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Contents

Page

Practical information about the BIPM Time Department

The BIPM Time Department issues four periodic publications. These are: UTCr (weekly), Circular T (monthly), TT(BIPM) (yearly) and the BIPM Annual Report on Time Activities.

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More information on the scientific work of the BIPM on time activities is available in https://www.bipm.org/en/publications/annual-review. All the documentation mentioned in this document is available on request from the BIPM.

WARNING : HTML links on the BIPM website changed in March 2021. For complete and up-to date information please refer to the BIPM Time Department's FTP server and Database.

Access to electronic files on the FTP server and the data base of the BIPM Time Department.

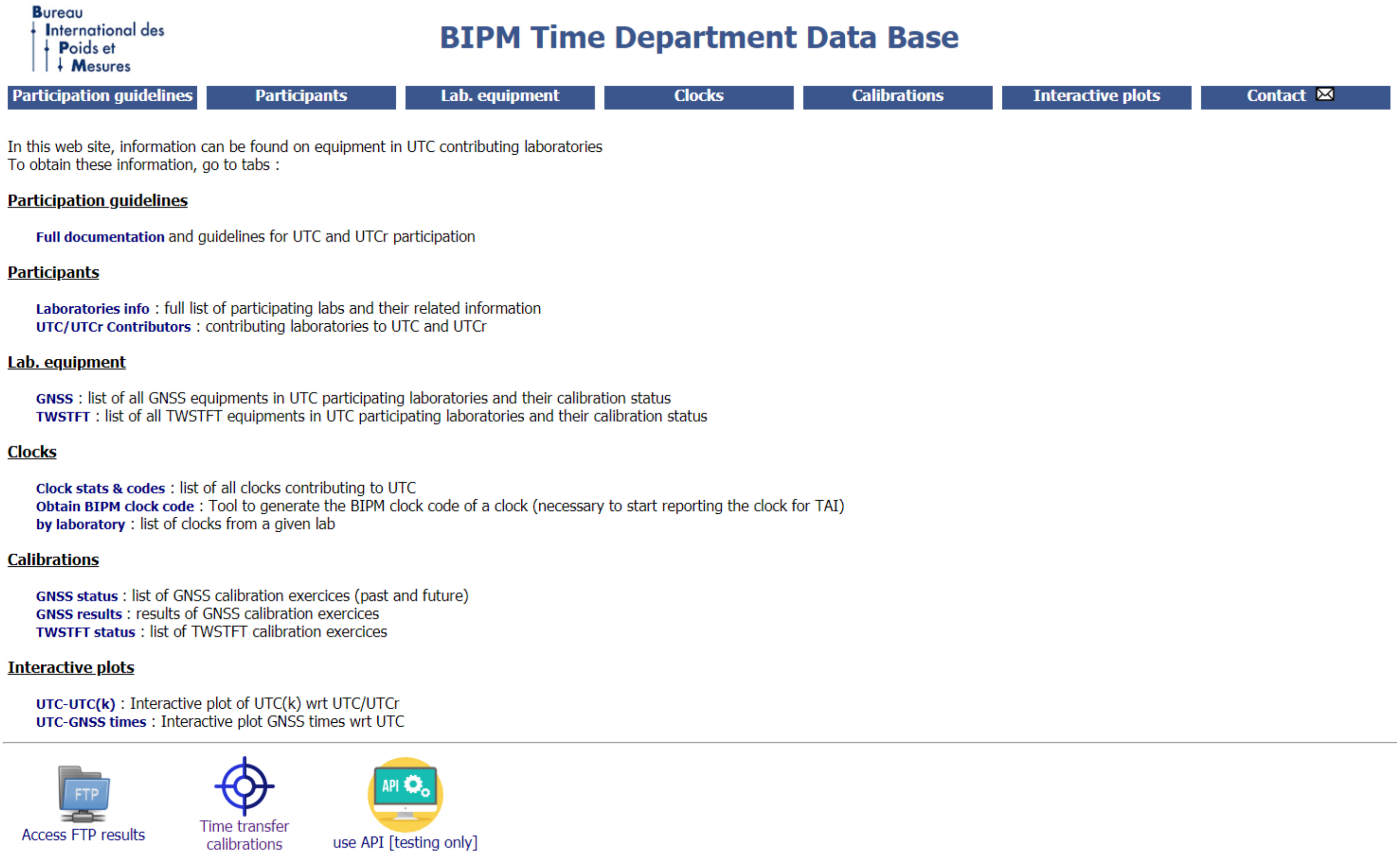
The files and information related to BIPM Time Activities are available from the website: https://www.bipm.org/en/time-metrology.

Items accessible through this webpage include :

1. Information on various time scales computed by the BIPM Time Department (TAI/UTC, UTCr, TT(BIPM),…)
2. Key comparison CCTF-K001.UTC results
3. BIPM products:
    a. BIPM Time Department FTP server : all publications on the public FTP server
    b. BIPM Time Department Database : information on participating laboratory equipment and interactive plots of published values.
    c. Information on calibration of time transfer systems used to generate UTC
    d. Application Programming Interface for diffusion of results by machine readable data

BIPM Time Department Database content :

The BIPM Time Department Database contains information on the UTC laboratory time scale, GNSS calibration and overall guidelines.



In this web site, information can be found on equipment in UTC contributing laboratories
To obtain these information, go to tabs :

Participation guidelines

Full documentation and guidelines for UTC and UTCr participation

Participants

Laboratories info : full list of participating labs and their related information
UTC/UTCr Contributors : contributing laboratories to UTC and UTCr

Lab. equipment

GNSS : list of all GNSS equipments in UTC participating laboratories and their calibration status
TWSTFT : list of all TWSTFT equipments in UTC participating laboratories and their calibration status

Clocks

Clock stats & codes : list of all clocks contributing to UTC
Obtain BIPM clock code : Tool to generate the BIPM clock code of a clock (necessary to start reporting the clock for TAI)
by laboratory : list of clocks from a given lab

Calibrations

GNSS status : list of GNSS calibration exercices (past and future)
GNSS results : results of GNSS calibration exercices
TWSTFT status : list of TWSTFT calibration exercices

Interactive plots

UTC-UTC(k) : Interactive plot of UTC(k) wrt UTC/UTCr
UTC-GNSS times : Interactive plot GNSS times wrt UTC

BIPM Time Department FTP server content :

The files can be found in the eight subdirectories: **Circular-T, Rapid-UTC, ttbipm, data, other-products, Links results, hardware delay characterization, and annual-reports.** They are all available by ftp (62.161.69.5 or ftp2.bipm.org, user anonymous, e-mail address as password, cd pub/tai).

Circular-T – All issues of BIPM *Circular T*.

Rapid-UTC – From February 2012 until June 2013 results of the Pilot Experiment on Rapid UTC (UTCr). Starting in July 2013 official results of Rapid UTC (UTCr).

TT(BIPM) – The realizations of terrestrial time TT(BIPMXY).

Data – All data used for the computation of TAI, including reports of evaluation of primary and secondary frequency standards and all clock and time transfer data files used for the computation of TAI, arranged in yearly directories. See readme for details.

Other-products – Other products, including time differences and monthly values of clock weights and frequency drifts, etc.

Links results – Results of time links and time link comparisons processed with *Circular T*.

Hardware delay characterization – All characterized hardware delays of time transfer equipment, including reports.

Annual reports – Archive of the BIPM Annual Reports on Time Activities and extracts from the BIH Annual Reports.

BIPM Time Department main products :

In the following directories XY represents the last two digits of the year number (19XY or 20XY); YYYY represents the year number; WW represents the week number in the year, ZT represents the month number in the year (01-12) except until 1997 when Z represents the two-month interval of TAI computation (Z =1 for Jan.-Feb., 2 for Mar.- Apr., etc…); XX, XXX are ordinal numbers.

products	**filename/link**
Acronyms of laboratories	Database
Circular T	cirt.XXX
Circular T HTML	cirt.XXX.html (starting 2016)
UTCr	UTCr_XYWW
Fractional frequency of EAL from primary and secondary frequency standards	etXY.ZT
Weights of clocks participating in the computation of TAI	wXY.ZT
Rates relative to TAI of clocks participating in the computation of TAI	rXY.ZT
Frequency drifts of clocks participating in the computation of TAI	dXY.ZT
Daily values of the differences between UTCr and its local representation by the given laboratory	UTCr - lab
Values of the differences between TAI and the local atomic scale of the given laboratory, including relevant notes	TAI - lab
Values of the differences between UTC and its local representation by the given laboratory including graphics and relevant notes	UTC - lab (+ plots)

Relations of UTC and TAI with GPS and GLONASS system times, and also with the predictions of UTC(*k*) disseminated by GNSS	UTC-GNSS (starting January 2011)
TT(BIPMXY) computation ending in 19XY or 20XY	TTBIPM.YYYY
Difference between the normalized frequencies of EAL and TAI	f(EAL)-f(TAI)
Difference between PSFS ensemble frequency and TAI frequency (d)	fpsfs-ftai
Difference between PSFS frequency and TAI frequency (d)	PSFS-ftai
Measurements of the duration of the TAI scale interval	utaiYYYY.pdf (starting 1995)
Mean fractional deviation of the TAI scale interval from that of TT duration of TAI scale interval	sitaiYYYY.pdf (starting 2000)

Information on time dissemination by laboratories :

Time scales data	**filename/link**
Time Dissemination Services	TIMESERVICES.PDF
Time Signals	TIMESIGNALS.PDF

The leap seconds table is no longer updated on the ftp site but it is available here: https://hpiers.obspm.fr/eoppc/bul/bulc/Leap_Second.dat

Older files can be accessed directly from the ftp site (62.161.69.5 or ftp2.bipm.org).

Any comments or queries should be sent to: tai@bipm.org

Leap seconds

Since 1 January 1988, the maintenance of International Atomic Time, TAI, and of Coordinated Universal Time, UTC (with the exception of decisions and announcements concerning leap seconds of UTC) has been the responsibility of the International Bureau of Weights and Measures (BIPM) under the authority of the International Committee for Weights and Measures (CIPM). The dates of leap seconds of UTC are decided and announced by the International Earth Rotation and Reference Systems Service (IERS), which is responsible for the determination of Earth rotation parameters and the maintenance of the related celestial and terrestrial reference systems.

Further information about leap seconds can be obtained from the IERS:

IERS Earth Orientation Centre
Dr Christian Bizouard
Observatoire de Paris
61, avenue de l'Observatoire
75014 Paris, France

Telephone:	+ 33 1 40 51 23 35
Telefax:	+ 33 1 40 51 22 91
Email:	services.iers@obspm.fr
Website:	http://hpiers.obspm.fr/eop-pc
Anonymous:	ftp://hpiers.obspm.fr or ftp://145.238.203.2/

Establishment of International Atomic Time and Coordinated Universal Time

1. Data and computation

International Atomic Time (TAI) and Coordinated Universal Time (UTC) are obtained from a combination of data from about 450 atomic clocks operated by more than 80 timing centres, which maintain a local UTC, UTC(*k*) (see https://webtai.bipm.org/database/showlab.html). The data are in the form of time differences [*UTC*(*k*) - *Clock*] taken at 5-day intervals for Modified Julian Dates (MJD) ending in 4 and 9, at 0 h UTC; these dates are referred to here as “standard dates”. The equipment maintained by the timing centres is detailed in Table 4.

