Strategy 2025-2035
Consultative Committee for Time and Frequency (CCTF)

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1. Executive summary

The Consultative Committee for Time and Frequency (CCTF) was created by the CIPM in 1997, succeeding the Consultative Committee for the Definition of the Second (CCDS) that was set up in 1956. CCTF activities concern matters in Time and Frequency (TF) metrology, namely the definition and *mise en pratique* of the SI second, TF transfer techniques, establishment and diffusion of international atomic time scales, metrological traceability and advice to the CIPM on matters related to time and time scales.

The CCTF is organized in nine working groups [1] (Figure 1):

- WGSP - Strategic Planning
- WGPSFS - Primary and Secondary Frequency Standards
- CCL-CCTF WGFS: Frequency Standards (Joint CCL-CCTF Working Group)
- WG-ALGO: Time Scale Algorithms
- WGTAI: International Atomic Time
- WGGNSS: GNSS Time Transfer
  WGTWSTFT: Two-Way Satellite Time and Frequency Transfer
- WGATFT: Development of Advanced Time and Frequency Transfer Techniques
- WGMRA: Mutual Recognition Agreement.

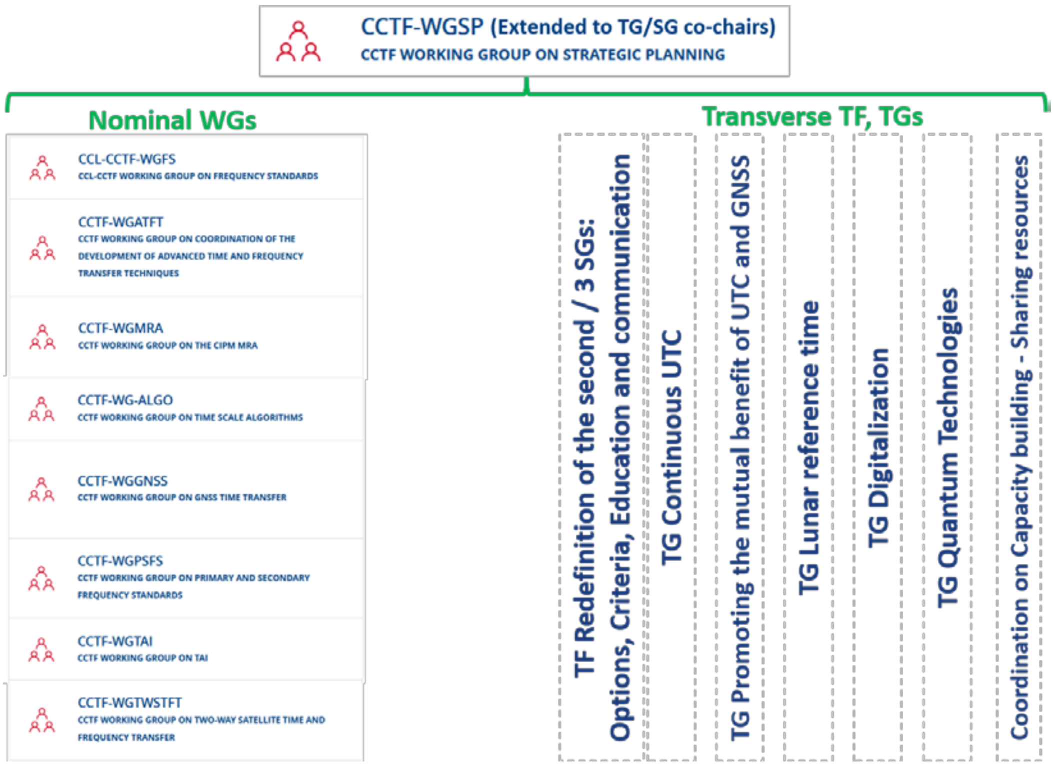

Figure 1: Organization of CCTF in nominal WGs and transverse TGs (till September 2025)

In order to meet the current and future needs in TF metrology, the CCTF has updated its 2016 strategy [2] to address new cross-cutting themes that correspond to major challenges in TF Metrology, and that are addressed in dedicated CCTF task groups:

- Roadmap towards the redefinition of the second
- Leap seconds in UTC and building a consensus for a continuous time scale

- Promotion of the mutual benefit of UTC and GNSS
- Sharing of resources to improve international timekeeping
- Lunar time
- Digitalization
- Quantum technologies.

The overall coherence of the CCTF strategy, in total synergy with the Work programme of the BIPM Time Department [3], is ensured by the CCTF Working Group on Strategic Planning composed of the chairs of all CCTF Working Groups extended to the co-chairs of the task groups on cross-cutting topics [4].

This organization has proven its efficiency and agility to address and move forward on the horizontal core topics and the vertical cross-cutting themes. The evolution of this organization, proposed by the WG on Strategic Planning, was validated at the 24th CCTF – Session meeting in September 2025 (Figure 2):

- Nominal CCTF WGs:
  - Maintain WGs: SP (extended), CCL-CCTF FS, PSFS, GNSS, TWSTFT, ATFT, TAI, MRA;
  - Cease WGs: Algorithms (topics concerning mainly education and training are addressed in WGs TAI, TG Capacity Building, BIPM Time department).
- CCTF TF / SGs, TGs
  - Maintain the Task Force on the Redefinition of the second with 3 SGs (Options, Criteria, Education and communication);
  - Maintain TGs on Continuous UTC, Lunar Reference Time, Digitalization, Quantum Technologies, Coordination of Capacity Building and Resources Sharing;
  - Focus of the TG Mutual benefit of UTC and GNSS to Traceability to UTC from GNSS measurements.

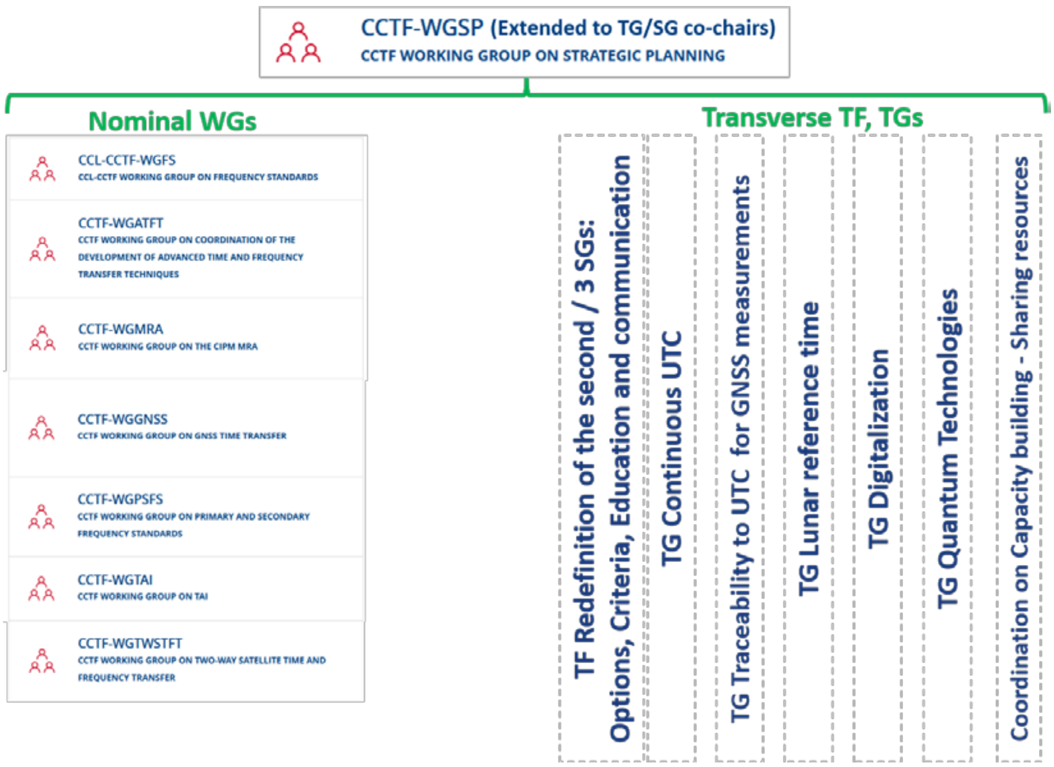

Figure 2 : Evolution of the CCTF organization (validated at the 24th CCTF – Session 2 meeting in September 2025)

2. Scientific, economic and social challenges

In order to help identify the main issues and diverse needs of the TF stakeholder, a survey was conducted in 2021. More than 200 responses were received from diverse categories (Table 1), covering all activity areas (Figure 3) and all Regional Metrology Organizations (RMOs): EURAMET (149 answers), SIM (48), APMP (40), COOMET (25), AFRIMETS (5), GULFMET (1).

