GULF COOPERATION COUNCIL STANDARDIZATION ORGANIZATION – REGIONAL METROLOGY ORGANIZATION (GULFMET)

Supplementary Comparison of UTC Time Scales Between UTC(SASO), UTC(UME), UTC(UZ), UTC(NIS), UTC(EMI), UTC(AZ) Using Global Navigation Satellite Systems (GNSS)

Technical protocol (GULFMET-TF-S2)

Contents

1 Introduction

The participating national metrology institutes have reached an agreement to undertake a **supplementary comparison of UTC time scales**. The objective is to evaluate the consistency of UTC realizations across the participating institutes and to strengthen regional cooperation in time and frequency metrology.

For the comparison methodology, the **GNSS common-view technique** has been selected. This method enables the precise comparison of remote time scales by analyzing measurements obtained simultaneously from the same navigation satellites, as observed at different geographic locations. Only satellites within the overlapping visibility zones of the participating receivers are used in the analysis, thereby ensuring robust and traceable estimation of the time differences between the UTC(k) realizations maintained by SASO, UME, UzNIM, NIS, EMI, and AzMI.

2 Organization of comparisons

2.1 Participants

2.1.1 SASO-NMCC Time and Frequency Laboratory (Saudi Arabia) is appointed as the pilot laboratory and is responsible for coordinating the comparison and managing the data analysis.

2.1.2 Other comparison participants are listed in section 2.2

2.1.3 This technical protocol was prepared by the pilot laboratory (SASO-NMCC) in consultation with all participating institutes and has been formally agreed upon. The protocol specifies the procedures for carrying out the measurements, data processing, and reporting during the course of the comparison.

2.1.4 Once approved, no amendments to this protocol may be introduced without prior consent of the participants and the corresponding technical committee on Time and Frequency under the framework of GULFMET.

2.2 Information about Participants

Information about the participants is provided in Table 1.

Table 1

	National Metrology Institute (NMI), address	The abbreviation for NMI	Contact Person	Contact Information
Participant 1	Saudi Standards, Metrology and Quality Organization – National Measurement and Calibration Center (SASO-NMCC) Prince Turki Ibn Abdulaziz Al Awwal Rd, Riyadh, KINGDOM OF SAUDI ARABIA	SASO-NMCC	Khalid Aldawood Ramiz Hamid Waleed Alharbi Assaf Alassaf	k.dawood@saso.gov.sa ramiz.hamid@yahoo.com wm.harbi@saso.gov.sa a.assaf@saso.gov.sa
Participant 2	National Metrology Institute of Türkiye, TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr.Zeki Acar Cad. No:1, 41470, Gebze / KOCAELİ, TÜRKİYE	TÜBİTAK UME	Adem Gedik	adem.gedik@tubitak.gov.tr

Participant 3	Uzbekistan National Institute of Metrology, Republic of Uzbekistan, Tashkent City, 100174, Almazar District, Farobiy Street, 333A, 333B	UzNIM	Sheroz Ismatullaev Lyubov Gazieva Vohobjon Nishonov	sh.ismatullaev@nim.uz l.gazieva@nim.uz v.nishonov@nim.uz
Participant 4	National Institute for Standards (NIS) Tersa Street, El-Haram, Giza, EGYPT	NIS	Mohamed El Hawary Aly Ibrahim Mostafa	mohamed.ibrahim@nis.sci.eg aly.ibrahim@nis.sci.eg
Participant 5	Emirates Metrology Institute (EMI) Masdar City, Abu Dhabi, UNITED ARAB EMIRATES	EMI	Jon Bartholomew	jon.bartholomew@qcc.gov.ae
Participant 6	Azerbaijan Institute of Metrology (AzMI) 7th Kondalan street, Elchin Isagzadeh settlement, AZ1029, Baku, Azerbaijan	AzMI	Shamkhal Abbasov Nazrin Aliyeva	shamkhal.abbasov@metrology.gov.az nazrin.aliyeva@metrology.gov.az

2.3 Procedure of organizing comparisons

The comparison is based on measurements of remote UTC(k) time scales carried out by the participating institutes. The **pilot laboratory (SASO-NMCC)** is responsible for coordinating the overall process, including data collection, processing, and analysis.

For conducting the comparison, the required measurement equipment and facilities will be provided by the participating institutes: **SASO-NMCC (Saudi Arabia), TÜBİTAK UME (Türkiye), UzNIM (Uzbekistan), NIS (Egypt), EMI (United Arab Emirates), and AzMI (Azerbaijan)**, as specified in Table 2.