An iterative algorithm produces a free atomic time scale, EAL (Échelle Atomique Libre), defined as a weighted average of clock readings. The processing is carried out and, subsequently, treats one month batches of data. The weighting procedure and clock frequency prediction [1, 2] are chosen such that EAL is optimized for long-term stability. No attempt is made to ensure the conformity of the EAL scale interval with the second of the International System of Units (SI).

2. Accuracy

The duration of the scale interval of EAL is evaluated by comparison with the data of primary frequency caesium standards and secondary frequency standards recommended for secondary representations of the second, correcting their proper frequency as needed to account for known effects (e.g. general relativity, blackbody radiation). TAI is then derived from EAL by adding a linear function of time with an appropriate slope to ensure the accuracy of the TAI scale interval. The frequency offset between TAI and EAL is changed when necessary to maintain accuracy, the magnitude of the changes being of the same order as the frequency fluctuations resulting from the instability of EAL. This operation is referred to as the “steering of TAI” and file feal-ftai gives the normalized frequency offsets between EAL and TAI. Measurements of the duration of the TAI scale interval and estimates of its mean duration are reported in Table 6 and Table 7.

3. Availability

TAI and UTC are made available in the form of time differences with respect to the local time scales UTC(*k*), which approximate UTC, and TA(*k*), the independent local atomic time scales. These differences, *[TAI - TA(k)]* and *[UTC - UTC(k)]*, are computed for the standard dates including uncertainties of
[UTC – UTC(*k*)] [3].

The computation of TAI/UTC is carried out every month and the results are published monthly in
Circular T.

The BIPM pilots the key comparison in time CCTF-K001.UTC. Institutes participating in the key comparison are National Metrology Institutes and Designated Institutes; they constitute a sub-set of the participants in *Circular T*.

A rapid solution, *UTCr* has been published without interruption since July 2013. Regular publication of the values *[UTCr - UTC(k)]* allows weekly access to a prediction of UTC [4] for about fifty laboratories, which also contribute to the regular monthly publication. However, the final results published in BIPM *Circular T* remain the only official source of traceability to the SI second for participating laboratories.

The difference between UTC and UTCr (calculated as a weighted average over the laboratories participating to UTCr) is reported in Figure (1) from August 2012 until June 2021.

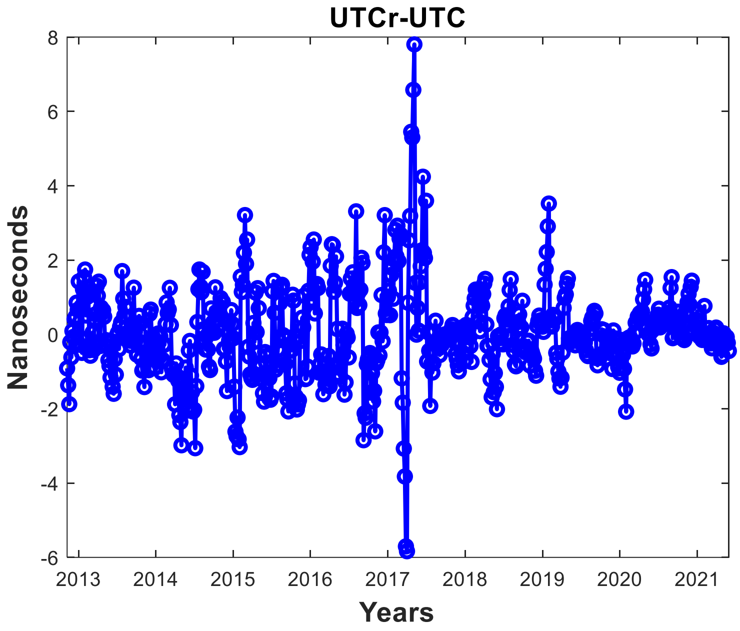


Figure 1. Difference between UTC and UTCr until June 2021.

4. Time links

The BIPM organizes the international network of time links to compare local realizations of UTC in contributing laboratories and uses them in the calculation of TAI. The network of time links used by the BIPM is non-redundant and relies on observation of GNSS satellites and on two-way satellite time and frequency transfer (TWSTFT). A first step in the use of redundant links was recently published [19].

Most time links are based on GPS satellite observations. Data from multi-channel dual-frequency GPS receivers are regularly used in the calculation of time links, in addition to that acquired by a few multi-channel single-frequency GPS time receivers. For those links realized using more than one technique, one of them is considered official for UTC and the others are calculated as back-ups. Single-frequency GPS data are corrected using the ionospheric maps produced by the Centre for Orbit Determination in Europe (CODE); all GPS data are corrected using precise satellite ephemerides and clocks produced by the International GNSS Service (IGS).

GPS links are computed using the method known as “GPS all in view” [5], with a network of time links that uses the PTB as a unique pivot laboratory for all the GPS links. Links between laboratories equipped with dual-frequency receivers providing Rinex format files are computed with the “Precise Point Positioning” method GPS PPP [6].

Clock comparisons using GLONASS C/A (L1C frequency) satellite observations with multi-channel receivers have been in use since October 2009 [7]. These links are computed using the “common-view” [8] method; data are corrected using the IAC ephemerides SP3 files and the CODE ionospheric maps. They can also be used in a combination of GPS and GLONASS links [9].

Finally, a combination of individual TWSTFT and GPS PPP links [10] are currently used in the calculation of TAI. The figure showing the time link techniques in the contributing laboratories can be downloaded from the BIPM website and is also reported below as “*Geographical distribution of the laboratories that contribute to TAI and time transfer equipment*”. For more detailed information on the equipment refer to Table 4, and to BIPM *Circular T* for the techniques and methods of time transfer officially used and for the values of the uncertainty of [$UTC(k_1) - UTC(k_2)$], obtained at the BIPM with these procedures.

Since March 2020, a link based on the Software Defined Radio receiver [11] has been regularly used in *Circular T* concerning the link UTC(OP)- UTC(PTB).

Starting from 2020 some links based on the European Galileo system are also computed and added as back up links. Research is progressing on the use of the Chinese Beidou navigation system, particularly in the exploration of the time transfer capacity of BDT3 [12, 13]. Some link based on the Integer PPP are also regularly computed and published on the BIPM web page [14].

The BIPM publishes in *Circular T* daily values of [*UTC – UTC(USNO)_GPS*] and [*UTC – UTC(SU)_GLONASS*] where *UTC(USNO)_GPS* and *UTC(SU)_GLONASS* are respectively, UTC(USNO) and UTC(SU) as predicted and broadcast by GPS and GLONASS. Evaluations of [*UTC - GPS time*] and [*UTC - GLONASS time*] are provided only through the ftp server of the Time Department. These tables are based on GPS data provided by the Paris Observatory (LNE-SYRTE), France, and on GLONASS data provided by the Astrogeodynamical Observatory (AOS), Poland.

5. Time scales established in retrospect

For the most demanding applications, such as millisecond pulsar timing, the BIPM retrospectively issues atomic time scales. These are designated TT(BIPMxx) where 19xx or 20xx is the year of computation [15, 16, 17]. The successive versions of TT(BIPMxx) are both updates and revisions; they may differ for common dates.

Starting with TT(BIPM09), until TT(BIPM12) extrapolation for the current year of the latest realization TT(BIPMxx) had been provided in the file TTBIPMxx.ext. It had been updated each month after the TAI computation. Starting with TT(BIPM13), a formula for extrapolation is provided in the file TTBIPM.yyyy where yyyy is the year number.

In Figure (2) the difference between the frequency of PFS/SFS and TTBIPM is reported.

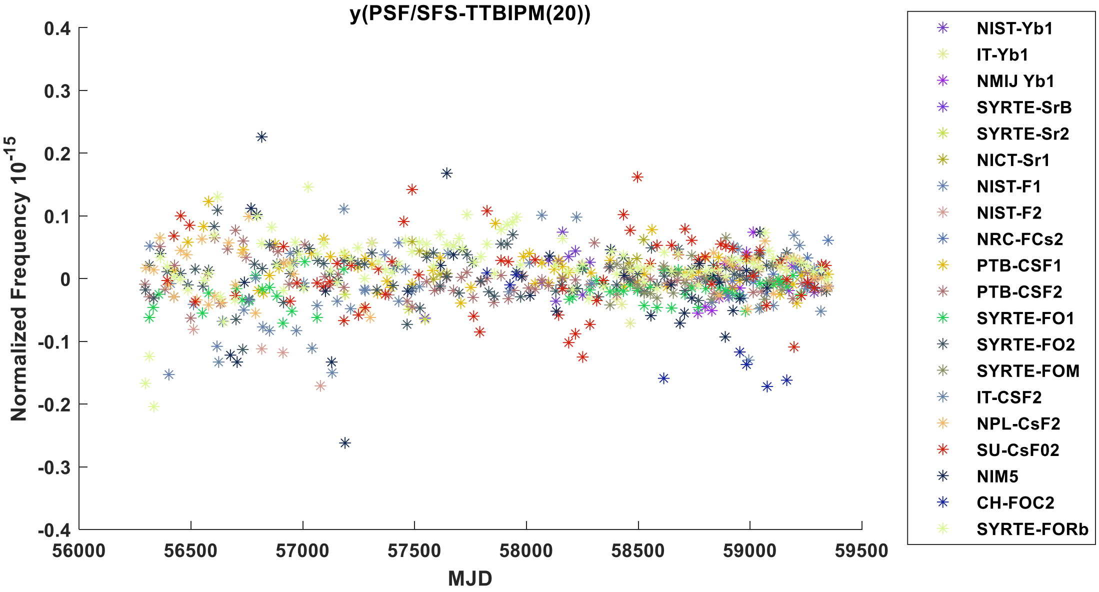


Figure 2. Difference between the frequency of PFS/SFS and TT (BIPM20).

Notes

Since January 2016 BIPM *Circular T* has been published in a new format with a different distribution of content in the sections. See https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.5.pdf .

Since September 2016, a Time Department Database has been made accessible via the website at https://webtai.bipm.org/database/. It contains all relevant information relating to contributions to UTC and UTCr.

A full list of time signals and time dissemination services is compiled by the BIPM from the information provided by the time laboratories.