Category	Number of answers
CCTF Members, Observers, and UTC contributors	78 (among which 24 CCTF members, 53 UTC(*k*) representatives)
NMIs not yet contributing to UTC	12
CCTF liaisons	4
Stakeholders	117

Table 1: Number of answers to the survey, by category

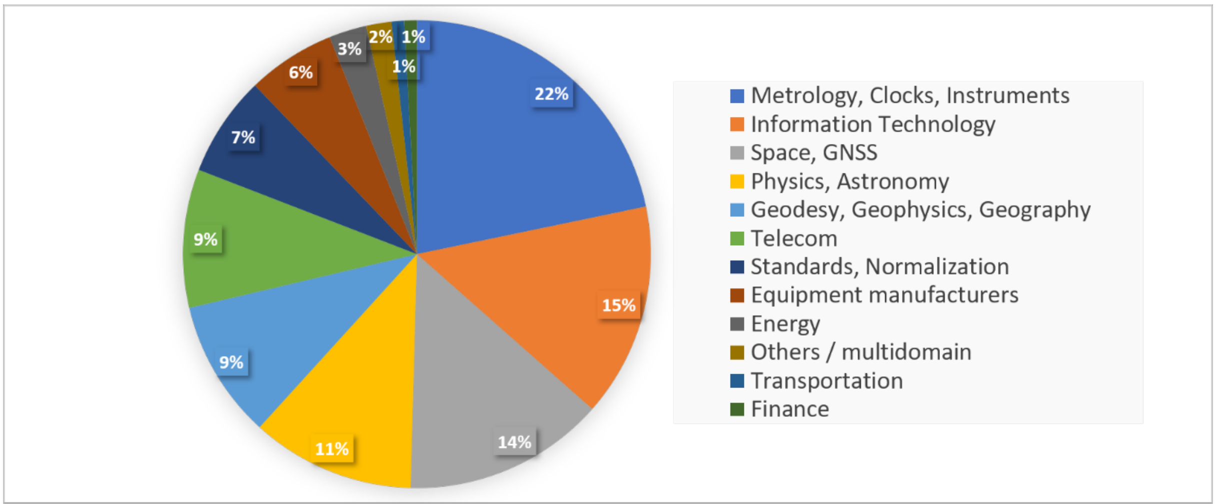

Figure 3: Number of answers to the survey from stakeholders, by activity sector

In the following Table 2 and Table 3 the demands for the emerging science and technology fields are summarized as reported in the CCTF survey results, for reference time and frequency signal accuracy requirements.

Uncertainty level	Application opportunity
10 ns	Positioning, telecom, quantum communication
1 ns	Positioning, telecom, quantum communication, radar
100 ps	Positioning, power
10 ps	Satellite time transfer
10 as	VLBI

Table 2: CCTF survey results summary for reference time signal accuracy requirements

Uncertainty level	Application opportunity
1×10^{-14}	Holdover
1×10^{-15}	Holdover, spectroscopy, secure communication
1×10^{-16}	Cosmology
1×10^{-17}	Dark matter detection, connected interferometry
1×10^{-18}	Positioning, real-time geodesy, new clocks

1×10^{-19}	Geodynamics
1×10^{-20}	Relativistic geodesy, alternative theories of gravitation

Table 3: CCTF survey results summary for reference frequency signal accuracy requirements

Concerning time scales, the answers to the survey have clearly expressed the need for a continuous UTC time scale (without leap seconds) and for well-defined rules and procedures to ensure the traceability to UTC from GNSS measurements.

3. Vision and mission

The CCTF vision is to be the recognized international focus for TF metrology, meeting the needs of the global community and society by providing a reliable measurement foundation for science, innovation in industry and emerging technologies, in a digital world in which time and synchronization challenges are underlying the operation of all critical systems.

The CCTF mission is to:

- provide a collective leadership in progressing the science and the application of TF metrology, by monitoring the achievements and progress of the NMIs and of the BIPM Time Department;
- provide an international forum for coordination, in synergy with the BIPM Time Department, NMIs and stakeholders (International Organizations, industrial communities, space agencies, etc.), with the aim to maintain a global momentum by fostering debates, collaborations and coordination on topics related to the definition of the SI second, its realization and its dissemination, the comparison of atomic frequency standards, the construction of atomic time scales, and the coordination of capacity building actions and of the sharing of resources to improve national and international time keeping;
- advance harmonization and global comparability of TF measurement worldwide, promote the traceability to the SI second and to the reference time scale UTC, and enable Member States and Associates to provide and use TF standards with confidence.

4. Roadmap towards the redefinition of the second

Since 1967, the definition of the SI second has relied on the caesium atom hyperfine transition frequency. Caesium primary frequency standards are currently realizing this unit with a relative frequency uncertainty at the low 10^{-16} level, but in the last two decades they have been surpassed by optical frequency standards (OFS) demonstrating the capability of much lower realization uncertainties, typically 2 orders of magnitude better, after a redefinition. The latest (May 2019) revision of the SI introduced revolutionary changes and placed the unit of time, the second, in a special position since all the other base units of the SI are now relying on the unit of time (except for the mole). So the future redefinition of the second is a major challenge in the revised SI.

The CCTF set up a dedicated task force in 2020 to update its roadmap towards the re-definition of the second [5]. This updated roadmap was approved by the 27th meeting of the General Conference on Weights and Measures (CGPM) in 2022 that adopted Resolution 5 “On the future re-definition of the second” [6]. This Resolution:

- encouraged the International Committee for Weights and Measures (CIPM)

- to promote the importance of achieving the objectives in the roadmap for the redefinition of the second,
- to bring proposals to the 28th meeting of the CGPM (2026) for the choice of the preferred species, or ensemble of species for a new definition of the second, and for the further steps that must be taken for a new definition to be adopted at the 29th meeting of the CGPM (2030),

- and invited Member States to support research activities, and the development of national and international infrastructures, to allow progress towards the adoption of a new definition of the second.

Details of this 2022 version of the roadmap can be found in [7] published in the *Metrologia* Special Focus issue on Challenges in Time and Frequency Metrology, especially:

- the description of options that can be envisaged for the new definition (Option 1 with a single reference optical frequency, Option 2 with an ensemble of reference optical frequencies, Option 3 with the fixed value of another fundamental constant);
- the mandatory criteria and ancillary conditions that quantify the status of the developments and the maturity of Optical Frequency Standards (OFS) and TF transfer techniques for the realization and the dissemination of the new definition, and their current fulfilment levels;
- the envisaged schedule, with a current baseline for the redefinition in 2030.

Frequently Asked Questions and the associated answers concerning the redefinition and its *mise en pratique* can be found on the dedicated BIPM web page [5].

The task force focused on gauging the accuracy requirements of the user community, the legal and regulatory implications, as well as the technical readiness and acceptance of the new standard. The responses received from National Metrology Institutes (NMIs), Designated Institutes (DIs) and stakeholders showed that the large majority were aware of the redefinition efforts and supportive of them. About half the responses indicated that changes to laws and regulations might be needed because of specific references to caesium therein, but the effort required was generally judged to be modest. The issue of changes to laws and regulations needs to be dealt with on several fronts: All NMIs need to be made aware of the redefinition since they are best placed to advise their respective governments. This can be done through the Regional Metrology Organizations (RMOs) where the Technical Committee for Time and Frequency could be responsible for providing information at the NMI level. NMIs are best positioned to identify local stakeholders and regulations that might be affected. No international regulations that would be affected by the redefinition have been identified to date. In the event this does occur, such changes would have to be considered by the appropriate international forum. To capture those stakeholders not represented by an NMI, some effort must be made to raise awareness of the redefinition through international and professional organizations such as International Telecommunication Union Radiocommunication Sector (ITU-R), International Union of Radio Science (URSI) and Institute of Electrical and Electronics Engineers (IEEE).

Some of the responses to the survey suggested a possible confusion by users regarding their requirements for accuracy and stability and the ways in which these can be evaluated and specified, and of the concept of metrological traceability, pointing to a need for further education. This indicates a need for more in-depth training on time and frequency, aimed at scientists and technical staff in new and developing UTC(*k*) laboratories, observatories, academic institutions but also high-tech industry. These training activities can be provided by NMI or academic TF experts regardless of their current involvement in optical frequency standards development. Suggested forums include online education and seminars, in-person short courses and on-site laboratory training.

