Traceability to UTC from GNSS measurements

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On behalf of the CCTF Task Force on Traceability to UTC from GNSS measurements
expected number of units sold for Time and Synchronisation purposes in different sectors.
Increasing use of GNSS for synchronization & increasing demand for traceability

Need for guidelines on
- how the user can get UTC from GNSS (including equipment and calibration)
- and how traceability can be obtained when using GNSS for synchronization to UTC

Task force of the GNSS WG, with the help of the WG on MRA.
- Provide guidelines
- Disseminate the information to the end user, via e.g. RMOs, ICG, GNSS providers, GNSS stakeholders
Metrological Traceability

DEFINITION from The International vocabulary of metrology (VIM)

“property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty”

BIPM, International Organization of Legal Metrology (OIML), and accreditation bodies:

The required calibrations should be performed by NMIs or DIs participating in the CIPM-MRA and having their CMCs published in the KCDB.

In addition, measurements traceable to the SI can as well be made by an accredited laboratory whose calibration and testing capabilities were formally approved by an accreditation body, so that they fulfil the rules of ISO/IEC 17025 recommended by CIPM.
Traceability to SI second / to UTC

In both cases: traceability requires

- Calibration of the user device
- Traceability route to UTC
Different kinds of users

**U1:** User operates GNSS-DO for “all you can get” from GNSS: time-of-day, PPS, standard frequency

**U2:** User – UTC(k)
GNSS Common View

**TS_user:** local time scale (1 PPS, 10 MHz)

**U3:**
Distribution of time-of-day via NTP to user NTP_Client
**Traceability route to UTC**

**U1: GNSS DO**

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**U1.1**

- BIPM
  - UTC – UTC(k) \( (u_i) \)

- NMI / DI
  - Key Comparison “CCTF-K001.UTC”
  - NMI / DI bulletin

**U1.2**

- BIPM
  - UTC – bUTC\(_{GNSS} \) \( (u_4) \)
  - Circular T Section 4

**U1.3**

- BIPM
  - UTC – bUTC\(_{GNSS} \) \( (u_G) \)
  - Demonstrated by GNSS, audited under ISO/IEC 17025

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**U1.3**

Documentation by GNSS operator, audited under ISO/IEC 17025: not yet available

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**U1.2**

Circular T Section 4:
reports on UTC-Broadcast\(_{UTC_{GNSS}}\)
(no info available for Galileo and BeiDou,
no uncertainties, "work in progress")

*Agreed under some conditions e.g. ISO/IEC under 17025*

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**U1.1**

*NMI Bulletin:* reports on UTC(NMI)-Broadcast\(_{UTC_{GNSS}}\)
U1: calibration - Frequency

**U > 1 \times 10^{-8} (1-day av.)**
- One unit calibrated by accredited lab.
- One unit of each model (SW/HW/FW) calibrated by manufacturer; certificate of conformity for all units of the same model

**1 \times 10^{-8} > U > 1 \times 10^{-10} (1-day av.)**
- One unit calibrated by accredited lab.
- Certificate of calibration or of conformity for each individual unit of the same model

**1 \times 10^{-10} > U > 1 \times 10^{-12} (1-day av.)**
- All units individually calibrated by accredited lab.
- or NMI

**U < 1 \times 10^{-12} (1-day av.)**
- All units regularly calibrated by an NMI/DI

**Color code:**
- Calibrated by NMI/DI
- Calibrated by accredited lab.
- Calibrated by the manufacturer
- Not directly calibrated

ICG – October 2023
U1: calibration - Time

- **Calibration by accredited lab.**
  - One unit calibrated by accredited lab.
  - One unit of each model (SW/HW/FW) calibrated by manufacturer; certificate of conformity for all units of the same model.

- **Calibration by NMI/DI**
  - Certificates of conformity for units calibrated by accredited lab.

- **Calibration by the manufacturer**
  - All other units individually calibrated by the manufacturer, certificate of conformity for each unit of the same model.

- **Not directly calibrated**
  - Units calibrated by accredited lab. or NMI/DI.
  - Optionally comparison via GNSS CV.

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*IGC – October 2023*
Traceability route to UTC

BIPM

Key Comparison “CCTF-K001.UTC”

UTC – UTC(k) (u_t)

NMI / DI

Calibrated GNSS CV comparison

TS_user – UTC(k) (u_{cu}, u_{cv})

U2: GNSS CV with NMI / DI

- Services offered by NIST, NPL, other NMIs (?) (commercially)
- Calibration of user terminal only needed for time, must be done by the NMI / DI
- Technically complex, but ideal from metrological standpoint
- Very low uncertainties possible on user-UTC(k) (< 10^{-12} @ 1 day and a few ns)
Traceability route to UTC

U3: Dissemination via NTP

- Concerns User that operates NTP-servers for distributing time-of-day in a LAN.

- User establish link to NTP server operated by NMI, and monitor the locally distributed time. This is technically feasible even if access from LAN to the public Internet is blocked (IT security).

- only valid for uncertainty requirement $\geq 1$ ms (properties of NTP and typical applications)

- No calibration required

or routes as for U1
Remark on calibration

Calibration is done at a given epoch

→ Requires **continuous monitoring that the device is operating correctly between calibrations**

Different options exist

→ monitor DO parameters :
  → lock onto the GNSS signals,
  → oscillator control voltage variations.

→ Compare GNSS DO outputs with another local time reference / frequency standard (can be another GNSS DO from another manufacturer)
Services by NMIs*

- Frequency calibration by direct comparisons
  ("Local frequency standard" service under the "Frequency” branch)
- Frequency calibration via GNSS CV
  ("Remote frequency standard” service under the “Frequency” branch)
- Time comparison via GNSS CV
  ("Remote clock vs. UTC(NMI)” service under the “Time scale difference” branch)
- Calibration of GNSS equipment delays
  ("Delay meter” service under the “Time interval” branch)  PROPOSED
- Regular publication of UTC(k) - bUTC\textsubscript{GNSS}
  (a new service to create under the “Time scale difference” branch) NEW

*or UTC(k) labs with QMS and accredited for this service
Recommendations to GNSS DO manufacturers

• to seek **calibration** of their GNSS DO models as proposed by the Task Group;

• to provide **technical documentation** of their devices including specifications on the parameters of time accuracy to UTC and frequency instability as function of averaging time etc. **according to metrological rules** and adapted to the users’ needs;

• to include **functions** in their devices that allow the user **to verify correct operation**, for example, by monitoring and keeping records of its internal control parameters.
Recommendations to users

- to carefully **analyze** their respective **needs** and **improve the wording** and communication on “**traceability**” in view of the established meaning of this term in metrology;

- to **analyze** their **needs** regarding the **uncertainty** for the time and/or frequency offset of their internal clocks from UTC or its national realizations UTC(k);

- to follow the advice regarding **calibration** of their GNSS disciplined oscillators

  *The tighter the uncertainty requirements for time and frequency signals used within their realms, the more care in calibration and monitoring is required.*
Recommendations to **GNSS providers**

- to seek the **collaboration with NMI s/DIs** regarding GNSS system time realization and monitoring

- to **describe** the realization of **GNSS system times** as well as the data contents in the **navigation messages** following **metrological practice and vocabulary**.
Thank You

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