A recent overview of UTC computation and realization can be found here [18]. A formal definition of TAI and UTC can be found in Resolution 2 of the 26th meeting of the CGPM (2018).
https://www.bipm.org/documents/20126/30876792/CGPM26.pdf/9db96c32-a986-e32a-09f9-3ed7e6c77cf7 .

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Geographical distribution of the laboratories that contribute to TAI and time transfer equipment (2020)

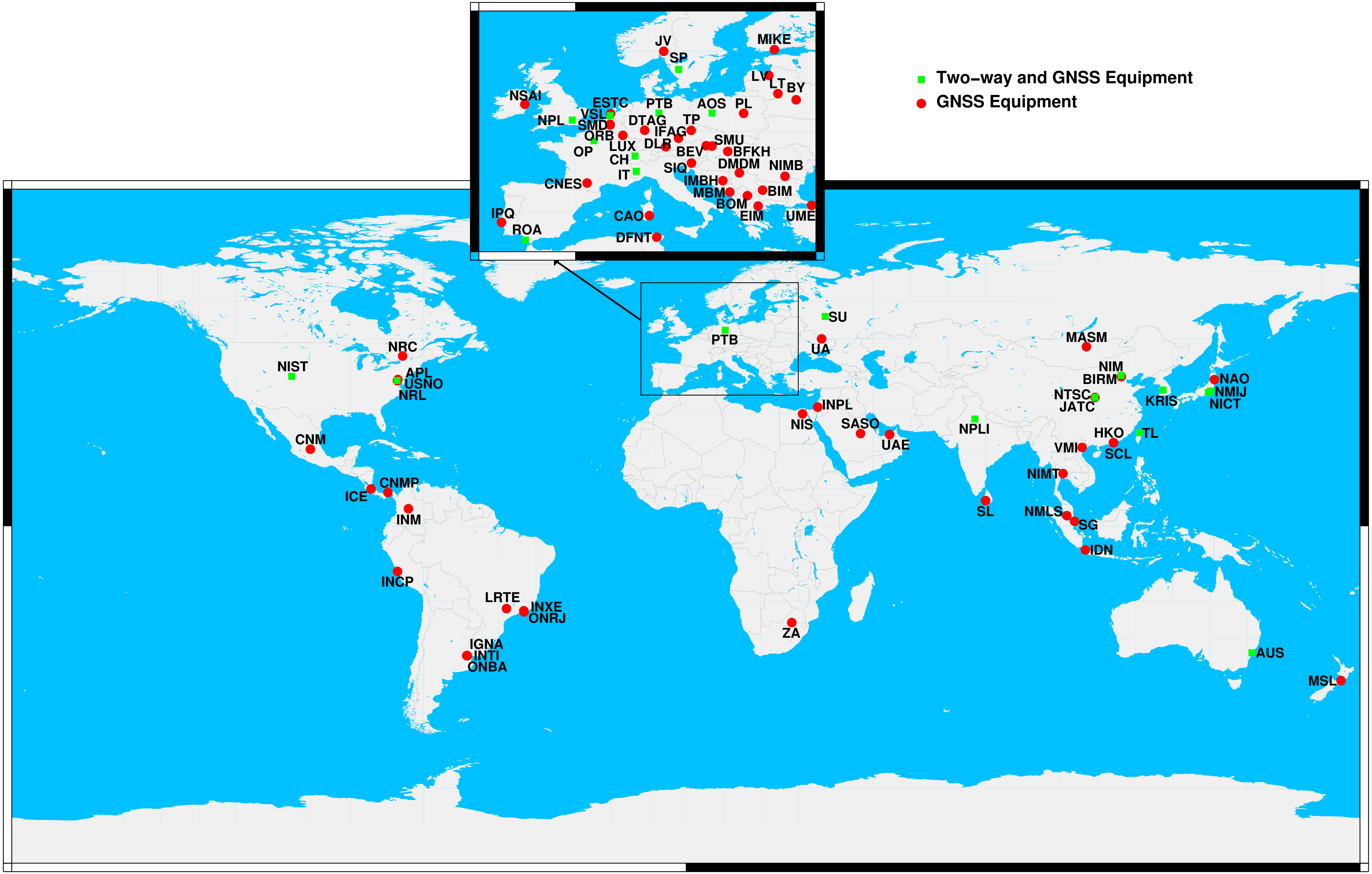

Table 1. Relative frequency offsets and step adjustments of UTC, up to 31 December 2021

Date (at 0 h UTC)	Offsets	Steps/s	
1961 Jan. 1		-150×10^{-10}	
1961 Aug. 1	"	+0.050	
1962 Jan. 1		-130×10^{-10}	
1963 Nov. 1	"		−0.100
1964 Jan. 1		-150×10^{-10}	
1964 Apr. 1	"		−0.100
1964 Sep. 1	"		−0.100
1965 Jan. 1	"		−0.100
1965 Mar. 1	"		−0.100
1965 Jul. 1	"		−0.100
1965 Sep. 1	"	−0.100	
1966 Jan. 1		-300×10^{-10}	
1968 Feb. 1	"		+0.100
1972 Jan. 1	0		−0.107 7580
1972 Jul. 1	"		−1
1973 Jan. 1	"		−1
1974 Jan. 1	"		−1
1975 Jan. 1	"		−1
1976 Jan. 1	"		−1
1977 Jan. 1	"		−1
1978 Jan. 1	"		−1
1979 Jan. 1	"		−1
1980 Jan. 1	"		−1
1981 Jul. 1	"		−1
1982 Jul. 1	"		−1
1983 Jul. 1	"		−1
1985 Jul. 1	"		−1
1988 Jan. 1	"		−1
1990 Jan. 1	"		−1
1991 Jan. 1	"		−1
1992 Jul. 1	"		−1
1993 Jul. 1	"		−1
1994 Jul. 1	"		−1
1996 Jan. 1	"		−1
1997 Jul. 1	"		−1
1999 Jan. 1	"		−1
2006 Jan. 1	"		−1
2009 Jan. 1	"		−1
2012 Jul. 1	"		−1
2015 Jul. 1	"		−1
2017 Jan. 1	"		−1

This table is also available here: https://hpiers.obspm.fr/eoppc/bul/bulc/TimeSteps.history

Table 2. Relationship between TAI and UTC, up to 31 December 2021

Limits of validity (at 0 h UTC)	[*TAI* - *UTC*] / s
1961 Jan. 1 - 1961 Aug. 1	1.422 8180 + (MJD - 37300) × 0.001 296
1961 Aug. 1 - 1962 Jan. 1	1.372 8180 + " "
1962 Jan. 1 - 1963 Nov. 1	1.845 8580 + (MJD - 37665) × 0.001 1232
1963 Nov. 1 - 1964 Jan. 1	1.945 8580 + " "
1964 Jan. 1 - 1964 Apr. 1	3.240 1300 + (MJD - 38761) × 0.001 296
1964 Apr. 1 - 1964 Sep. 1	3.340 1300 + " "
1964 Sep. 1 - 1965 Jan. 1	3.440 1300 + " "
1965 Jan. 1 - 1965 Mar. 1	3.540 1300 + " "
1965 Mar. 1 - 1965 Jul. 1	3.640 1300 + " "
1965 Jul. 1 - 1965 Sep. 1	3.740 1300 + " "
1965 Sep. 1 - 1966 Jan. 1	3.840 1300 + " "
1966 Jan. 1 - 1968 Feb. 1	4.313 1700 + (MJD - 39126) × 0.002 592
1968 Feb. 1 - 1972 Jan. 1	4.213 1700 + " "
1972 Jan. 1 - 1972 Jul. 1	10 (integral number of seconds)
1972 Jul. 1 - 1973 Jan. 1	11
1973 Jan. 1 - 1974 Jan. 1	12
1974 Jan. 1 - 1975 Jan. 1	13
1975 Jan. 1 - 1976 Jan. 1	14
1976 Jan. 1 - 1977 Jan. 1	15
1977 Jan. 1 - 1978 Jan. 1	16
1978 Jan. 1 - 1979 Jan. 1	17
1979 Jan. 1 - 1980 Jan. 1	18
1980 Jan. 1 - 1981 Jul. 1	19
1981 Jul. 1 - 1982 Jul. 1	20
1982 Jul. 1 - 1983 Jul. 1	21
1983 Jul. 1 - 1985 Jul. 1	22
1985 Jul. 1 - 1988 Jan. 1	23
1988 Jan. 1 - 1990 Jan. 1	24
1990 Jan. 1 - 1991 Jan. 1	25
1991 Jan. 1 - 1992 Jul. 1	26
1992 Jul. 1 - 1993 Jul. 1	27
1993 Jul. 1 - 1994 Jul. 1	28
1994 Jul. 1 - 1996 Jan. 1	29
1996 Jan. 1 - 1997 Jul. 1	30
1997 Jul. 1 - 1999 Jan. 1	31
1999 Jan. 1 - 2006 Jan. 1	32
2006 Jan. 1 - 2009 Jan. 1	33
2009 Jan. 1 - 2012 Jul. 1	34
2012 Jul. 1 - 2015 Jul. 1	35
2015 Jul. 1 - 2017 Jan. 1	36
2017 Jan. 1 -	37

This table is also available here: https://hpiers.obspm.fr/eoppc/bul/bulc/UTC-TAI.history

Table 3. Acronyms and locations of the timing centres which maintain a local approximation of UTC, UTC(*k*), and/or an independent local time scale, TA(*k*)

The up-to-date list and historical information of laboratories are available at https://webtai.bipm.org/database/showlab.html.