The Roadmap towards the redefinition of the second has been updated in 2025 [5]. A huge amount of work has been already done, with significant progress being made since the first version (2016) of the roadmap. The momentum has been maintained thanks to engagement of the CCTF Task Force, its subgroups and the NMIs. Extensive activities have been supported by NMIs on optical frequency standards (OFS) based on different species and transitions, with the best devices surpassing the accuracy achievable by the realization of the current definition by a factor of up to 100. The reliability and uncertainty of the related time and frequency transfers are continuously improving thanks to the development of transportable OFS and of national / international infrastructures. These advances are likely to lead to improvements to the realization and the dissemination of time scales, particularly Coordinated Universal Time (UTC), with the potential to be more accurate than the time scale based on the current definition of the second.

It is important to recall that the change of the definition of the second, its realization and its dissemination are major challenges both on scientific, technological and operational aspects, requiring a minimum ensemble of operational state-of-the-art instruments and infrastructures as well as the mastering of relativistic effects at the proper uncertainty level. Everything matters to ensure that the new definition will bring a real improvement with respect to the current definition using caesium: evaluation and validation of the OFS uncertainty budgets, comparisons with fibre networks or transportable OFS, knowledge of the gravitational potential, etc.

In 2025, there was no clear consensus neither on the choice between Option 1 (one species) and Option 2 (ensemble of species) for the new definition, nor on the choice of the preferred species or ensemble of species, despite an active scientific debate that is important to ensure a solid and long lasting basis for the final choice, and the international acceptability of the new definition. Moreover, the maturity of the optical frequency standards is growing impressively even if noticeable inconsistencies in some comparisons of OFS and in a part of the frequency ratio measurements with OFS have been observed at recent comparison campaigns. That is why in 2025 the CCTF Task Force proposed a short list of four possibilities for the redefinition. The CCTF strategy and work plan are aiming to converge to a shortened list of 1-2 possibilities by the end of 2027 and to a single possibility by the third quarter of 2029.

Some criteria are still far from being fulfilled, for instance the criterion concerning the validation of OFS accuracy budgets by frequency comparisons or frequency ratios measurements, or the criterion concerning the contribution of OFS to the calibration of TAI. Criticalities are identified and a clear mitigation plan is being developed to ensure the necessary progress to be ready in 2030 for a major decision on the redefinition. Thus, all the criteria could be realistically fulfilled by 2030 thanks to international efforts coordinated by the CCTF and the engagement of NMIs to pursue and strengthen their activities aiming at fulfilling the mandatory criteria.

Therefore, the 2025 version of the roadmap towards the redefinition of the SI second maintains the scheduled scenario of keeping the 29th CGPM in 2030 as a decisive milestone, either to approve the new definition or to postpone it to the 30th CGPM in 2034, assuming the prerequisites for a redefinition (consensual choice of a single species or ensemble of species, fulfilment of mandatory criteria) are satisfied. The outcome of this roadmap will be a success if all concerned NMIs are supportive and continue to contribute actively to the process, both for the choice of the new definition and for the progress in the criteria fulfilment in due time.

5. Primary and Secondary Frequency Standards

The topics related to Primary and Secondary Frequency Standards (PSFS) are addressed in two CCTF Working Groups:

- Joint CCL-CCTF Working Group on Frequency Standards (CCL-CCTF WGFS) [9]
- CCTF Working Group on Primary and Secondary Frequency Standards (CCTF-WGPSFS) [10]

The CCL-CCTF WGFS activities include tasks related to the Consultative Committee for Length (CCL) and to the realization of the metre and tasks related to CCTF. We are mainly focusing here on the latter. The CCL-CCTF WGFS maintains, together with the BIPM, the list of recommended frequency standard values and wavelength values for applications including the practical realization of the definition of the metre and secondary representations of the second. Recommended frequencies with the smallest uncertainty are determined from a global adjustment of measurements of frequency ratios published in peer-reviewed publications. In the last few years, this global adjustment has grown in complexity, owing to the increasing number of frequency ratio measurements with excellent uncertainties. It has also grown in significance because of the increasing use of secondary representations of the second to calibrate the scale interval of TAI and because it is a mean to verify the consistency of optical frequency ratio measurements. Both are important prerequisites for the redefinition of the second.

The 2025 global fit input data includes 146 measurements used in the fit (instead of 105 in 2021). The amount and complexity of this 2025 global fit input data is significantly increased compared to previous determinations of recommended frequencies. Estimating and considering correlations between measurements has become a demanding task that goes well beyond collecting final ratio measurement values reported in peer-reviewed publications. Over the last few years, several new frequency measurements have been published that are relevant for consideration. Among them, new optical transitions have been approved as secondary representation of the second (SRS): two in 2021 and one in 2025. In total, there are currently eleven optical transitions, and one microwave transition approved as SRS.

Many of them have a recommended uncertainty close to the limit of realization of the SI second by atomic fountains, the lowest recommended uncertainty being 1.7×10^{-16}. The current and complete list of recommended values can be found on the BIPM website [11].

The WGFS will consider improvement of the whole process. Improvements to the practices to report and gather the information needed to estimate correlations will be considered, with the help and contribution of institutes that report measurements. Due to the anticipated and desired increase weight of secondary frequency standards in the calibration of the TAI scale interval, it will be necessary to better account for correlations associated to frequency measurements against the TAI. The WGFS will also consider improving its approach to deal with the sparsity of certain measurements, particularly in the case of optical frequency ratios. The WGFS will discuss conventions and choices to make the output covariance matrix of the global fit available. It may also examine possibilities to further test and enhance the robustness of the adjusted values and uncertainties. Finally, the WGFS will reflect on the status of adjusted frequency ratios, in particular, optical frequency ratios, and on the publication and the tracking of their values and uncertainties through successive adjustments. The increased focus on adjusted frequency ratios has several motivations. The first is that several of them have fractional uncertainties below that of SRS. The second is that they are natural quantities, independently to the chosen system of units. A third motivation is that adjusted frequency ratios will be essential to the redefinition process, both to ensure the continuity between the present and the future redefinition and to further realize and disseminate the unit after the redefinition. Finally, the use of the adjustment by the WGFS as a means to verify the consistency between the diverse most accurate frequency standards will remain relevant now and in the future.

In recent years the two focuses of the CCTF Working Group on Primary and Secondary Frequency Standards (CCTF-WGPSFS) were the continued assessment of first reports of new PSFSs for steering the frequency of TAI and updating and fixing new documentation standards for PSFSs contributing to TAI, both of which are items entirely within the scope of the WG PSFS' Terms of Reference. Regarding the first item, a significant increase in the number of first and subsequent reports from Optical Frequency Standards (OFS) was observed in the period from 2021 to 2023. This development has been accommodated by increasing the number of experts in OFS in the membership of the WGPSFS. After the number of OFS reports fell to less than one per month in 2024, it rose again to more than two per month in 2025.

Documentation standards have been updated by adding information in "Section 3 - Duration of the TAI scale interval d" of BIPM *Circular T* [12] to better access the performance of the PSFSs. Additionally, new "Guidelines for reporting primary (PFS) or secondary (SFS) frequency standards data for TAI calibration" were established to accommodate the increasing number of contributing PSFSs from an increasing number of NMIs.

In the coming years, apart from the continuation of the assessment of first reports of new PSFSs for TAI steering and the monitoring of appropriate documentation, possible issues to be considered by the WGPSFS are the impact of deadtime and direct frequency measurements of OFS by optical links to be inserted in TAI. Moreover, the WGPSFS will actively accompany the process for the redefinition. This implies support from the BIPM regarding questions about the impact of a redefinition on TAI.

6. Time and frequency transfer techniques

The topics related to time and frequency transfer techniques are addressed in three CCTF Working Groups on:

- GNSS Time Transfer (WGGNSS) [13]
- Two-Way Satellite Time and Frequency Transfer (WGTWSTFT) [14]
- Advanced Time and Frequency Transfer Techniques (WGATFT) [15]

In recent years the WGGNSS has reinforced the collaboration between the UTC and GNSS communities. With the deployment of new GNSS constellations and new signals, the WG has put forward the calibration (absolute and relative) of all new signals for time transfer. In collaboration with the RMOs, the WG reinforced the calibration of UTC(*k*) laboratories, leading to nearly 70 % of the laboratories having a calibration in agreement with the guidelines younger than 5 years, and already 26 laboratories (as in 2022) have calibrated for Galileo in addition to GPS. The calibrations for BeiDou signals started in 2022, and the WGGNSS effort for improved calibration of all UTC(*k*) laboratories will be pursued in the coming years.