Table 2. Specifications of Time and Frequency Measurement Devices

Device name	Model	Serial number	Specifications
SASO-NMCC			
Primary Frequency and Time Standard	5071A	US49352932	Accuracy: $2 \cdot 10^{-14}$
Multi-Channel GNSS Receiver with Antenna	TTS 4	135	System Support: GPS / GLONASS / GALILEO. - Phase observation accuracy for short baseline short-term accuracy: < 12 ps root mean square - Code observation accuracy: < 0.5 ns root mean square for short baseline Output data formats: RINEX and CGGTTS CGGTTS data availability: 30 seconds after each observation session Access to the receiver via local console / built-in touch

			screen, web interface, and remote access through network
State Institution “UzNIM”			
Primary Frequency and Time Standard	5071A	US49355005	Accuracy: $2 \cdot 10^{-14}$
Multi-Channel GNSS Receiver with Antenna	TTS 5	1027	System Support: GPS / GLONASS / GALILEO. - Phase observation accuracy for short baseline short-term accuracy: < 12 ps root mean square - Code observation accuracy: < 0.5 ns root mean square for short baseline Output data formats: RINEX and CGGTTS CGGTTS data availability: 30 seconds after each observation session Access to the receiver via local console / built-in touch screen, web interface, and remote access through network
TÜBİTAK UME			
Active Hydrogen Maser	iMaser 3000	128	Allan deviation (1Hz bandwidth): 1 s 6E-14 1’000 s 1.5E-15 10’000 s 1E-15 Low Phase Noise (5MHz) -132 dBc/Hz @ 1Hz
Additionally 4 Primary Frequency and Time Standards 5071A with high performance tube. Special algorithm is used for averaging time of cesium atomic clocks. Hydrogen Maser is synchronized to generate averaging time by cesium atomic clocks.			
Multi-Channel GNSS Receiver with Antenna	TTS 4	0137	System Support: GPS / GLONASS / GALILEO. - Phase observation accuracy for short baseline short-term accuracy: < 12 ps root mean square - Code observation accuracy: < 0.5 ns root mean square for short baseline Output data formats: RINEX and CGGTTS CGGTTS data availability: 30 seconds after each observation session Access to the receiver via local console / built-in touch screen, web interface, and remote access through network
NIS			
Primary Frequency and Time Standard	5071A	US49353654	Accuracy: $2 \cdot 10^{-14}$
Multi-Channel GNSS Receiver with Antenna	TTS 5	1026	System Support: GPS / GLONASS / GALILEO. - Phase observation accuracy for short baseline short-term accuracy: < 12 ps root mean square - Code observation accuracy: < 0.5 ns root mean square for short baseline Output data formats: RINEX and CGGTTS CGGTTS data availability: 30 seconds after each observation session Access to the receiver via local console / built-in touch screen, web interface, and remote access through network
EMI			
Primary Frequency and Time Standard	5071A	US49352938	Accuracy: $2 \cdot 10^{-14}$
Multi-Channel GNSS Receiver with Antenna	PolaRx5TR	4701676	Supported signals: GPS (L1P, L1CA, L2, L5), GLONASS (L1, L2, L3) GALILEO (E1, E5ab, AltBoc, E6), BEIDOU (B1, B2, B3), SBAS (L1, L5), IRNSS (L5), QZSS (L1, L2, L5)
AzMI			
Primary Frequency and Time Standard	5071B	US49355360	Accuracy: $2 \cdot 10^{-14}$
Multi-Channel GNSS Receiver with Antenna	TTS 5	1030	System Support: GPS / GLONASS / GALILEO. - Phase observation accuracy for short baseline short-term accuracy: < 12 ps root mean square

			- Code observation accuracy: < 0.5 ns root mean square for short baseline Output data formats: RINEX and CGGTTS CGGTTS data availability: 30 seconds after each observation session Access to the receiver via local console / built-in touch screen, web interface, and remote access through network

By confirming their participation in the comparison, each institute acknowledges its ability to perform the required measurements within the agreed timeframe. This commitment is essential to ensure the timely completion of the comparison.

Participants are allocated **one month to conduct the measurements** and an additional **one month to process the acquired data**.

In the event that results cannot be delivered within the specified period—due to equipment malfunction, unexpected technical issues, or other unforeseen circumstances—the participant must promptly notify the pilot laboratory and the other parties concerned. Appropriate adjustments to the schedule and measurement sequence will then be coordinated.

Upon completion of the measurements and data processing, each participant shall submit the finalized results to the **pilot laboratory (SASO-NMCC)** for central analysis and reporting.

2.4 Comparison schedule

After the participants have agreed on the schedule, the dates specified in the table become fixed.