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2020

Equipment abbreviation used in this table

Atomic clocks (details can be found here)
Ind. Cs: industrial caesium standard
Ind. Rb: industrial rubidium standard
Lab. Cs: laboratory caesium standard
Lab. Rb: laboratory rubidium standard
Lab. Sr: laboratory strontium standard
Lab. Yb: laboratory ytterbium standard
H-maser: hydrogen maser

Time transfer techniques
GNSS: Global Navigation Satellite System receiver (details can be found here)
TWSTFT: Two-Way Satellite Time and Frequency Transfer (details can be found here)

* means ‘yes’

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
AOS (a)	3 Ind. Cs 2 H-masers (18)	1 H-maser (2) + microphase-stepper	* (18)	*	*	*
APL	4 Ind. Cs 3 H-masers	1 H-maser + frequency synthesizer steered to UTC(APL)			*	
AUS	5 Ind. Cs	1 Cs		*	*	*
BEV	2 Ind. Cs 1 H-maser	1 Cs		*	*	
BFKH	1 Ind. Cs	1 Cs			*	
BIM	2 Ind. Cs	1 Cs			*	
BIRM (a)	4 Ind. Cs 6 H-masers	1 H-maser + microphase-stepper		*	*	
BOM	2 Ind. Cs	1 Cs		*	*	
BY	7 H-masers	3-6 H-masers + microphase-stepper			*	
CAO (a)	2 Ind. Cs	1 Cs			*	

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
CH	1 Lab. Cs (3) 1 Ind. Cs (3) 4 H-masers	1 H-maser (3) + frequency synthesizer steered to UTC(CH.P)	*	*	*	*
CNES	5 Ind. Cs (4) 3 H-masers	1 H-maser (4) + microphase-stepper			*	
CNM	3 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper	*	*	*	
CNMP (a)	5 Ind. Cs	1 Cs + frequency offset generator		*	*	
DFNT	2 Ind. Cs	1 Cs			*	
DLR	5 Ind. Cs 3 H-masers	1 Cs + microphase-stepper		*	*	
DMDM	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
DTAG	3 Ind. Cs	1 Cs		*	*	
EIM	1 Ind. Cs	1 Cs			*	
ESTC	3 Ind. Cs 3 H-masers	1 H-maser + microphase-stepper		*	*	
HKO	2 Ind. Cs	1 Cs		*	*	
ICE	3 Ind. Cs	1 Cs + frequency offset generator		*	*	
IDN	4 Ind. Cs	1 Cs			*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2020 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
IFAG	5 Ind. Cs 2 H-masers (5)	1 Cs + microphase-stepper		*	*	
IGNA (a)	1 Ind. Cs	1 Cs + time/frequency steering		*	*	
IMBH	2 Ind. Cs	1 Cs + frequency offset generator		*	*	
INCP	2 Ind. Cs	1 Cs			*	
INM	3 Ind. Cs	1 Cs + microphase-stepper			*	
INPL	4 Ind. Cs	1 Cs			*	
INTI	3 Ind. Cs	1 Cs		*	*	
INXE	1 Ind. Cs 1 Ind. Rb 1 Lab. Cs	1 Cs + microphase-stepper		*	*	
IPQ	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
IT	4 Ind. Cs 4 H-masers 1 Lab. Cs 1 Lab. Yb	1 H-maser + microphase-stepper + time scale switch		*	*	*
JATC	8 Ind. Cs 3 H-masers	1 H-maser + microphase-stepper	*		*	
JV	3 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	
KRIS	2 Ind. Cs 4 H-masers	1 H-maser + microphase-stepper	*	*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2020 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
LRTE	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
LT	2 Ind. Cs	1 Cs		*	*	
LUX	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
LV	2 Ind. Cs	1 Cs			*	
MASM	1 Ind. Cs	1 Cs + time/frequency steering		*	*	
MBM	1 Ind. Cs	1 Cs			*	
MIKE	1 Ind. Cs 4 H-masers	1 H-maser + microphase-stepper		*	*	
MSL	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
NAO	4 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	
NICT	34 Ind. Cs 8 H-masers (7) 1 Lab. Cs 1 Lab. Sr (8)	1 H-maser (9) + microphase-stepper	* (10)	*	*	*
NIM	7 Ind. Cs 13 H-masers 1 Lab. Cs	1 H-maser + microphase-stepper		*	*	*
NIMB	2 Ind. Cs	1 Cs		*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2020 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
NIMT	4 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	
NIS	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
NIST	1 Lab. Cs 1 Lab. Yb 13 Ind. Cs 13 H-masers	4 Cs 7 H-masers + microphase-stepper	*	*	*	*
NMIJ	1 Ind. Cs 1 Lab. Cs 2 H-masers 1 Lab. Yb (11)	1 H-maser + microphase-stepper		*	*	*
NMLS	2 Ind. Cs	1 Cs		*	*	
NPL	2 Ind. Cs 5 H-masers	1 H-maser		*	*	*
NPLI	5 Ind. Cs 6 H-maser	1 H-maser + microphase-stepper		*	*	*
NRC	1 Lab. Cs (12) 6 Ind. Cs (13) 2 H-masers	1 H-maser + microphase-stepper	*	*	*	
NRL	1 Ind. Cs 8 H-masers	1 H-maser + Auxiliary Output Generator steered to UTC(NRL)		*	*	
NSAI	1 Ind. Cs	1 Cs		*	*	
NTSC	24 Ind. Cs 8 H-masers	1 H-maser + microphase-stepper	*	*	*	*
ONBA	2 Ind. Cs	1 Cs			*	
ONRJ	7 Ind. Cs 2 H-masers	7 Cs 2 H-masers + frequency offset generator	* (14)	*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2020 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
OP	3 Ind. Cs 3 Lab. Cs 1 Lab. Rb 2 Lab. Sr 5 H-masers	1 H-maser (15) + microphase-stepper	* (16)	*	*	*
ORB	3 Ind. Cs 2 H-maser	1 H-maser + femtostepper		*	*	
PL	12 Ind. Cs 5 H-masers	1 H-maser (17) + femtostepper	* (18)	*	*	* (19)
PTB	3 Ind. Cs 4 Lab. Cs (20) 6 H-masers	1 H-maser (21) + microphase-stepper	* (22)	*	*	*
ROA	6 Ind. Cs (23) 2 H-masers	1 H-maser (24) + frequency synthesizer steered to UTC(ROA)		*	*	*
SASO (a)	5 Ind. Cs	1 Cs		*	*	
SCL	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
SG	5 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
SIQ	1 Ind. Cs	1 Cs			*	
SL	1 Ind. Cs	1 Cs		*	*	
SMD	4 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
SMU	1 Ind. Cs	1 Cs + output frequency steering			*	
SP	16 Ind. Cs (25) 10 H-masers	1 H-maser + microphase-stepper		*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2020 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
SU	1 Lab. Cs (26) 4 Lab. Rb (27) 16 H-masers	8-14 H-masers (28)	* (29)	*	*	* (30)
TL	6 Ind. Cs 3 H-masers	1 H-maser (31) + microphase-stepper	* (31)	*	*	*
TP	4 Ind. Cs 2 H-maser	1 Cs + output frequency steering		*	*	
UA	2 Ind. Cs + (1 Ind. CS (32)) 4 H-masers 2 Lab. Rb (32)	2 Cs 2 H-masers + microphase-stepper	*		*	
UAE	3 Ind. Cs	3 Cs (33)			*	
UME	5 Ind. Cs 1 H-maser	1 H-maser + frequency offset generator		*	*	
USNO (a)	62 Ind. Cs 35 H-masers 6 Lab. Rb	1 H-maser (34) + frequency synthesizer steered to create UTC(USNO)	* (34)	*	*	*
VMI	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
VSL	3 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	*
ZA	2 H-maser	1 H-maser			*	

Notes

(a) Information based on the Annual Report for 2018, not confirmed by the laboratory.

(1) When several clocks are indicated as a source of UTC(*k*), laboratory k computes a software clock, steered to UTC. Often a physical realization of UTC(*k*) is obtained using a Cs clock or H-maser and a micro-phase-stepper.

(2) AOS The UTC(AOS) is formed technically using one hydrogen maser and microstepper, it is steered using TA(PL) data as a reference.
TA(PL) laboratories are linked via MC GPS-CV and/or two-directional optical fibre connections. Optical Fibre Link *UTC*(*AOS*)-*UTC*(*PL*) is 420 km long.

(3) CH All the standards are located in Bern at METAS (Swiss Federal Institute of Metrology).
In addition to the Ind. Cs, there is one active hydrogen maser and three passive hydrogen masers.
UTC(CH) is defined by one of two redundant master clocks, both steered to track the same paper time scale based on all the clocks.
The paper time scale is steered weekly to track UTC.
The Lab. Cs is FoCS2 a cesium fountain which is used as a primary frequency standard to evaluate TAI.

(4) CNES All the standards are located in Toulouse at CNES (French Space Agency).
UTC(CNES) is defined in real time by an H-Maser, steered to UTC.

(5) IFAG One H-maser is still in maintenance at the manufacturer and could not yet be returned due to COVID-19 limitations.

(6) KZ The standards are located as follows:

*Kazakhstan Institute for Metrology (Astana)	4 Cs
*South-Kazakhstan branch of Kazakhstan Institute for Metrology (Almaty)	1 Cs

(7) NICT The standards are located as follows:

* Koganei Headquarters	18 Cs, 6 H-masers
* Ohtakadoya-yama LF station	6 Cs
* Hagane-yama LF station	6 Cs
* Advanced ICT Research Institute in Kobe	6 Cs, 2 H-masers

(8) NICT The laboratory Sr (NICT-Sr1) is an optical lattice clock intermittently operated as a frequency standard. Contributions to TAI are made through comparison with NICT's hydrogen maser.

(9) NICT UTC(NICT) is generated from the output of a hydrogen maser, steered to TA(NICT) regularly, and steered to UTC if necessary.

(10) NICT The NICT atomic timescale TA(NICT) is computed from the weighted average of 18 commercial Cs clocks at the Koganei HQ.

(11) NMIJ The laboratory Yb (NMIJ-Yb1) is an optical lattice clock operated as a frequency standard. Contributions to TAI are made through comparison with UTC(NMIJ).

(12) NRC FCs2 is a fountain frequency standard using laser cooled caesium atoms.
FCs2 operated regularly and contributed to TAI.

Notes (Cont.)

(13) NRC The standards are located as follows:

* NRC Metrology (Ottawa)	1 Lab. Cs, 4 Cs, 2 H-masers
* CHU Time signal radio station (Ottawa)	2 Cs

(14) ONRJ The Brazilian atomic time scale TA(ONRJ) is computed by the National Observatory Time Service Division in Rio de Janeiro with data from seven industrial caesium clocks and two hydrogen masers.

(15) OP Since MJD 56218 UTC(OP) is based on the output signal of a H-maser frequency steered towards UTC using the LNE-SYRTE fountains calibrations.

(16) OP The French atomic time scale TA(F) is computed by the LNE-SYRTE with data from up to 18 industrial caesium clocks in 2020 located as follows :

* Direction Générale de l’Armement (DGA, Rennes)	2 Cs
* Centre National d’Etudes Spatiales (CNES, Toulouse)	4 Cs
* Orange Labs réseaux (Lannion)	1 Cs
* Observatoire de Paris (LNE-SYRTE, Paris)	3 Cs
* Observatoire de Besançon (OB, Besançon)	3 Cs
* Marine Nationale (Brest)	4 Cs
* Spectracom, Orolia (Les Ulis)	1 Cs

All laboratories are linked via GPS receivers. The TA(F) frequency is steered using the LNE-SYRTE PSFS data. The difference TA(F) – UTC(OP) is published in the OP Time Service Bulletin.

(17) PL The Polish official timescale UTC(PL) is maintained by the GUM.