In view of redefinition of the second, the Working group is also continuing its development of the comparisons of remote PSFS, with the technique making use of GNSS code and carrier phase measurements at the state of the art (Precise Point Positioning with ambiguity resolution, also called

IPPP). In the coming years it will generalize the use of this technique and work at improving its performance thanks to a combination of enhanced data modelling and multi-GNSS.

The WGGNSS will furthermore continuously provide its support to GNSS providers to help with their timing systems and time dissemination services, and to the IGS for a correct use of time scales, in particular UTC, and GNSS timing signals in their standard formats. It will also reinforce its collaboration with IGS about all products needed for GNSS frequency transfer.

Two Way Satellite Time and Frequency Transfer (TWSTFT) is one of the two major intercontinental time and frequency transfer methods and offers true independence from GNSS. The main collaborative challenge is to maintain robust and reliable TWSTFT networks and to achieve high quality link calibrations with close to one nanosecond uncertainties. During recent years, time transfer stability and accuracy has been improved by implementing higher chip rates, improving the environment, and updating equipment at many participating stations. So far, TWSTFT has not been able to offer frequency comparisons of optical standards at the 10^{-18} level. However, the use of software-defined receivers has reduced daily variations, which have been one of main instabilities observed in the TWSTFT results and the implementation of carrier-phase measurements has greatly improved the precision. TWSTFT has potential to further advance by the use of substantially higher carrier frequencies as well as advanced digital technologies, which requires close cooperation between the NMIs, industry and service providers.

Advanced Time and Frequency Transfer Techniques included all the new techniques that were beyond standard or common satellite methods, in particular GNSS and TW satellite-based. Among those techniques, the most prominent has been the transfer methods based on the use of laser radiation over optical fibres [16, 17]. The so-called “fibre-links” have been developed over twenty years and are rather mature. One of the last campaigns among remote optical clock in Europe has demonstrated their present capabilities in terms of metrological performances in Time and Frequency [18]. The optical fibre techniques are divided into two main technical families. The first is the best performing in terms of accuracy and stability and is based on the frequency transfer of an ultra-stable coherent laser radiation, together with the suppression of the phase noise introduced by the optical fibre itself. The second is based on amplitude modulation of an optical carrier and the compensation of delays, using a TW technique on the optical fibre. This family is well represented by the IEEE 1588 standard, the Precision Time Protocol (PTP), also with the High Accuracy opticon, that is still commonly referred to as the “White Rabbit” technique.

Another relevant Advanced Technique is the optical transfer in free space, both ground-to-ground, and ground-to-space. Optical satellite techniques could be the future for intercontinental comparisons. Presently, relevant results have been obtained on ground-to-ground transfer, up to about 100 km, using different approaches [19, 20], for example, involving optical frequency combs.

Other techniques have been explored, for example the use of the Very Long Baseline Interferometry network for radioastronomy for remote comparison of clocks [21], but they seem less developed.

7. Atomic time scales

7.1 Construction of TAI and UTC

The BIPM Time Department is responsible for the generation of the international reference UTC, published each month, and TT(BIPMYY) (YY is the publication year), each year. Appropriate algorithms are developed to generate UTC and TT(BIPMYY). It is also responsible for the generation of UTCr that has been recently updated to maintain a rapid availability and a close agreement (1 ns) with UTC.

The topics related to the construction of TAI and UTC are mainly addressed in two CCTF Working Groups:

- Working Group on International Atomic Time (WGTAI) [16]
- Working Group on Time Scale Algorithms (WG-ALGO) [17]

WGs GNSS, TWSTFT, and PSFS are also involved, by giving direct inputs on the links and PSFS to be used.

The WGTAI is the largest Working group in the CCTF and comprises all timing laboratories contributing to UTC, and CCTF key liaisons. It is the interface between UTC labs and BIPM and treats topics that the UTC labs propose such as Technical Exchanges, discussion forum, and CBKT. Its agenda changes over the years depending on the key issues occupying the timing community. Over the last few years, the WGTAI has been focusing on better equipping UTC laboratories with tools and resources to improve the quality of UTC(*k*) data submissions to the BIPM, laboratory automation, traceability of UTC(*k*) links and dissemination services.

A web forum platform was created on the WGTAI website to improve communication and information sharing between timing laboratories. During the WGTAI virtual meetings in the period 2021-2024, technical presentations were organized as training opportunities on specific topics relevant to UTC(*k*) operations. In 2021, four talks were presented on various solutions for automated equipment and measurement monitoring and validation. In 2022 the focus was on improving the understanding of the various sections of *Circular T* and on the changes to the UTC(*k*) uncertainty assignments and their impact on calibration and dissemination services. In 2022, eight talks from UTC(*k*) laboratories were presented on Network Time Dissemination Services, such as NTP. The meeting in 2023 focused on updates from the BIPM on various changes to *Circular T*, GNSS calibration status and CGPM resolutions.

WGTAI collaborates with other working groups and task forces to organize Technical Exchange meetings on topics relevant to their individual specialization. Two technical exchanges in 2024 focused on setting up a UTC(*k*) laboratory and expanding UTC(*k*) services. At the first session, “The fundamentals of getting started as a UTC contributor” there were four presentations from UTC(*k*) and BIPM and in the second session, “Case Studies from UTC laboratories: Up and Coming UTC(*k*) Labs and UTC(*k*) Labs Implementing Expanded Capacity” eight UTC(*k*) laboratories presented their systems and shared their experiences. Additional technical exchanges on other topics, such as traceability via GNSS broadcasts, the redefinition of the second, and continuous UTC were held in 2024 and 2025..

The goals of WG-ALGO are diverse: to promote and support the development and improvement of mathematical algorithms; to aid in the dissemination of the developed algorithms and tools to promote their correct use in time and frequency metrology; to support any necessary modernization and improvement of the TAI algorithm should a need arise, and support the validation of the proposed updates in TAI algorithm; to assist developing or new laboratories in the correct understanding and implementation of time and frequency algorithms; to support the correct understanding and application of time and frequency algorithms in other fields of study; and to organize workshops and symposia to support the scientific community to identify new needs and to devise, develop, and disseminate algorithms.

There are currently 15 members of WG-ALGO. The membership includes representatives of the laboratories contributing to TAI with expertise and interest in algorithms, individuals responsible for

TAI at the BIPM, and members of other organizations and institutions interested in the development and use of algorithms.

The current main focus of WG-ALGO is to develop learning opportunities for the community through workshops and other capacity building opportunities in conjunction with the WGTAI and the BIPM Time Department.

The mandates of these two Working groups overlap with the CCTF "hot topic" activities on "Sharing of resources to improve international timekeeping" (see Section 10) and starting in 2023 the WGTAI and the WG-ALGO took over the responsibility for implementing some of the activities recommended by the "hot topic" initiative listed above. At the CCTF meeting in 2025, WG-ALGO was disbanded due to limited availability of the community, but its major activities are maintained in WGTAI and in the TG "Sharing of resources to improve international timekeeping".

7.2 Continuous UTC and leap seconds

Coordinated Universal Time (UTC) is derived from International Atomic Time (TAI), by adjustments that maintain a link between UTC and UT1, a time scale related to the angular position of Earth. Since 1972, the adjustments have been realized by one-second changes in UTC with respect to TAI whenever the magnitude of the difference UT1-UTC is predicted to approach 0.9 s. An adjustment of 10 seconds was added to UTC in 1972 to compensate for the deviation between UT1 and UTC since 1958, and an additional 27 seconds have been added to UTC since that time. The last leap second adjustment was made at the end of 2016.

Leap seconds have been inserted into the last minute of the last day of June or December. The adjustment process introduces a discontinuity in frequency and in time-interval calculations. In addition, the official name of the leap second is 23:59:60, which is a time stamp that cannot be represented by most clocks and especially by time systems that represent time as the number of seconds since some origin. These difficulties have been recognized for some time; they have become increasingly serious in recent years because of the many technical, commercial and financial applications of time and frequency data and signals.

The CCTF considered this issue, and from the online questionnaire in 2021, realized that the discontinuities in UTC are a threat for the synchronization of national critical infrastructures. In addition, several users are opting for other reference time scales such as GPS time or TAI, creating a potential confusion and undermining the recognition of UTC as unique international time standard [18]. This led the CGPM in 2022 to adopt Resolution 4 "On the use and future development of UTC" [19] deciding that the maximum value for the difference (UT1-UTC) will be increased in, or before, 2035.