Table 3 – Comparison schedule

	Action	Date
1	Final agreement and formal approval of the technical protocol by all participants	1 October 2025
2	Preparation of the comparison standards and initiation of pilot measurements by the pilot laboratory (**SASO-NMCC**)	2 November 2025
3	Execution of measurements by the participating institutes (**TÜBİTAK UME, UzNIM, NIS, EMI, AzMI**)	27 November 2025
4	Submission of measurement results and supporting protocols from all participating institutes (**TÜBİTAK UME, UzNIM, NIS, EMI, AzMI**) to the pilot laboratory (**SASO-NMCC**)	22 December 2025
5	Consolidation of data, analysis of results, and preparation of the draft comparison report by the pilot laboratory (**SASO-NMCC**)	29 January 2026
6	Circulation of the draft report to all participants for review and comments (**SASO-NMCC, TÜBİTAK UME, UzNIM, NIS, EMI, AZMI**)	16 February 2026
7	Finalization and approval of the comparison report by consensus of all participants	30 March 2026

2.5 Handling the standard

The comparison standard shall be operated only by **qualified personnel** or by an individual formally designated as responsible for its custody and use.

Operation of the standard is permitted solely under conditions where the required environmental and installation parameters are maintained. The laboratory in which the standard is housed must meet the following criteria:

- Ambient temperature: **21 °C to 25 °C**
- Relative humidity: **30 % to 70 %**
- Supply voltage: **218 V to 222 V**
- Power frequency: **49 Hz to 51 Hz**

A reliable **uninterruptible power supply (UPS)** must be installed to ensure continuity of operation.

The laboratory atmosphere shall be free from excessive dust, corrosive gases, aggressive vapors, or any other contaminants that could compromise the integrity of the standard.

Use of the standard shall be **suspended immediately** if there is any doubt concerning its metrological characteristics, functional performance, or compliance with the manufacturer’s specifications.

3 Measurement methodology

The comparison will be carried out using the **Global Navigation Satellite Systems (GNSS) common-view method**, as illustrated in **Figure 1**.

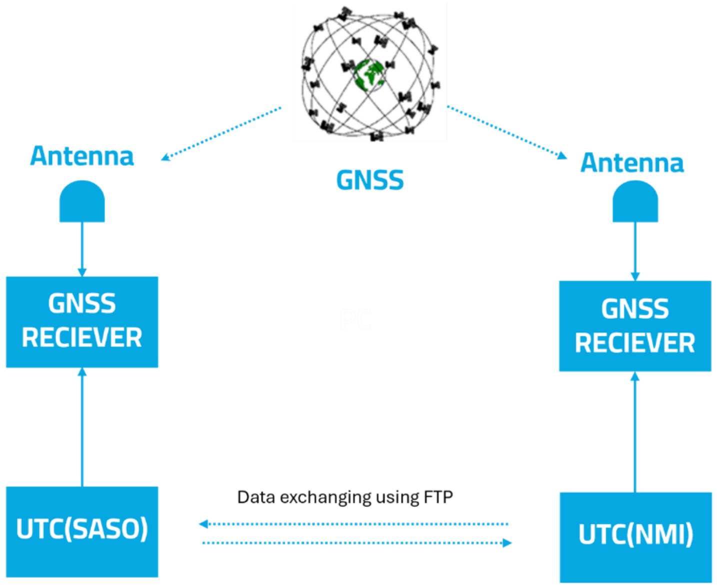

Figure 1. GNSS Common View Method

The common-view technique enables the direct comparison of clocks located at different laboratories by simultaneously receiving GNSS signals from a common satellite. In this method, two stations (A and B) each record the time difference between their local clock and the transmitted GNSS signal. These data are then exchanged between the two stations by any convenient means.

The relative time difference between the two clocks is determined by subtracting the measurements obtained at the two sites:

$$(\mathbf{A}-\mathbf{R}-\mathbf{d_a})-(\boldsymbol{B}-\boldsymbol{R}-\boldsymbol{d_B})=(\boldsymbol{A}-\boldsymbol{B})-(\boldsymbol{d_A}-\boldsymbol{d_B})$$

where:

- A – local clock at Laboratory A
- B – local clock at Laboratory B
- R – GNSS system time (e.g., GPS time)
- d_A – propagation delay of the signal to Laboratory A
- d_B – propagation delay of the signal to Laboratory B

In this formulation, the contribution of the GNSS system clock (R) cancels out, while a significant portion of the propagation delay is also removed. The residual error is primarily associated with uncorrected path delays and receiver-dependent effects.

The GNSS common-view technique has been applied extensively in international time comparisons and is one of the principal methods recognized by the Bureau International des Poids et Mesures (BIPM). The BIPM routinely publishes satellite tracking schedules that enable participating laboratories to coordinate simultaneous observations on common satellites, thereby ensuring comparability and traceability of results.

4. Processing of measurement results

4.1 Conducting Measurements

The comparison is conducted among the participating institutes' national time scales (UTC(SASO), UTC(UME), UTC(UZ), UTC(NIS), UTC(EMI), and UTC(AZ)) over the agreed measurement period (expressed in Modified Julian Date, MJD) using the GPS Common-View method.