(18) PL The Polish atomic timescale TA(PL) is computed by the AOS and GUM with data from 12 caesium clocks and five hydrogen masers located as follows:

* Central Office of Measures (GUM, Warsaw)	2 Cs, 1 H-maser
* Astrogeodynamical Observatory, Space Research Center P.A.S. (AOS, Borowiec)	2 Cs, 2 H-masers
* National Institute of Telecommunications (IŁ, Warsaw)	2 Cs, 1 H-maser
* Polish Telecom (Orange Polska S.A., Warsaw)	1 Cs
* Military Primary Standards Laboratory (CWOM, Warsaw and Poznan)	3 Cs
* Poznan Supercomputing and Networking Center (PSNC, Poznan)	1 H-maser

and additionally

* Time and Frequency Standard Laboratory of the Center for Physical Science and Technology (FTMC), a guest laboratory from Lithuania (LT, Vilnius, Lithuania)	2 Cs

All laboratories are linked via MC GPS-CV and/or two-directional optical fibre connections.

(19) PL NIT/GUM station of TWSTFT is maintained and operated by the National Institute of Telecommunications (IŁ) and is connected to UTC(PL) using the optical fibre link, with a stabilized propagation delay, of c. 30 km long.

Notes (Cont.)

(20) PTB The laboratory Cs, PTB CS1 and PTB CS2 are operated continuously as clocks.
PTB CSF1 and CSF2 are fountain frequency standards using laser cooled caesium atoms. Both are intermittently operated as frequency standards. Contributions to TAI are made through comparisons with one of PTB's hydrogen masers. PTB operates five active masers and one passive maser.

(21) PTB UTC(PTB) is based on the output of an active hydrogen maser steered in frequency since MJD 55224 (February 2010).

(22) PTB Since MJD 56079 0:00 UTC TA(PTB) has been generated from an active hydrogen maser, steered in frequency so as to follow PTB caesium fountains as close as possible. The deviation *d* between the fountains and the TAI second is not taken into account.
TAI-TA(PTB) got an initial arbitrary offset from TAI without continuity to the data reported in previous months.

(23) ROA The standards are located as follows:

* Real Observatorio de la Armada en San Fernando	5 Cs, 2 H-maser
* Centro Español de Metrología	1 Cs

(24) ROA Since March 2009, UTC(ROA) is defined in real time by a hydrogen maser, steered to the paper time scale UTC(ROA), which is defined as a weighted average of all the clocks, steered to UTC.

(25) SP The standards are located as follows:

* RISE Research Institutes of Sweden (RISE, Borås)	3 Cs, 4 H-masers
* RISE Research Institutes of Sweden (RISE, Stockholm)	5 Cs, 2 H-masers
* STUPI AB (Stockholm)	7 Cs, 2 H-masers
* Onsala Space Observatory (Onsala)	1 Cs, 2 H-masers

(26) SU CsFO1 and CsFO2 are fountain frequency standards using laser cooled caesium atoms.
CsFO2 operated as frequency standard almost regularly and contributed to TAI.

(27) SU Rb01 to Rb04 are fountain frequency standards using laser cooled rubidium atoms. These standards run continuously, sometimes with considerable gaps, and produce Rb(i) – H-maser(j) frequency difference on a one day basis. These values contributed into time scale maintenance.

(28) SU Laboratory computes UTC(SU) as a software clock, steered to UTC.

(29) SU TA(SU) is generated from an ensemble of active hydrogen masers, software steered in frequency so as to follow SU caesium fountains as close as possible. The deviation d between the fountains and the TAI second published in *Circular T* was not taken into account. TAI-TA(SU) has an initial arbitrary offset from TAI.

(30) SU TW time link was stopped at June 2017.

(31) TL TA(TL) is generated from a 6-caesium-clock + 3-hydrogen-maser hybrid ensemble from January 2019.
UTC(TL) is steered according to UTCr, UTC, and TA(TL).

Notes (Cont.)

(32)	UA	1 Ind. Cs, 2 Lab. Rb were tested and remain in reserve for use when necessary.
(33)	UAE	UTC (UAE) is a software clock, steered to UTC, based on the weighted average of the Cs clocks. A physical realization of UTC(UAE) is obtained using a Cs clock and a frequency synthesizer.
(34)	USNO	The time scales A.1(MEAN) and UTC(USNO) are computed by USNO. They are determined by a weighted average of Cs clocks, hydrogen masers, and rubidium fountains located at the USNO. A.1(MEAN) is a free atomic time scale, while UTC(USNO) is steered to UTC. Included in the total number of USNO atomic standards are the clocks located at the USNO Alternate Master Clock in Colorado Springs, CO.

Table 5. Differences between the normalized frequencies of EAL and TAI

Values of the difference between the normalized frequencies of EAL and TAI since the beginning of the steering, in 1977, are available at https://webtai.bipm.org/ftp/pub/tai/other-products/ealtai/feal-ftai). This file is updated on a monthly basis, with *Circular T* publication.

As the time scales UTC and TAI differ by an integral number of seconds (see Tables 1 and 2), UTC is necessarily subjected to the same intentional frequency adjustment as TAI.

Table 6. Measurements of the duration of the TAI scale interval

(File available on https://webtai.bipm.org/ftp/pub/tai/other-products/utai/)

TAI is a realization of coordinate time TT. The following tables give the fractional deviation *d* of the scale interval of TAI from that of TT (in practice the SI second on the geoid), i.e. the fractional frequency deviation of TAI with the opposite sign: $d = -y_{\mathrm{TAI}}$.

In Table 6A, *d* is obtained on the given periods of estimation by comparison of the TAI frequency with that of the primary frequency standards (PFS) IT-CsF2, METAS-FOC2, NIM5, NPL-CsF2, NRC-FCs2, PTB-CS1, PTB-CS2, PTB-CSF1, PTB-CSF2, SU-CsFO2, SYRTE-FO1, SYRTE-FO2 and SYRTE-FOM reported on the year 2020.
In Table 6B, *d* is obtained on the given periods of estimation by comparison of the TAI frequency with that of the secondary frequency standards (SFS) NICT-Sr1, NMIJ-Yb1 and SYRTE-FORb reported on the year 2020.
Previous calibrations are available in the successive annual reports of the BIPM Time Section volumes 1 to 18 and in the BIPM Annual Report on Time Activities volumes 1 to 14 (web only since volume 4 for 2009).

Each comparison is provided with the following information:
u_{A} is the uncertainty originating in the instability of the PFS,
u_{B} is the combined uncertainty from systematic effects (including the relativistic frequency shift),
$u_{\mathrm{A/lab}}$ and $u_{\mathrm{B/lab}}$ represent the uncertainty in the link between the standard and the clock participating in TAI, respectively from statistical fluctuations including the uncertainty due to the dead-time for $u_{\mathrm{A/lab}}$, and from systematic effects for $u_{\mathrm{B/lab}}$,
$u_{\mathrm{link/TAI}}$ is the uncertainty in the link to TAI, computed using the standard uncertainty of [UTC-UTC(*k*)],
u is the quadratic sum of all four uncertainty values.
Uptime is the percentage of the period of estimation when the frequency of the standard is actually measured.

In addition, Table 6B includes the following information:
u_{SRep} is the recommended uncertainty of the secondary representation of the second, as specified in the CIPM Recommendation identified under Ref(u_{S}).

In these tables, a frequency over a time interval is defined as the ratio of the end-point phase difference to the duration of the interval.

The typical characteristics of the calibrations of the TAI frequency provided by the different primary and secondary standards reported in 2020 are indicated below. Reports of individual evaluations may be found at https://webtai.bipm.org/ftp/pub/tai/data/PSFS_reports/. Ref(u_{B}) is a reference giving information on the value of u_{B} as stated in the 2020 reports, u_{B}(Ref) is the u_{B} value stated in this reference. Note that the current u_{B} values are generally not the same as the peer reviewed values given in Ref(u_{B}).

Primary Standard	Type /selection	Type B std. uncertainty/ 10^{-15}	u_{B}(Ref)/10^{-15}	Ref(u_{B})	Comparison with	Number/typical duration of comp.
IT-CsF2	Fountain	0.17 to 0.36	0.19	[1]	H maser	9 / 10 d to 35 d
METAS-FOC2	Fountain	1.4	1.99	[2]	H maser	4 / 25 d to 30 d
NIM5	Fountain	0.9	1.4	[3]	H maser	8 / 20 d to 30 d
NPL-CsF2	Fountain	0.24 to 0.48 then 0.20	0.23	[4]	UTC(NPL)	12 / 15 d to 35 d
NRC-FCs2	Fountain	0.21 to 0.54	0.23	[5]	H maser	14 / 25 d to 35 d
PTB-CS1	Beam /Mag.	8	8.	[6]	TAI	12 / 25 d to 35 d
PTB-CS2	Beam /Mag.	12	12.	[7]	TAI	12 / 25 d to 35 d
PTB-CSF1	Fountain	0.24 to 0.40	0.28	[8]	H maser	10 / 15 d to 35 d
PTB-CSF2	Fountain	0.17	0.17	[8]	H maser	14 / 10 d to 25 d
SU-CsFO2	Fountain	0.22	0.50	[9]	H maser	11 / 15 d to 35 d
SYRTE-FO1	Fountain	0.31 to 0.35	0.37	[10]	H maser	12 / 10 d to 35 d
SYRTE-FO2	Fountain	0.21 to 0.23	0.23	[10]	H maser	12 / 15 d to 30 d
SYRTE-FOM	Fountain	0.57 to 0.66	0.7	[10]	H maser	8 / 10 d to 35 d

Secondary Standard	Type	Type B std. uncertainty/ 10^{-15}	u_{B}(Ref)/10^{-15}	Ref(u_{B})	Comparison with	Number/typical duration of comp.
NICT-Sr1	Lattice	0.07	0.06	[11]	H maser	1 / 20 d
NMIJ-Yb1	Lattice	0.40 then 0.22	0.36	[12]	UTC(NMIJ)	12 / 5 d to 35 d
SYRTE-FORb	Fountain	0.25 to 0.26	0.34	[13]	H maser	12 / 10 d to 35 d

More detailed information on the characteristics and operation of individual PFS and SFS may be found in the annexes supplied by the individual laboratories.

Table 6A. Measurements of the duration of the TAI scale interval by Primary Frequency Standards

Until Circular T388, $u_{A/lab}$ and $u_{B/lab}$ were not reported separately and the total value of $u_{link/lab}$ appears under $u_{A/lab}$. The value of Uptime was not reported either.