The insertion of the leap second and the code for transmitting the offset UT1-UTC by radio stations are described in a Recommendation of the International Telecommunication Union [20]. To coherently update the ITU recommendation, the CCTF community has worked in collaboration with the ITU for several years leading to the endorsement of the CGPM 2022 decision by the ITU World Radio Conference in November 2023 [21]. The WRC resolution recommends extending the tolerance UT1-UTC at least to 100 seconds and to implement continuous UTC in 2035.

The CGPM will consider the question at its next meeting in 2026 and will decide on the new tolerance, its implementation date and the periodicity with which this decision will have to be reconsidered in case a better understanding of the Earth's rotation in the future would allow a more adapted solution.

The CCTF has evaluated three possibilities for the value of the tolerance:

- A new tolerance of the order of minutes. Based on the historical record, this maximum tolerance would not be reached for about a century. The historical deviations from the long-term trend in the evolution of UT1-UTC do not significantly change this estimate.
- A new tolerance of the order of one hour. This tolerance would never have been reached in the historical record back to the 17th century and will not be reached for several centuries to come.
- Allowing an unbounded value for UT1 - UTC. At least for the foreseeable future, this option is not different from option 2 – both of them would not require any adjustment to UTC for the next few centuries.

The maximum value for the difference |UT1-UTC|that will be proposed to the 28th meeting of the CGPM (2026) will be 3600 seconds (1 hour), ensuring the long-term continuity of UTC for several centuries.

Whatever the choice, the knowledge of the value of UT1-UTC is necessary for several users and will be made available by the IERS. The CCTF is engaged in collaborating with the IERS to help with the dissemination of this value.

The Length of Day (LOD) has been increasing for many centuries so that the second of UT1 time is longer than the second in UTC. Therefore, only positive adjustments have been required until now. These adjustments effectively slow the advance of UTC so that UT1 can catch up. The LOD has nevertheless been decreasing since at least about 1970. If this trend were to continue, a negative leap second would be required. The possibility of a negative leap second is a concern because it has not previously been applied, and it is considered to pose a high risk of causing anomalies and disruption to many critical infrastructures that are largely unprepared, and the preparation would create, for the synchronization industries, a need for financial investment, whose amount is estimated to be similar to their preparation for the millennium bug. Moreover, the growing influence of IoT (Internet of Things) technologies, dispersed multi-sensor systems, smart grids, and virtual services for contemporary society, creates an increasing risk of malfunction or breaks in operation of many systems and services with any leap second, especially a negative one.

The possibility for a negative leap second has increased the pressure on changing the method of relating UTC to UT1 in the near future, before 2035. In 2025, a workshop organized by the CCTF and IERS, including experts on earth rotation, estimated that the probability of a negative leap second before 2035 is approximately 30 % and increases rapidly in the following years. Following that workshop, the CCTF concluded that an acceptable risk of about 5 % probability can be ensured only within 2027–2028, taking into account the large uncertainty of any Earth rotation prediction model. That is why a proposal will be made to the 28th meeting of the CGPM (2026) that continuous UTC becomes effective on 20 May 2027).

In relation to this topic, the CCTF is working in close contact with the user communities and the affected International Organizations, such as the ITU, IAU and IUGG to address these concerns with the best possible consensus.

7.3 Mutual benefit of UTC and GNSS

The optimal use of GNSS signals in the process of generating UTC is the main focus of the GNSS Working Group (see Section 6). In parallel, the use and benefits of UTC for GNSS operators should be highlighted. Each GNSS provides a prediction of the difference between its reference time scale and

UTC in its signal, possibly via some UTC(*k*). This allows any GNSS receiver to determine the synchronization error between its clock and the prediction of UTC broadcast by the GNSS, and hence to synchronize its clock on this prediction of UTC. The reception of signals from GNSS as a source of time and frequency (synchronization and syntonization) has found wide use in many sectors, including electrical power supply, telecommunications, and financial institutions. Furthermore, there is an increasing demand for traceability to UTC, whatever the source of time signals, but in particular for the GNSS disciplined clocks. The CCTF created a Task Group with the goal to propose practical steps to ensure traceability to UTC from GNSS measurements to a wide community of GNSS users, depending on the required uncertainty in time and frequency offset from UTC. Some practical measures are suggested that can be followed by users in addition to improvements to the services provided by National Metrology Institutes (NMIs) [22].

In order to strengthen the benefit of UTC to the GNSS community, the CCTF recommended that the BIPM continues to validate the prediction of UTC broadcast by the GNSS in Section 4 of *Circular T*, adding the new GNSS constellations [23]. This validation is achieved thanks to calibrated multi-GNSS receivers maintained by some UTC(*k*) laboratories [24].

The CCTF promoted the use of UTC as a possible reference to determine the inter-system biases: combining GNSS signals from multiple constellations can significantly improve the positioning and timing performances at the user level, especially in situations of low visibility. However, it requires knowledge of the offsets between the different GNSS time scales, called inter-system biases [25]. Using the prediction of UTC broadcast by the different systems as a pivot to determine the inter-system biases eliminates the need to create an additional *ad hoc* time scale. This was recommended by the CCTF to the GNSS providers, at the International Committee of GNSS (ICG), a sub-committee of the United Nations, of which the core mission is to encourage co-ordination among providers of GNSS to ensure greater compatibility, interoperability and transparency. CCTF studies have confirmed that the current differences between the broadcast UTC predictions have no significant impact on GNSS positioning and timing.

7.4 Lunar time

There is a growing interest in space missions around or on the Moon. Various State's space agencies and private investors are working on plans to launch and operate spacecraft in the cislunar environment and are looking for a framework that would enable easier and more efficient positioning and data transfer. Possible interoperability of the devices is seen as a cost-cutting and performance enhancement feature.

This calls for the establishment of standards embracing these aspects, including lunar reference systems, with a higher accuracy than what has been sufficient until now.

The question of a Lunar Time and its relationship with UTC is one of the central questions that has to be answered in order to set the requirements for the design of these missions. There is a growing consensus that this matter should be dealt with at an international level, involving the various organizations that discuss and regulate these standards. Multiple working groups are currently being initiated under the auspices of these organizations, including the CCTF, but also the IAU, IAG, ICG, ITU, etc... Good communication between these groups is pivotal to the discussions, and this is partially achieved by overlap in membership of these groups. Some members of the BIPM Time Department are currently members of these external Working Groups.

From a technical point of view, the situation is as follows: it is obvious that the proper framework for a Lunar Time reference has to be relativistic, as the difference of gravity potential between Earth surface and cislunar environment is very large. For example, an ideal clock on the Moon's surface, when compared to an ideal clock on Earth surface, would exhibit a drift larger than 50 µs/d, which will quickly be impossible to ignore for most practical purposes. On top of this secular drift, variations of the Earth-Moon distance (due to the eccentricity of the Moon's orbit) and other perturbations introduce pseudo-periodic variations (amplitude around 0.6 µs). It is therefore difficult to use UTC directly as the reference time scale in the cislunar environment, and space missions' designers are asking for an intermediate, practical, coordinated time scale that would be used as the reference time scale in this environment, effectively mimicking the UTC time scale we use on Earth. While point-to-point relationships are always possible to calculate or model, a lunar coordinated time that would be useful for synchronizing clocks globally in a cislunar environment is much harder to design, and thorough studies will be required to determine what kind of errors will be encountered in the process.

Discussions are ongoing but some clear steps have already been taken: in its XXXII General Assembly in August 2024, the IAU issued three recommendations, two of them being related to Lunar time [26-27]. Resolution II states that the future Lunar time system is a particular case of the more general framework the IAU described in its previous 1991 and 2000 resolutions and provides a designation to refer to it. Resolution III explicitly mentions the BIPM as the producer of UTC and recommends that "the relationships between the possible versions of a lunar reference time scale and other time scales, in particular a lunar coordinate time and UTC, are pursued in collaborative agreement among the relevant international organizations". This is a strong message, which encourages the CCTF to work actively towards a consensus with other organizations.

8. CIPM Mutual Recognition Agreement (CIPM MRA)

The CIPM Mutual Recognition Agreement (CIPM MRA) [28] requires the establishment of the degree of equivalence of national measurement standards maintained by NMIs, to provide for the mutual recognition of calibration and measurement certificates issued by NMIs. It provides governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs. This aspect is particularly important in the field of time and frequency where TF measurements underpin legal activities and critical systems for security, defence, telecom, trading, etc. A dedicated CCTF Working Group on the CIPM MRA (CCTF-WGMRA) [29] has the task to provide guidance and procedures related to the CIPM MRA, Calibration and Measurement capabilities (CMCs) and comparisons in the following branches: Time scale difference, Frequency and Time interval. To fulfil this task, the WGMRA has published a number of guidance documents related to regional comparisons, traceability in the field of time and frequency, uncertainty of measurement and participation in CCTF key comparisons. The working group will review and update these documents over the next few years. Specific attention will be given to changes caused by the upgrade of the BIPM key comparison database (KCDB) interface and proposals for new CMC service categories. The working group will further cooperate with the working group on GNSS to formulate new guidelines on achieving traceability of GNSS time signals to UTC.

