

Furthermore, UTC(KZ) has appeared in 100 % of monthly Circular T bulletins since June 2021, with no missed months, eliminating the periodic data-submission interruptions that affected the previous standard. In January 2022, KazStandard became the first Central Asian laboratory to participate in weekly UTCr activities, and UTC(KZ) ranks 25th out of 97 laboratories worldwide (top 26 %) in the CCTF-K001.UTC key comparison, having advanced from 42nd just three years earlier. According to the latest BIPM Circular T (213 reporting dates from 4 June 2023 to 29 April 2026), UTC(KZ) achieves a standard deviation of $\sigma = 2.53$ ns. The Top-10 of CCTF-K001.UTC operate in the 0.5–1.3 ns range – including PTB (Germany, $\sigma = 0.77$ ns, rank #3), NIST (USA, $\sigma = 0.99$ ns, rank #7), SU/VNIIFTRI (Russia, $\sigma = 1.04$ ns, rank #5) and OP (France, $\sigma = 1.22$ ns, rank #6); UTC(KZ) is therefore within a factor of 2–3 of the entire Top-10 cohort.

The KZ contribution to TAI grew steadily from 0.055 % in 2022 to a peak of 0.13 % in November 2025 – over a 2-fold increase over three years – and was restored to that level after a manual de-weighting and four-month re-evaluation by the BIPM in early 2025. The frequency stability of the KZ masers reaches $1-2 \times 10^{-15}$ at averaging times of 1 day or longer, precisely the regime that matters for weekly UTCr-based steering. These results also illustrate the wider significance of this achievement: among the five COOMET member time scales participating in the BIPM Circular T comparison (June 2025–April 2026), UTC(KZ) is the only one that satisfies the ITU-T 5G synchronization threshold of ± 10 ns. This result underscores the strategic and regional value of Kazakhstan’s investment in precision timekeeping infrastructure.

Among laboratories with an equipment class comparable to the modernized Kazakhstan standard (passive H-masers), UTC(KZ) is on par with Justervesenet (JV, Norway), as confirmed by the 2026 BIPM report.¹ A significant cost reduction has also been achieved: passive H-masers are more compact and 5–8 times less expensive than active masers ($\approx$ 60,000 USD versus 300,000–480,000 USD each), making world-class timekeeping accessible to other developing NMIs.

An illustration of both the challenges and progress of Kazakhstan’s now metrologically rigorous and precise timekeeping infrastructure is provided in **Figure 4**. The results of this successful metrological intervention have also been recently published.² For Kazakhstan, the upgrade delivers a sovereign, traceable national time scale UTC(KZ) for its critical infrastructure – telecommunications, power grids, financial systems, and GNSS-dependent services – reducing reliance on external time sources and positioning the country as a regional time-metrology hub for Central Asia.

As a result of this metrological intervention, Kazakhstan now maintains a sovereign, resilient, and internationally traceable national time scale, UTC(KZ), that supports the timing layer of the country’s critical infrastructure. Its impact extends beyond laboratory metrology: UTC(KZ) provides the national reference for telecommunications, digital services, financial timestamping, power-grid monitoring, transport systems, GNSS-dependent applications, and emerging IoT-based services in healthcare, agriculture, and smart-city systems. By reducing dependence on external timing sources and maintaining nanosecond-level alignment with UTC, the Kazakhstan standard strengthens national digital sovereignty and improves resilience against GNSS disruption, jamming, or spoofing.

Beyond Kazakhstan, this work demonstrates a cost-effective model for other developing or resource-constrained NMIs. A national time scale based on passive hydrogen masers and weekly UTCr-based steering can achieve high UTC tracking accuracy without the capital cost of active hydrogen masers or cesium fountains, thereby enabling more countries to participate effectively in TAI/UTC and build resilient timing infrastructure for modern digital economies.

POC: Smagulov Sultanbek, s.smagulov@ksm.kz

¹ Tavella P. Report to KazStandard on the Performance of UTC(KZ). Bureau International des Poids et Mesures (BIPM), 11 March 2026.

² Smagulov S.B., Mishagin K.G. Steering of the National Time Scale UTC(KZ) Based on Passive Hydrogen Masers According to the Rapid UTC Data. *Measurement Techniques*, 67, 684–692 (2024). <https://doi.org/10.1007/s11018-025-02389-3>