Standard	Period of estimation		$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{A/lab}$ $/10^{-15}$	$u_{B/lab}$ $/10^{-15}$	$u_{link/TAI}$ $/10^{-15}$	$u/10^{-15}$	Uptime %	Note
IT-CsF2	58899	58914	-0.79	0.64	0.17	0.36		0.37	0.84		
IT-CsF2	58919	58934	0.05	0.71	0.17	0.51		0.37	0.96		
IT-CsF2	58939	58954	0.03	0.64	0.17	0.18		0.37	0.78		
IT-CsF2	58964	58974	-0.76	0.66	0.17	0.22	0.01	0.53	0.89	83.0	
IT-CsF2	58989	58999	-1.80	0.67	0.17	0.14	0.01	0.53	0.88	90.0	
IT-CsF2	59019	59029	-0.58	0.56	0.17	0.10	0.01	0.53	0.79	97.0	
IT-CsF2	59029	59054	-1.11	0.29	0.17	0.14	0.01	0.23	0.43	89.0	
IT-CsF2	59089	59119	-0.96	0.37	0.17	0.22	0.01	0.20	0.50	78.0	
IT-CsF2	59179	59214	0.54	0.17	0.36	0.18	0.01	0.17	0.47	87.0	
METAS-FOC2	58939	58969	-1.61	0.06	1.42	0.04		0.20	1.44		
METAS-FOC2	58969	58999	-1.85	0.06	1.40	0.01	0.04	0.20	1.42	99.3	
METAS-FOC2	59064	59089	-2.37	0.08	1.38	0.02	0.04	0.23	1.40	98.2	
METAS-FOC2	59149	59179	-1.71	0.09	1.36	0.26	0.04	0.20	1.40	65.3	
NIM5	58819	58849	-0.58	0.20	0.90	0.20		0.20	0.96		
NIM5	58849	58879	-0.65	0.20	0.90	0.20		0.20	0.96		
NIM5	58879	58899	-1.46	0.20	0.90	0.20		0.28	0.98		
NIM5	58909	58939	-0.97	0.46	0.90	0.10		0.20	1.03		
NIM5	58939	58969	-0.76	0.41	0.90	0.10	0.00	0.20	1.01	92.6	
NIM5	58969	58999	-0.35	0.48	0.90	0.10	0.00	0.20	1.04	89.3	
NIM5	59029	59059	0.06	0.46	0.90	0.10	0.00	0.20	1.03	91.7	
NIM5	59064	59089	-0.80	0.47	0.90	0.10	0.00	0.23	1.05	96.3	
NPL-CsF2	58829	58844	-0.22	0.14	0.41	0.15	0.00	0.37	0.59	84.5	
NPL-CsF2	58844	58879	-0.88	0.09	0.26	0.07	0.00	0.17	0.33	92.0	
NPL-CsF2	58879	58904	-0.25	0.11	0.25	0.06	0.00	0.23	0.36	91.4	
NPL-CsF2	58904	58924	-0.24	0.15	0.40	0.16	0.00	0.28	0.54	58.8	
NPL-CsF2	58984	58994	-0.97	0.29	0.29	0.10	0.00	0.53	0.67	94.8	
NPL-CsF2	58999	59029	-0.27	0.17	0.48	0.25	0.00	0.20	0.60	85.8	
NPL-CsF2	59029	59059	-0.50	0.14	0.24	0.04	0.00	0.20	0.34	99.4	
NPL-CsF2	59059	59074	0.00	0.23	0.20	0.15	0.00	0.37	0.50	88.6	
NPL-CsF2	59089	59119	-0.77	0.12	0.20	0.05	0.00	0.20	0.31	91.4	
NPL-CsF2	59119	59149	-0.11	0.12	0.20	0.25	0.00	0.20	0.39	82.7	
NPL-CsF2	59149	59179	0.24	0.14	0.20	0.04	0.00	0.20	0.32	96.8	
NPL-CsF2	59179	59214	0.17	0.13	0.20	0.04	0.00	0.17	0.30	97.7	
NRC-FCs2	58754	58784	-0.33	0.10	0.21	0.10	0.00	0.20	0.32	98.0	
NRC-FCs2	58784	58814	-0.43	0.10	0.22	0.10	0.00	0.20	0.33	98.0	
NRC-FCs2	58814	58844	-0.97	0.10	0.33	0.12	0.00	0.20	0.41	85.0	
NRC-FCs2	58844	58879	-0.65	0.08	0.35	0.10	0.00	0.17	0.41	97.0	
NRC-FCs2	58879	58904	-0.74	0.09	0.31	0.11	0.00	0.23	0.41	96.0	
NRC-FCs2	58904	58939	-0.51	0.09	0.39	0.12	0.00	0.17	0.45	87.3	
NRC-FCs2	58939	58969	-0.70	0.11	0.54	0.12	0.00	0.20	0.60	90.7	
NRC-FCs2	58969	58994	-0.13	0.11	0.39	0.11	0.00	0.23	0.48	95.7	
NRC-FCs2	58999	59029	-0.62	0.13	0.39	0.13	0.00	0.20	0.47	84.4	
NRC-FCs2	59029	59059	-0.27	0.13	0.25	0.13	0.00	0.20	0.37	85.3	
NRC-FCs2	59059	59089	-0.89	0.12	0.34	0.13	0.00	0.20	0.43	84.9	
NRC-FCs2	59089	59119	-0.46	0.12	0.37	0.10	0.00	0.20	0.45	98.6	
NRC-FCs2	59119	59149	-0.39	0.11	0.40	0.10	0.00	0.20	0.47	98.1	
NRC-FCs2	59194	59214	0.04	0.15	0.46	0.10	0.00	0.28	0.57	99.6	

Standard	Period of estimation	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{A/lab}$ $/10^{-15}$	$u_{B/lab}$ $/10^{-15}$	$u_{link/TAI}$ $/10^{-15}$	$u/10^{-15}$	Uptime %	Note
PTB-CS1	58844 58879	-4.76	8.00	8.00	0.00		0.06	11.31		(1)
PTB-CS1	58879 58904	-7.22	8.00	8.00	0.00		0.08	11.31		
PTB-CS1	58904 58939	1.25	8.00	8.00	0.00		0.06	11.31		
PTB-CS1	58939 58969	2.80	8.00	8.00	0.00		0.07	11.31		
PTB-CS1	58969 58999	-3.26	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	58999 59029	-7.27	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	59029 59059	-9.20	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	59059 59089	-12.86	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	59089 59119	-11.50	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	59119 59149	-8.49	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	59149 59179	2.05	8.00	8.00	0.00	0.00	0.07	11.31	100.0	
PTB-CS1	59179 59214	8.47	8.00	8.00	0.00	0.00	0.06	11.31	100.0	
PTB-CS2	58844 58879	-5.82	5.00	12.00	0.00		0.06	13.00		(1)
PTB-CS2	58879 58904	-1.71	5.00	12.00	0.00		0.08	13.00		
PTB-CS2	58904 58939	-5.03	5.00	12.00	0.00		0.06	13.00		
PTB-CS2	58939 58969	-6.04	5.00	12.00	0.00		0.07	13.00		
PTB-CS2	58969 58999	-1.29	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	58999 59029	1.25	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	59029 59059	-1.52	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	59059 59089	-4.87	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	59089 59119	-8.65	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	59119 59149	-2.31	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	59149 59179	-0.49	5.00	12.00	0.00	0.00	0.07	13.00	100.0	
PTB-CS2	59179 59214	-0.79	5.00	12.00	0.00	0.00	0.06	13.00	100.0	
PTB-CSF1	58844 58874	-0.27	0.07	0.28	0.05		0.07	0.30		
PTB-CSF1	58904 58939	-0.63	0.07	0.31	0.06		0.06	0.33		
PTB-CSF1	58939 58969	-0.47	0.07	0.30	0.02		0.07	0.32		
PTB-CSF1	58969 58999	-0.18	0.07	0.28	0.03	0.01	0.07	0.30	93.2	
PTB-CSF1	58999 59029	-0.52	0.07	0.27	0.05	0.00	0.07	0.29	91.0	
PTB-CSF1	59029 59044	-0.30	0.11	0.24	0.05	0.00	0.12	0.30	91.3	
PTB-CSF1	59089 59119	-0.62	0.08	0.40	0.05	0.00	0.07	0.42	88.6	
PTB-CSF1	59119 59149	-0.55	0.07	0.35	0.03	0.00	0.07	0.36	93.5	
PTB-CSF1	59149 59179	0.04	0.07	0.29	0.01	0.00	0.07	0.31	97.0	
PTB-CSF1	59179 59204	-0.23	0.08	0.31	0.05	0.00	0.08	0.33	89.2	
PTB-CSF2	58834 58844	-0.87	0.17	0.17	0.01		0.18	0.30		
PTB-CSF2	58844 58874	-0.56	0.10	0.17	0.01		0.07	0.21		
PTB-CSF2	58874 58904	-0.55	0.11	0.17	0.01		0.07	0.21		
PTB-CSF2	58904 58939	-0.61	0.11	0.17	0.01		0.06	0.21		
PTB-CSF2	58939 58969	-0.29	0.11	0.17	0.01		0.07	0.21		
PTB-CSF2	58969 58999	-0.45	0.11	0.17	0.02	0.01	0.07	0.21	94.7	
PTB-CSF2	58999 59029	-0.79	0.11	0.17	0.01	0.00	0.07	0.21	97.8	
PTB-CSF2	59029 59044	-0.52	0.15	0.17	0.01	0.00	0.12	0.26	98.5	
PTB-CSF2	59044 59059	-0.88	0.15	0.17	0.02	0.00	0.12	0.26	93.0	
PTB-CSF2	59059 59089	-0.72	0.10	0.17	0.01	0.00	0.07	0.21	97.7	
PTB-CSF2	59089 59119	-0.56	0.11	0.17	0.02	0.00	0.07	0.21	94.7	
PTB-CSF2	59119 59149	-0.34	0.10	0.17	0.01	0.00	0.07	0.21	97.8	
PTB-CSF2	59149 59179	-0.15	0.11	0.17	0.01	0.00	0.07	0.21	97.2	
PTB-CSF2	59179 59204	-0.46	0.13	0.17	0.05	0.00	0.08	0.23	89.2	
SU-CsFO2	58844 58859	-0.45	0.25	0.22	0.11		0.85	0.92		
SU-CsFO2	58859 58879	-0.04	0.44	0.22	0.11		0.66	0.83		
SU-CsFO2	58879 58904	-0.01	0.25	0.22	0.10		0.54	0.64		
SU-CsFO2	58904 58939	0.01	0.19	0.22	0.11		0.40	0.50		
SU-CsFO2	58969 58999	-0.11	0.32	0.22	0.13	0.00	0.46	0.61	36.0	
SU-CsFO2	58999 59029	-0.53	0.20	0.22	0.11	0.00	0.46	0.56	73.9	
SU-CsFO2	59029 59059	-0.23	0.18	0.22	0.10	0.00	0.46	0.55	93.9	
SU-CsFO2	59059 59089	-1.08	0.21	0.22	0.11	0.00	0.46	0.56	73.3	
SU-CsFO2	59119 59149	-0.05	0.24	0.22	0.11	0.00	0.35	0.49	95.9	
SU-CsFO2	59149 59179	-0.10	0.24	0.22	0.12	0.00	0.20	0.40	83.6	
SU-CsFO2	59179 59214	-1.24	0.19	0.22	0.10	0.00	0.17	0.35	77.8	