9. Other cross-cutting themes

9.1 Digitalization

Time and frequency metrology has used digital methods for organizing and maintaining the activities that support the continuous key comparison CCTF-K001.UTC since early in its operation. The nature of the time coordinate implies real-time measurements, which are generally computerized, and network connected.

Standardized plain text data formats such as RINEX, CGGTTS and ITU-R TF.1153 are utilized to store and distribute GNSS and TWSTFT measurements for post-processing. Those data formats have evolved since their conception in the 1980s but have been functionally stable and adequate over a long time. However, they can be perceived as not being modern and lacking in terms of security. The working groups in GNSS and TWSTFT are planning to improve on the current file formats in the long term. File-based data is usually transported using legacy protocols such as FTP, SMTP or HTTP over open IP networks, which are also questionable in terms of security and authentication of the source of data. Today, transport security is often enforced by the individual institutes but there is no consensus or recommendation on its use and the BIPM is, for legacy reasons, still using FTP as its main tool for data collection and distribution of the UTC product.

Real-time application of time and frequency are typically IP protocol based, such as NTP/NTS or IEEE-1588 and are widely deployed on an application level and provide a typical NMI's major time distribution to the public. Augmentation of GNSS is usually not used by time metrology but is common for many user applications and use standards published by RTCM, SPARTN or 3GPP with varying levels of transport security. These are not specific for timing and typically allow an improvement in application timing or can be used to provide traceability. Furthermore, instrumentation, such as GNSS receivers or laboratory instruments, often provide vendor specific solutions that risk FAIR principles due to the proprietary nature of the data formats used.

During recent years the BIPM Time Department has made several efforts to make the UTC product and the CCL data base more machine readable by providing Application Programming Interface (API) access. This is a major step towards a modernization of the metrological timing infrastructure. In combination with the digital SI-reference point, users have access to a coherent representation of UTC and UTC(*k*). A similar approach could be recommended for the data input from the NMIs and DIs to the BIPM that could also facilitate FAIR principles for those institutes. For completeness, the digital access to CMCs, calibrations and calibration certificates with APIs are anticipated in the future. Provision of machine-readable standard algorithms and test vectors are yet another step towards providing FAIR knowledge transfer to new institutes and to the public. This is however not specific to time and frequency metrology but should use a common metrological framework.

The most serious shortcoming of the current approach on metrological time data handling is the total lack of proof of authenticity and it is strongly recommended to be developed in the near future. Whereas data transport security is relatively mature and implementable using current internet standards and practices, a metrological data authentication layer requires new approaches that allow the identification and documentation of the source of information.

The CCTF WGSP has inaugurated an informal group of metrologists and data experts that will be able to make recommendations based on the input of the different working groups. This group is represented in the Forum on Metrology and Digitalization (FORUM-MD) as part of its FORUM-MD Working Group on coordination between Consultative Committees (FORUM-MD-WG-CC).

9.2 Quantum Technologies

The ongoing synergy between TF metrology and quantum technologies represents a profound paradigm shift, moving beyond incremental improvements to fundamentally redefine the nature of timekeeping.

Atomic timekeeping is by definition a quantum technology, and the advent of laser-cooled atomic frequency standards resulted in the embedding of complex quantum processes in the exploitation of an atomic system as a reference for time and frequency.

If we elaborate more than the essence of an atomic clock as a quantum standard, we have to analyze the relationship between time and frequency metrology and the main branches of quantum technologies, i.e. quantum computing and simulation, quantum sensing and quantum communications.

Improving Atomic clocks with different quantum principles

While traditional atomic clocks rely on the stable, well-understood transitions of individual atoms, more quantum principles can be embedded in frequency standards. For many years, the use of squeezed states in atomic clock has been demonstrated [30], but effective advantages are not yet available. Several groups focus on the quest for an effective squeezing protocol that is able to offer an improvement of one order of magnitude for the clock instabilities. Moreover, new approaches delve into more complex quantum states, such as new schemes for Sisyphus cooling in optical clocks [31], to achieve better accuracy. Superposition and entanglement, across ensembles of atoms, are another area of research for improvements. This collective quantum behaviour promises for a more robust and less susceptible-to-noise measurement of time, leading to enhanced stability and a dramatic reduction in systematic uncertainties.

Quantum computing: platforms based on ions and neutral atoms

The relationship between quantum computing and time and frequency metrology had a strong connection in the past, when ions logic gates were demonstrated [32]. Since then, the advent of quantum computers based on superconductive junctions prevented the relation with time and frequency to be fully exploited. In recent years [33] quantum computing based on atomic platforms, both ions and neutral atoms, promises to establish a new fruitful interconnection. Indeed, quantum computers and atomic clocks have a common need: exploiting the use of quantum-forbidden atomic transitions, as insensitive as possible to decoherence and coupling with perturbing external fields. The difference is to address the logic qubit or locking a laser radiation frequency to an atomic reference, but most of the techniques are quite similar. A peculiar attribute of quantum computers is scalability, i.e. the need to collect, address and manipulate as many atoms as possible, possibly billions, and to exploit entanglement. As depicted in the previous paragraph, this could be very useful for clocks, boosting the use for precise measurement of time and frequency of large ensembles of atoms, maybe entangled.

Quantum sensing: clocks as spacetime quantum sensors, and the role of magnetometry and electric field measurement

The accuracy and stability demonstrated for contemporary atomic clocks are powerful features for sensing more than time. Indeed, atomic clocks have already been demonstrated as sensors for probing the fabric of spacetime. Experiments designed to test the predictions of general relativity, particularly those involving the subtle effects of gravitational time dilation, are benefiting immensely from the exquisite sensitivity of these new timekeepers. Chronometric levelling promises to open a new approach to spacetime in the Earth's gravitational field and beyond.

The same approach can be exploited in magnetometry and electric field sensing, where time and frequency measurement in atomic vapours offer sensing features of growing interest because of its sensitivity.

For those sensors, miniaturization is a relevant issue, and the development of portable and miniaturized quantum clocks is increasing its interest. The ability to deploy highly accurate timekeepers outside of specialized laboratories and in small devices is particularly relevant for electronics and space systems. This is a technological challenge, particularly how to reduce size, weight and consumption preventing the degradation of stability and accuracy. The new frontier is made up of traditional atomic clocks embedded in photonic platforms [34], but also the exploitation of nuclear transitions using ions in a solid matrix [35], avoiding the use of vacuum technology or laser cooling. This represents a large step forward from the technological point of view, even if for the moment the transition frequencies are in the ultraviolet domain.

Quantum communication: QKD protecting time dissemination and the limitations of time jitter in quantum communications

Precise clock synchronization signal distribution is of the utmost importance in applications such as financial transactions, classical communications, positioning and navigation. The infrastructures for accurate time dissemination are now considered critical and their resilience is a challenge. It is possible to encode the time signal to deny unauthorized use, for example, for the Global Positioning System (GPS) till 2000, when the so-called "Selective Availability" option was switched off. Quantum key distribution (QKD) and Quantum Communication can be used today to protect the dissemination of Time, as demonstrated in [36]: one of the first examples of quantum communication for time metrology.

A practical demonstration of frequency metrology for quantum communication is the effective implementation of the technique known as Twin-Field QKD [37].

Another relevant point is that any QKD and entanglement distribution [for examples, 38 and 39] relies on the detection of time of arrival and coincidences of single photons. One of the main limits to the bit rate is the jitter in this timing measurement. Synchronization from GNSS is often used, but in this case, an improvement of time dissemination could support better performances of the quantum communication, in particular in terms of bit error rate and secret key rate.

The long-term vision for time metrology and quantum technologies is for a global network of interconnected quantum clocks, operating with unprecedented accuracy and stability. Such a network could provide a universal, highly-reliable time standard that would benefit a wide range of scientific, technological and societal applications. The network will be connected to users with different techniques, namely more traditional satellite techniques, or the more advanced but now consolidated fibre optic connections.