For this comparison, the **GPS L3P code** is employed. Data are processed using the software **CGGTTS Analyser v1.0**, developed in cooperation with the **BIPM**. The software allows the computation of the time differences between each UTC(k) realization and GPS time, as well as inter-laboratory differences (e.g., UTC(SASO) – UTC(UME), UTC(SASO) – UTC(UZ), etc.) as a function of MJD.

The procedure for conducting and processing measurements is as follows:

- The measurement period is mutually agreed upon by all participating laboratories.
- Each participating laboratory measures the time difference between its UTC(k) realization and GPS time over the selected period.
- Measurement results are formatted in **CGGTTS** and transmitted to the pilot laboratory (**SASO-NMCC**) within the agreed timeframe.
- The pilot laboratory compiles and analyses the submitted data using **CGGTTS Analyser v1.0**. The software offers two processing methods: **Common-View Analysis** and **All-in-View Analysis**. For this comparison, **Common-View Analysis** is adopted.
- Results are presented as time series of UTC(k) – GPS and UTC(k1) – UTC(k2), expressed as a function of MJD. Graphical outputs and regression analysis are applied for evaluation.

The **CGGTTS format** is the internationally recognized standard for exchanging GNSS time-transfer data. Each measurement file corresponds to a 16-minute observation interval with a 13-minute averaging period, following the **UTC tracking schedule published by the BIPM**.

4.2 Calculation Methods

Two primary calculation approaches are applied:

4.2.1 Weighted REFSYS of each receiver

The weighted reference system (Refsys) for each receiver is computed as the elevation-weighted average of all available satellites at each epoch:

$$weighted\ Refsys_1 = \sum_{SAT(i=1)}^{n} \frac{Refsys_i . \sin^2(ELV_i)}{\sum_{i=1}^{n} \sin^2(ELV_i)}$$

$$weighted\ Refsys_2 = \sum_{SAT(i=1)}^{n} \frac{Refsys_i . \sin^2(ELV_i)}{\sum_{i=1}^{n} \sin^2(ELV_i)}$$

Where:

- **Refsys** – reference system time difference value reported by the receiver
- **ELV** – satellite elevation angle
- **n** – number of satellites in view

4.2.2 Common-View Method

The time difference between two stations is derived as the average difference between their weighted Refsys values at each epoch:

$$Common - View\ at\ each\ epoch = \frac{1}{n} \sum_{SAT(i=1)}^{n} (Refsys_{(1,i)} - Refsys_{(2,i)})$$

This approach cancels the contribution of the GNSS system time and minimizes common propagation delays, yielding the relative difference between the two UTC(k) realizations.

4.3 Uncertainty Evaluation

The statistical uncertainty of the comparison is evaluated through standard deviation analysis of the UTC(k1) – UTC(k2) time differences relative to their linear regression fit. The procedure is as follows:

1. Plot **UTC(k) – GPS** time series for each participating laboratory.
2. Derive inter-laboratory differences (e.g., UTC(SASO) – UTC(UZ)).
3. Perform linear regression analysis of the inter-laboratory differences.
4. Determine the residuals between the measured differences and the regression fit.
5. Compute the **standard deviation of the residuals**, which is taken as the uncertainty of the comparison.

5 Presentation of comparison results

Upon completion of the measurements, each participating institute shall transmit its results to the **pilot laboratory (SASO-NMCC)** in electronic form (via email) within the agreed timeframe. In the event of discrepancies between the electronic and paper submissions, the **signed paper version shall prevail**.

The submitted report must include:

- A final table of the comparison results
- A detailed description of the measurement procedure followed
- The full protocol for the calculation of measurement uncertainty

Evaluation of the reported results shall be performed in accordance with the **"Guide to the Expression of Uncertainty in Measurement (GUM)"**, developed under the auspices of the **International Committee for Weights and Measures (CIPM/BIPM)**.

Following the submission of results, the pilot laboratory will consolidate the data, perform the necessary analyses, and prepare the draft comparison report. This draft will be circulated to all participants for review and comment before finalization.

All reports and supporting documentation shall be submitted in **Microsoft Word format** (for text and tables), with accompanying data files provided in **CGGTTS or CSV format** as appropriate.

6 Registration of comparison results

The pilot laboratory (SASO-NMCC) shall analyze all submitted measurement results, consolidate the data, and prepare the final report of the comparison.

Upon approval by all participants, the protocol will be submitted to GULFMET (Time and Frequency) for official registration and subsequently forwarded to the BIPM for inclusion in the Key Comparison Database (KCDB), after finalizing comparison the prepared final report will also be circulated to all participants and then submitted to GULFMET and BIPM.

A copy of the approved report will also be provided to each participant for their records.