Standard	Period of estimation	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{A/lab}$ $/10^{-15}$	$u_{B/lab}$ $/10^{-15}$	$u_{link/TAI}$ $/10^{-15}$	$u/10^{-15}$	Uptime %	Note
SYRTE-FO1	58844 58879	-0.76	0.20	0.32	0.05		0.17	0.42		
SYRTE-FO1	58879 58904	-0.72	0.15	0.32	0.09		0.23	0.43		
SYRTE-FO1	58904 58939	-0.72	0.15	0.31	0.06		0.17	0.39		
SYRTE-FO1	58939 58969	-0.72	0.15	0.31	0.06		0.20	0.40		
SYRTE-FO1	58969 58989	-0.98	0.20	0.32	0.06	0.00	0.28	0.47	96.7	
SYRTE-FO1	59029 59059	-0.76	0.20	0.33	0.07	0.00	0.20	0.44	90.8	
SYRTE-FO1	59059 59089	-0.72	0.20	0.35	0.06	0.00	0.20	0.45	95.4	
SYRTE-FO1	59089 59119	-0.63	0.15	0.33	0.05	0.00	0.20	0.42	96.5	
SYRTE-FO1	59119 59134	-0.32	0.30	0.32	0.06	0.00	0.37	0.57	95.9	
SYRTE-FO1	59139 59149	-0.35	0.30	0.32	0.21	0.00	0.53	0.72	71.5	
SYRTE-FO1	59149 59179	-0.22	0.20	0.33	0.06	0.00	0.20	0.44	95.5	
SYRTE-FO1	59179 59204	-0.10	0.20	0.33	0.12	0.00	0.23	0.47	71.6	
SYRTE-FO2	58844 58869	-0.61	0.25	0.22	0.14		0.23	0.43		
SYRTE-FO2	58884 58899	-0.36	0.30	0.22	0.07		0.37	0.53		
SYRTE-FO2	58919 58939	-0.39	0.30	0.23	0.06		0.28	0.48		
SYRTE-FO2	58939 58969	-0.39	0.15	0.22	0.06		0.20	0.34		
SYRTE-FO2	58969 58999	-0.50	0.20	0.21	0.05	0.00	0.20	0.35	95.7	
SYRTE-FO2	58999 59029	-0.47	0.20	0.22	0.05	0.00	0.20	0.36	97.7	
SYRTE-FO2	59029 59059	-0.30	0.20	0.22	0.10	0.00	0.20	0.37	82.0	
SYRTE-FO2	59059 59089	-0.44	0.15	0.22	0.10	0.00	0.20	0.35	78.3	
SYRTE-FO2	59089 59109	-0.30	0.20	0.23	0.08	0.00	0.28	0.42	90.0	
SYRTE-FO2	59129 59149	0.00	0.20	0.22	0.06	0.00	0.28	0.41	96.4	
SYRTE-FO2	59149 59179	0.32	0.20	0.22	0.06	0.00	0.20	0.36	91.3	
SYRTE-FO2	59184 59204	0.16	0.20	0.23	0.06	0.00	0.28	0.42	94.7	
SYRTE-FOM	58844 58879	-0.86	0.20	0.66	0.06		0.17	0.71		
SYRTE-FOM	58879 58904	0.12	0.60	0.67	0.09		0.23	0.93		
SYRTE-FOM	58904 58929	-0.18	0.25	0.66	0.20		0.23	0.77		
SYRTE-FOM	59039 59059	-1.14	0.30	0.58	0.09	0.00	0.28	0.72	88.6	
SYRTE-FOM	59059 59069	-0.93	0.50	0.57	0.19	0.00	0.53	0.94	63.3	
SYRTE-FOM	59079 59089	-0.73	0.30	0.57	0.21	0.00	0.53	0.86	72.7	
SYRTE-FOM	59089 59119	-0.31	0.30	0.58	0.06	0.00	0.20	0.68	90.8	
SYRTE-FOM	59134 59149	-0.48	0.40	0.57	0.15	0.00	0.37	0.80	72.0	

Note:
(1) Continuously operating as a clock participating in TAI.

Table 6B. Measurements of the duration of the TAI scale interval by Secondary Frequency Standards

Until Circular T388, $u_{A/lab}$ and $u_{B/lab}$ were not reported separately and the total value of $u_{link/lab}$ appears under $u_{A/lab}$. The value of Uptime was not reported either.

Standard	Period of estimation	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{A/lab}$ $/10^{-15}$	$u_{B/lab}$ $/10^{-15}$	$u_{link/TAI}$ $/10^{-15}$	$u/10^{-15}$	u_{SRep} $/10^{-15}$	Ref(u_S)	Uptime %	Note
NICT-Sr1	58914 58934	-0.26	0.01	0.07	0.09		0.28	0.30	0.4	[14]		
NMIJ-Yb1	58754 58779	-0.87	0.01	0.40	0.20	0.22	0.23	0.55	0.5	[14]	90.1	
NMIJ-Yb1	58784 58814	-0.91	0.01	0.40	0.30	0.22	0.20	0.58	0.5	[14]	77.8	
NMIJ-Yb1	58814 58844	-1.11	0.01	0.41	0.33	0.22	0.20	0.60	0.5	[14]	80.4	
NMIJ-Yb1	58844 58879	-0.92	0.01	0.40	0.33	0.22	0.17	0.59	0.5	[14]	72.7	
NMIJ-Yb1	58879 58894	-0.29	0.01	0.40	0.14	0.22	0.37	0.60	0.5	[14]	82.9	
NMIJ-Yb1	58899 58904	-0.77	0.02	0.40	0.22	0.22	0.98	1.11	0.5	[14]	90.6	
NMIJ-Yb1	58904 58939	-0.23	0.01	0.40	0.08	0.22	0.17	0.49	0.5	[14]	92.6	
NMIJ-Yb1	58939 58969	-0.59	0.01	0.40	0.12	0.22	0.20	0.51	0.5	[14]	87.2	
NMIJ-Yb1	58969 58999	-0.06	0.01	0.40	0.16	0.22	0.20	0.52	0.5	[14]	84.2	
NMIJ-Yb1	58999 59029	0.17	0.01	0.40	0.28	0.22	0.20	0.57	0.5	[14]	69.8	
NMIJ-Yb1	59169 59179	-0.28	0.01	0.22	0.42	0.10	0.53	0.72	0.5	[14]	78.9	
NMIJ-Yb1	59179 59194	0.06	0.01	0.22	0.10	0.10	0.37	0.45	0.5	[14]	93.3	
SYRTE-FORb	58844 58879	-0.47	0.20	0.25	0.06		0.17	0.37	0.6	[14]		
SYRTE-FORb	58879 58904	-0.50	0.21	0.25	0.06		0.23	0.40	0.6	[14]		
SYRTE-FORb	58904 58939	-0.18	0.15	0.25	0.06		0.17	0.34	0.6	[14]		
SYRTE-FORb	58939 58969	-0.15	0.20	0.26	0.13		0.20	0.40	0.6	[14]		
SYRTE-FORb	58999 59029	-0.33	0.30	0.26	0.05	0.00	0.20	0.45	0.6	[14]	98.2	
SYRTE-FORb	59029 59059	-0.51	0.20	0.25	0.06	0.00	0.20	0.38	0.6	[14]	95.1	
SYRTE-FORb	59059 59074	0.13	0.35	0.26	0.12	0.00	0.37	0.58	0.6	[14]	83.0	
SYRTE-FORb	59079 59089	-0.25	0.25	0.26	0.09	0.00	0.53	0.64	0.6	[14]	86.8	
SYRTE-FORb	59089 59119	-0.21	0.20	0.25	0.05	0.00	0.20	0.38	0.6	[14]	97.5	
SYRTE-FORb	59119 59149	-0.10	0.20	0.25	0.05	0.00	0.20	0.38	0.6	[14]	97.8	
SYRTE-FORb	59149 59179	0.05	0.20	0.26	0.06	0.00	0.20	0.39	0.6	[14]	95.2	
SYRTE-FORb	59179 59204	0.17	0.20	0.26	0.06	0.00	0.23	0.41	0.6	[14]	95.7	

References:

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[14] CCTF Recommendation 2 (2017) : Updates to the CIPM list of standard frequencies in Consultative Committee for Time and Frequency Report of the 21st meeting (2017), 2017, 56 p.

Operation of the METAS-FOC2 primary frequency standard in 2020

The Swiss continuous Cs fountain clock METAS-FOC2 [1] delivered four contributions to the calibration of TAI, which were published in Circular T 388, 389, 392 and 395.

During these observation periods, the standard was operated with an uptime of, respectively, 98.4%, 99.3%, 98.2% and 65.3%.

The local oscillator was the METAS hydrogen maser (HM, BIPM clock code 1405701). The typical short-term frequency instability of METAS-FOC2 was around $1.0 \times 10^{-13}\ (\tau/s)^{-1/2}$ for these four contributions.

The following table summarizes the published values:

#	Evaluation period	d / 10^{-15}	u_{A} / 10^{-15}	u_{B} / 10^{-15}	u_{lab} / 10^{-15}	u_{TAI} / 10^{-15}	u_{total} / 10^{-15}
1	58939-58969	-1.61	0.06	1.42	0.04	0.20	1.44

#	Evaluation period	d / 10^{-15}	u_{A} / 10^{-15}	u_{B} / 10^{-15}	uA_{lab} / 10^{-15}	uB_{lab} / 10^{-15}	u_{TAI} / 10^{-15}	u_{total} / 10^{-15}
2	58969-58999	-1.85	0.06	1.40	0.01	0.04	0.20	1.42
3	59064-59089	-2.37	0.08	1.38	0.02	0.04	0.23	1.40
4	59149-59179	-1.71	0.09	1.36	0.26	0.04	0.20	1.40

One last 30-days long measurement series was realized in December 2021 for control purposes.

The following table shows the uncertainty budget (k=1) used for the calibration in November 2020:

Physical effect	Frequency shift / 10^{-15}	Uncertainty / 10^{-15}
Second-order Zeeman	24.02	0.20
Gravitational	59.72	0.02
Second-order Doppler	-0.01	<0.01
Blackbody radiation	-16.67	0.04
Microwave spectrum purity	0.00	0.05
Light shift from source	-0.16	0.04
Cavity pulling	0.00	<0.01
Rabi pulling	0.00	0.02
Ramsey pulling	0.05	0.10
End-to-end	2.17	0.27
Collisional Cs-Cs	-0.29	0.16
Light shift from detection	-0.10	0.41
RF leakage	0.00	0.47
Majorana transitions	0.00	0.50
DCPS	—	1.03
Total	68.72	1.36

Reference:

[1] A. Jallageas et al., Metrologia **55** 366, (2018).