In conclusion, the convergence of time metrology and quantum technologies is a transformative force, reshaping our understanding and utilization of time. From fundamental physics research to practical applications in navigation, telecommunications, and beyond, quantum clocks are poised to revolutionize the way we measure and interact with the temporal dimension. As research continues and technologies mature, the full potential of this exciting field will undoubtedly unfold, leading to a future where timekeeping is more accurate, more stable, and more deeply intertwined with the quantum nature of reality.

The technological exchange between time and frequency dissemination and quantum communication will provide cross-fertilization between the two disciplines, as well the common technological basis between atomic clocks and quantum computers based on atomic platforms. The exploration of entanglement-enhanced measurements, the development of new quantum algorithms for clock operation, and the search for novel quantum systems suitable for timekeeping are just a few more examples of the many avenues being pursued.

10. Resource sharing for capacity building and improving (inter)national timekeeping

One of the CCTF's priority themes at the moment and in the near future is to enhance the capabilities of timing laboratories across a large number of NMIs to improve their UTC(*k*) realization capacity and ultimately to improve the accuracy of UTC. The CCTF aims to achieve this goal by relying on available expertise and resources from different NMIs and by fostering and supporting a collaborative culture and resource sharing practices among NMIs and DIs.

The UTC time scale is a product and a service that relies entirely on the community it supports and serves. Regular, timely, accurate and complete data submission to the BIPM by the UTC(*k*) laboratories is essential for constructing a time scale that can meet the accuracy requirements of the most challenging metrology applications and support the transition to the optically-based SI second. There are around 90 UTC(*k*) laboratories with varying levels of data processing automation and validation implemented and any anomalies in their clock or link data have the potential to impact UTC and affect the entire timing community as well as the users of accurate time everywhere. By learning about the best practices and the best methods implemented across the laboratories, the UTC(*k*) community can greatly enhance its overall capacity and data quality.

There are several guideline documents prepared by the BIPM Time Department that describe the submission process in detail, the equipment requirements and the data format. These can be found on BIPM Time Department database at [40]. However, the data submitted to the BIPM for the computation of UTC and Rapid UTC (UTCr) often presents problems that call for the special attention of BIPM staff, including double checking and contacting the originating laboratory, which require additional time and, in some cases, additional manual interventions during the computation. Making the submission process more efficient will help achieve full automation of the computation process, which would reduce the delays, the need for additional resources, and most importantly, the risk of errors.
The most common and critical problems encountered in the data submission include:

- Missing files or missing data inside the files
- Wrong data format, file naming convention, date and month allocation, measurement units
- Problems with data accuracy and consistency with previous submissions, disagreements between UTC and UTCr submissions.

These and other issues (for example, phase jumps caused by controlled laboratory activity) with submission data show that a pre-processing or just a simple visualization of the data in the UTC laboratory, before submitting it to the BIPM, would help in detecting and possibly solving the problems. The CCTF is aiming to share the pre-processing tools among laboratories to help each laboratory provide the best quality data which would mean better UTC(*k*), and, hence, better UTC. The implementation of these automated tools becomes increasingly important when the regularity of data submission (daily for UTCr) makes manual data validation impossible. The first such tool, the software for visualizing the TF link data in the CGGTTS format has been developed by a secondee to the BIPM Time Department in 2024 and is available to the community on the BIPM e-learning platform [41].

In parallel, in recent years the international community has been focusing on open and FAIR (Findable, Accessible, Interoperable and Reusable) data. The metrology community in particular has been developing new approaches to global information sharing and digital SI development. The TF community that has been sharing data as the basis of its operations (GNSS and TWSTFT links and clock measurements data) can lead by further incorporating the FAIR data standards and transitioning to a digital SI. Homogenizing data formats and access methods is key to data sharing, as it simplifies access and allows focusing on data processing and combination, rather than on the interface developments. It also allows for efficient sharing of software tools between the laboratories.

The survey of NMIs and DIs conducted by the CCTF in 2021 reinforced the notion that TF is a collaborative community where UTC(*k*) laboratories are interested in learning as well as sharing their expertise and resources. All but one responder indicated their interest in participating in capacity building activities and, moreover, UTC(*k*) operation strongly supported the addition of UTC training to BIPM core activities. In order to implement these initiatives and benefit from UTC(*k*), members' goodwill and initiatives to support their colleagues and the community, along with a continuous commitment and dedicated resources and activities under the guidance of the CCTF are required. The work started by the dedicated task group has been continued by the CCTF-WGTAI and a secondee position at the BIPM, starting in 2024, has focused their work on resource sharing tasks from platform setup, training material selection, collection and preparation, to SW tools and data standards development. The first e-learning course on "Time Transfer Through GNSS Pseudorange Measurements" has been developed by the BIPM secondee in collaboration with WGGNSS and is available through the BIPM e-learning platform [42]. A call to UTC(*k*) laboratories went out to share their software or training materials. In addition, the lecture materials from WGTAI Technical Exchanges are accessible on-line [43].

11. Activities to support the strategy

11.1 Progressing TF measurement science

The CCTF provides leadership and vision to NMIs, DIs and beyond (International Organizations and Unions, space agencies, industry, …) in support of TF measurement science, research and services. The particular focus is on cross-cutting "hot topics" with major scientific, technological and societal challenges, in particular: redefinition of the second, continuous UTC, Lunar reference time, traceability to UTC through GNSS measurements, capacity building and sharing of resources to improve national and international time scales. Atomic frequency standards, TF transfer techniques and construction, and dissemination of international time scales have been linked for decades to digitalization and quantum technologies; the CCTF pursues and strengthens its activities in support of these rapidly growing fields.

The CCTF has a guiding and coordinating role to support and promote progress on these topics and to support awareness through the production of documents and the organization of information exchanges and workshops. It will continue this coordination role not only with NMIs and DIs but also with major stakeholders to identify current and future challenges for TF measurements through CCTF strategy documents and work plans of the CCTF WGs and TGs, especially on the "hot topics":

- Redefinition of the second: choose the species or the ensemble of species and ensure the fulfilment of all mandatory criteria by pushing the limits of OFS and TF transfer techniques, with a decision on the redefinition targeted in 2030;
- Continuous UTC: fix the new maximum limit of UTC-UT1 and decide the date for the implementation of the change, taking into account the possible occurrence of a negative leap second in the next decade;
- Lunar Reference Time: converge towards a unique Lunar reference time scale traceable to UTC to ensure interoperability and comparability of measurements on the Moon;
- Traceability to UTC from GNSS measurements: raise the awareness and educate users about the methods to obtain traceability to UTC through GNSS and the importance of GNSS equipment calibration at user level, at a level appropriate to their requirements; encourage the NMIs to provide GNSS equipment calibration services and the RMOs to organize comparisons to support the validation of the calibration methods; inform industry about how they can support these traceability paths; facilitate recognition of these traceability paths by stakeholders and accreditation authorities;
- Resource sharing for capacity building: continue organizing regular technical exchanges and training materials on topics related to laboratories' performance improvement opportunities and on topics under study by various CCTF Working Groups and task groups.

Due to the ubiquitous use of time and frequency measurements, the CCTF promotes cross-discipline collaborations with other Consultative Committees. Some examples of these interfaces with other CCs: The CCU for the redefinition of the second, Joint CCL-CCTF WGFS for the recommended values of standard frequencies for the secondary realization of the second and the practical realization of the definition of the metre. In addition, the CCTF collaborates with the CCEM on phase noise measurements in oscillators and with the CCAUV on angular velocity (or rotational speed) measurements for tachometers, stroboscopes, centrifuges, etc.

11.2 Promoting global comparability

The CCTF ensures global comparability of time and frequency measurements by implementing the CIPM MRA in the field of time and frequency, in particular to:

- perform coordination activities relating to the CIPM MRA between RMOs;
- act as point of contact for the BIPM and Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) on CIPM MRA matters;
- identify areas where additional key comparisons and supplementary comparisons are needed, and develop the necessary guidelines and procedures;
- provide guidance on the range of CMCs supported by particular key and supplementary comparisons;
- establish and maintain a list of service categories, and where necessary, rules for the preparation of CMC entries;
- agree on detailed technical review criteria;
- coordinate the review of existing CMCs in the context of new results of key and supplementary comparisons;
- define frames of reference, edits rules and organize education actions in collaboration with other CCTF WGs on specific topics, for instance the traceability to UTC with GNSS measurements.

Section 8 contains further information on the role and contribution of the CCTF WG on MRA in promoting global comparability and supporting the CIPM MRA.

11.3 Improving stakeholder involvement

The CCTF has a large international representation with typically 90 delegates representing at the CCTF meetings:

- 25 institutes as Members
- 3 institutes as Official Observers + several institutes as Invited Observers
- 5 Liaisons (IAU, IGS, ITU-R, IUGG, URSI)
- Guests (RMO representatives, …)

CCTF meetings have been organized every year between 2020 and 2025 to provide updated information and involve the community in a step-by-step approach. Future CCTF meetings are planned in 2027 and 2029 to prepare the decision on the redefinition of the second that is envisaged at the 29th meeting of the CGPM in 2030.

CCTF WGs and TGs membership ensure an inclusive and worldwide representation of institutes and Member States. For some specific topics, the organization of surveys, Technical Exchanges, workshops or dedicated sessions in international conferences allows the CCTF to provide information and messages to the concerned communities, and to get feedback from stakeholders to be considered in the reflections and taken into account in the decisions.

In order to optimize interactions with other communities, the CCTF and the BIPM Time Department are also represented in committees or WGs of international organizations, and participate regularly to international conferences to present the CCTF strategy, the progress and prospects in the various CCTF topics.

Our aim is to pursue these necessary interactions and strengthen the networking activities of the CCTF with major stakeholders (international organizations and unions, space agencies, industry, …) to take into account their vision in relation to the CCTF topics, especially the following ones: redefinition of the second, continuous UTC, Lunar reference time, traceability to UTC for GNSS measurements.

11.4 Interaction with RMO activities

RMOs are represented at the CCTF meetings by their Technical Committee Chairs and the CCTF activities and progress are presented at the meetings of the RMO Technical Committee on Time and Frequency (TCTF). They are systematically consulted on important topics and they are represented in the associated CCTF TGs. For instance, RMOS are represented in the TG on continuous UTC and they have been consulted about the preferred value and the date of implementation of the new tolerance for the difference between UTC and the time provided by the Earth orientation UT1.

RMOs are also deeply involved in the organization of the calibration of GNSS stations in the time laboratories, which are needed for their contribution to UTC.

11.5 Articulation with the work program of the BIPM Time Department

There is an excellent synergy between the CCTF and BIPM strategies and work plans. The BIPM Time Department strategy follows four main lines: [3]

1. To calculate, disseminate and improve the world reference time scale through integrating data from atomic clocks at the NMIs, continuing the process of automatization and availability of digital data.

2. To promote the importance and benefits to all user communities of a unique international reference time scale UTC, meeting the needs of the current and future user communities.
3. To support the work of NMIs in the development of optical frequency standards, their comparison, and use in time scales and UTC, towards a future redefinition of the second and of timekeeping based on optical clocks, following the roadmap of the CCTF.
4. To enhance the capacity of UTC labs to realize, monitor, and automate the generation and dissemination of UTC(*k*) time scales to serve their national and international users.

The BIPM Strategy and Work Programme contains details on future developments concerning TAI and UTC concepts, including redundant links and new link technologies, and also UTCr that is a very useful product for small and emerging labs for good timekeeping. The implementation of some developments is subject to the availability of secondees.

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ANNEX

General information (as of 2025)

CC Name: Consultative Committee for Time and Frequency

Date established: 1997, succeeding the Consultative Committee for the Definition of the Second (CCDS) that was set up by the CIPM in 1956

Webpage: https://www.bipm.org/en/committees/cc/cctf

CCTF President (since 2019): Pr. Noël Dimarcq (ARTEMIS, France)

CCTF Executive Secretary (since 2019): Dr. Patrizia Tavella (BIPM)

Number of Members: 25

Number of Official observers: 3

Number of Liaisons: 5

CCTF meetings in the period 2020-2025 (90-100 participants at each meeting)

22nd CCTF – Session 1	28,29 Oct. 2020	On-line
22nd CCTF – Session 2	11, 12, 18, 19 March 2021	On-line
23rd CCTF	29,30 June, 1 July 2022	On-line
CCTF Information meeting	16 Nov. 2023	On-line
24th CCTF – Session 1	14,15,21,22 Nov. 2024	On-line
24th CCTF – Session 2	18-19 Sept. 2025	In person at BIPM HQ (+ possible participation on-line)

Chairs of CCTF Working Groups

Working Group	Chair (over the period 2020 - Sept. 2025)	Chair (From Sept. 2025) (*)
CCTF Working Group on Strategic Planning (CCTF-WGSP)	CCTF President	CCTF President
CCTF Frequency Standards Working Group (CCL-CCTF-WGFS)	For the CCTF: S. Bize (LNE-SYRTE, France) For the CCL: M. Matus (BEV, Austria)	For the CCTF: H. Margolis (NPL, UK) For the CCL: M. Matus (BEV, Austria)
CCTF Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques (CCTF-WGATFT)	D. Calonico (INRIM, Italy)	D. Calonico (INRIM, Italy)
CCTF Working Group on GNSS Time Transfer (CCTF-WGGNSS)	P. Defraigne (ORB, Belgium)	P. Defraigne (ORB, Belgium)
CCTF Working Group on Primary and Secondary Frequency Standards (CCTF-WGPSFS)	S. Weyers (PTB, Germany)	F. Fang (NIM, China)
CCTF Working Group on TAI (CCTF-WGTAI)	M. Gerstvolf (NRC, Canada) till April 2025	J. Sherman (NIST, USA)
CCTF Working Group on the CIPM MRA (CCTF-WGMRA)	C. Matthee (NMISA, South Africa)	J. Achkar (LNE-OP, France)
CCTF Working Group on Time Scale Algorithms (CCTF-WG-ALGO)	Y. Hanado (NICT, Japan) till 2022 E. Donley (NIST, USA) since 2022	WG stopped in Sept. 2025
CCTF Working Group on Two-Way Satellite Time and Frequency Transfer (CCTF-WGTWSTFT)	C. Rieck (RISE, Sweden)	C. Rieck (RISE, Sweden)

(*) Validated at the 24th CCTF-Session 2 meeting in Sept. 2025

Chairs of the CCTF Task Force on the Redefinition of the second and its subgroups (since its reorganization in 2022)

Task Force Redefinition of the second	Chair (over the period 2020 - Sept. 2025)	Chair (From Sept. 2025) (*)
Task Force	N. Dimarcq (ARTEMIS, France) P. Tavella (BIPM)	N. Dimarcq (ARTEMIS, France) P. Tavella (BIPM)
Task Force Subgroups:		
SG1 – Options for the new definition	S. Bize (LNE-SYRTE, France) F. Fang (NIM, China) E. Peik (PTB, Germany)	S. Bize (LNE-SYRTE, France) F. Fang (NIM, China) E. Peik (PTB, Germany)
SG2 – Criteria	D. Calonico (INRIM, Italy) T. Ido (NICT, Japan) S. Weyers (PTB, Germany)	D. Calonico (INRIM, Italy) T. Ido (NICT, Japan) S. Weyers (PTB, Germany)
SG3 – Education	M. Gertsvolf (NRC, Canada) till April 2025 G. Mileti (UNINE, Switzerland)	P. Arora (NPLI, India) G. Mileti (UNINE, Switzerland)

(*) Validated at the 24th CCTF-Session 2 meeting in Sept. 2025

(Co)Chairs of other CCTF Task Groups

Task Group	(co)Chairs (over the period 2020 - Sept. 2025)	(co)Chairs (From Sept. 2025) (*)
Leap seconds in UTC and building a consensus for a continuous time scale	J. Levine (NIST, USA) P. Tavella (BIPM)	T. Ido (NICT, Japan) P. Tavella (BIPM)
Lunar reference time (TG created in 2023)	P. Defraigne (ORB, Belgium) F. Meynadier (BIPM) P. Tavella (BIPM)	P. Defraigne (ORB, Belgium) M. Sekido (NICT, Japan)
Promotion of the mutual benefit of UTC and GNSS	P. Defraigne (ORB, Belgium) M. Wouters (NMIA, Australia) for the SG on the traceability to UTC of GNSS measurements	TG activity focused on traceability to UTC of GNSS measurements (see following raw)
TG Traceability to UTC		M. Wouters (NMIA, Australia)
Sharing of resources to improve international timekeeping	Coordination team: E. Donley (NIST, USA) M. Gertsvolf (NRC, Canada) till April 2025 P. Tavella (BIPM)	Coordination team: P. Arora (NPLI, India) J. Shermann (NIST, USA) P. Tavella (BIPM)
Digitalization (TG created in 2023)	C. Rieck (RISE, Sweden)	C. Rieck (RISE, Sweden)
Quantum technologies (TG created in 2023)	D. Calonico (INRIM, Italy)	D. Calonico (INRIM, Italy)

(*) Validated at the 24th CCTF-Session 2 meeting in Sept. 2025