Operation of IT-CsF2 in 2020

F. Levi, M. Gozzelino and G.A. Costanzo

IT-CsF2 is the primary atomic frequency standard operated at INRIM. The frequency standard is based on a laser cooled Cs fountain apparatus operating at cryogenic temperature (88.5K), in order to reduce the blackbody radiation shift. The formal evaluation of the frequency standard is published in [1], while TAI calibration data are reported to BIPM since the end of 2013 and are published in the Circular T. The accuracy evaluation of the PFS involves periodical checks and validations of the whole set of parameters affecting the standard frequency: i.e. Zeeman shift, spectral purity of the microwave synthesis chain, interaction region temperature, atomic density shift, gravitational potential, and laser and microwave leakage. During 2020 we reported to BIPM nine formal TAI evaluations of the standard hereafter summarized. The total operating time of IT-CsF2 as PFS during 2020 was 165 days.

Circ T	Period	days	d(ITCsF2)-d(BIPM) (10^{-15})	uA (10^{-15})	uB (10^{-15})	Ul/Lab (10^{-15})	Ul/Tai (10^{-15})	Up time	u (10^{-15})
388	58899 58914	15	-0.39	0.64	0.17	0.36	0.37	80%	0.84
388	58919 58934	15	0.45	0.71	0.17	0.51	0.37	56%	0.96
388	58939 58954	15	0.43	0.64	0.17	0.18	0.37	88%	0.78
389	58964 58974	10	-0.31	0.66	0.17	0.22	0.53	83%	0.89
389	58989 58999	10	-1.35	0.67	0.17	0.14	0.53	97%	0.88
390	59019 59029	10	0.04	0.56	0.17	0.10	0.53	97%	0.79
391	59029 59054	25	-0.58	0.29	0.17	0.14	0.23	89%	0.43
393	59089 59119	30	-0.42	0.37	0.17	0.22	0.20	78%	0.50
396	59179 59214	35	0.73	0.17	0.36	0.18	0.17	87%	0.47

The weighted mean associated to the difference between the d(ITCsF2) and d(BIPM) has a value of

[d(ITCsF2) - d(BIPM)] = - 0.13 ± 0.37

showing a good agreement with the other frequency standards. The accuracy of ITCsF2 is nearly the same that was reported in [1] and it is summarized in the following table. Starting with the December evaluation, the way of reporting the uncertainty from the atomic density was changed from the type A (before December) to the type B. It is worth mentioning that the statistical uncertainty associated with the atomic density is obtained with long measurement time and thus vary from case to case according to the available set of data. Typically the low density uncertainty can reach ~3x10^{-16}.

1. Typical accuracy evaluation reported for Circ T 393

Physical effect	Bias (10^{-16})	Uncert. (10^{-16})
Zeeman effect	1099.3	0.8
Blackbody radiation	-1.45	0.12
Gravitational redshift	260.4	0.1
Microwave leakage	-1.2	1.4
DCP	-	0.2
2nd order cavity pulling	-	0.3
Background gas	**-**	0.5
Total Type B	**1357.1**	**1.7**
Atomic density (typical LD)*	-10.6	1.9

[1] Accuracy evaluation of ITCsF2: a nitrogen cooled caesium fountain, F. Levi, D. Calonico, C.E. Calosso, A. Godone, S. Micalizio and G.A. Costanzo; Metrologia 51 (2014) 270–284

Report of the operation of NICT-Sr1 in 2020

The frequency standard NICT-Sr1 is an ^{87}Sr optical lattice clock operated at NICT. Utilizing the method of intermittent evaluation [1, 2], NICT-Sr1 contributed to TAI calibration as published in the *Circular T* for the following intervals:

MJD 58914 to 58934 (20 days) for March 2020, *Circular T* 387

This contains two measurements on MJD 58918 to 58929 and MJD 58932, with a 62.9% coverage of the earlier 12 day period and with a total uptime 38.5%.

Measurements of the scale interval use an optical frequency comb to down-convert the optical frequency of 429 THz stabilized to NICT-Sr1 to a signal in the microwave domain. This then serves as a reference to evaluate the frequency of a hydrogen maser (HM). In typical intermittent evaluation, the HM frequency is measured for three hours approximately once per week, and the mean frequency of the HM with respect to the frequency of NICT-Sr1 is determined from several such data blocks distributed over the target period. The uncertainty due to non-operation time of NICT-Sr1 [3-5] is then included in uIA/Lab. Additionally, an average over multiple HMs mitigates the effect of sporadic phase excursions of a specific HM [4]. Intermittent evaluation makes it easier to extend the evaluation interval, reducing the uncertainty ul/Tai of the satellite link to TAI. At shorter evaluation intervals, this uncertainty ul/Tai tends to limit the overall uncertainty.

Table 1 summarizes the uncertainty contributions for the evaluation. uA/Lab and uB/Lab indicate the uncertainties due to the link between NICT-Sr1 and the local HM. The Type A uncertainty uA/Lab represents the linear trend estimation in addition to the uncertainty due to the stochastic noise of the HM during unobserved intervals, and the Type B uncertainty uB/Lab is due to the frequency comparison between microwave and optical signals, including distribution of the microwave signals.

Period of evaluation (MJD)	Evaluation mode	uA	uB	uA/Lab	uB/Lab	ul/Tai	u	uSrep
58914 – 58934 (20 days)	Intermittent	0.09	0.72	0.86	0.32	2.8	3.0	4

Table 1: Reported uncertainty contributions applying the method of intermittent evaluation. Part of the evaluation period was covered by a near-continuous measurement of 12 days. Values are given in units of 10^{-16}.

The typical systematic corrections and their uncertainties for NICT-Sr1 as previously published [4] are summarized as follows:

Effect	Correction (10^{-17})	Uncertainty (10^{-17})
Blackbody radiation	512.8	2.5
Lattice scalar / tensor	0	5.3
Lattice hyperpolarizability	–0.2	0.1
Lattice E2/M1	0	0.5
Probe light	0.1	0.1
Dc Stark	0.1	0.2
Quadratic Zeeman	50.9	0.6
Density	0.4	0.6
Background gas collisions	0	1.8
Line pulling	0	0.1
Servo error	–1.3	2.9
Total	562.8	6.9
Gravitational redshift	–834.1	2.2
Total (with gravitational effect)	–271.3	7.2

Table 2. Systematic corrections and their uncertainties for NICT-Sr1 between MJD 58914 and 58934.

References

[1] H. Hachisu and T. Ido, “Intermittent optical frequency measurements to reduce the dead time uncertainty of frequency link,” Jpn. J. Appl. Phys. **54**, 112401 (2015).

[2] H. Hachisu, F. Nakagawa, Y. Hanado and T. Ido, “Months-long real-time generation of a time scale based on an optical clock,” Sci. Reports **8**, 4243 (2018).

[3] C. Grebing, A. A-Masoudi, S. Dörcher, S Häfner, V. Gerginov, S. Weyers, B. Lipphardt, F. Riehle, U. Sterr, and C. Lisdat, “Realization of a timescale with an accurate optical lattice clock,” Optica **3**, 563 (2016).

[4] H. Hachisu, G. Petit, F. Nakagawa, Y. Hanado and T. Ido, “SI-traceable measurement of an optical frequency at low 10^{-16} level without a local primary standard,” Opt. Express **25**, 8511 (2017).

[5] N. Nemitz, T. Gotoh, F. Nakagawa, H. Ito, Y. Hanado, T. Ido, and H. Hachisu, “Absolute frequnecy of 87Sr at 1.8×10^{-16} uncertainty by reference to remote primary frequency standards,” Metrologia **58**, .25006 (2021).

Operation of the NIM5 primary frequency standard in 2020

The NIM5 Cs fountain primary frequency standard at NIM was operated for 7 months and the average frequencies of the hydrogen maser H50 (1404850) against NIM5 were measured and the results, including all relevant biases and uncertainties, were reported to the BIPM and published in Circular T as shown in the following table.

MJD periods	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$U_{A/lab}/10^{-15}$	$U_{B/lab}/10^{-15}$	$U_{l/TAI}/10^{-15}$	$u/10^{-15}$
58849.0-58879.0	-0.65	0.20	0.90	0.20		0.20	0.96
58879.0-58899.0	-1.46	0.20	0.90	0.20		0.28	0.98
58909.0-58939.0	-0.97	0.46	0.90	0.10	0.00	0.20	1.03
58839.0-58969.0	-0.76	0.41	0.90	0.10	0.00	0.20	1.01
58969.0-58999.0	-0.35	0.48	0.90	0.10	0.00	0.20	1.04
59029.0-59059.0	0.06	0.46	0.90	0.10	0.00	0.20	1.03
59064.0-59089.0	-0.80	0.47	0.90	0.10	0.00	0.23	1.05

During a formal evaluation, NIM5 operated alternatively in the high and low densities with a ratio about 2 to determine frequencies at zero density. The C-field has been checked once each month without a significant variation. The microwave-related frequency shifts have been checked by comparison between the frequency difference between a $\pi/2$ Ramsey pulse and $3\pi/2$, the relative frequency difference is always less than 1×10^{-15}. The microwave leakage due to the RF interferometric switch has been checked each month to check its attenuation. The temperate of the flight tube was monitored and recorded automatically.

The H-maser H50 instability and phase noise has been evaluated and the dead time uncertainty due to the operation ratio has been evaluated. This work is done mainly for the frequency measurement of the Sr optical clock. The paper is published as shown in reference [1].

Meanwhile, a new Rb fountain clock RbF1 has been built with an instability of 1.5×10^{-13} at 1 s and 5×10^{-16} at 1 d has been achieved. The fountain operates semi-continuous and aims to steer an H-maser directly.

[1] Yige Lin， et al, “A ^{87}Sr optical lattice clock with 2.9×10^{-17} uncertainty and its absolute frequency measurement, Metrologia, **58**, 035010 (2021)

Operation of NMIJ-Yb1 in 2020

During a period from October 2019 to April 2020, the ^{171}Yb optical lattice clock NMIJ-Yb1 [1,2] has calibrated the TAI frequency through comparison with UTC(NMIJ). Reports of these calibration results have been reviewed by the Working Group on PSFS, and then published in Circular T 392. In addition, the TAI frequencies measured in May, June, November, and December 2020 have been published in Circular T 396 and 398. The uptimes of NMIJ-Yb1 were 69.8 - 93.3 % for calibration periods ranging from 5 to 35 d.

u_A was estimated from the instability of NMIJ-Yb1 (1×10^{-14} / $(\tau/\mathrm{s})^{1/2}$) which was evaluated by our ^{87}Sr optical lattice clock [3]. u_B was estimated based on methods in Refs. [1,2]. For the reports in November and December 2020, u_B was improved to 2×10^{-16} as shown in Table 1 compared with an uncertainty of 4×10^{-16} in Ref. [2]. This improvement was made by reevaluation of the lattice light shift and density shift and operation of NMIJ-Yb1 with a smaller potential depth of the trap.

$u_{A/Lab}$ arose from the dead time in the comparison between NMIJ-Yb1 and UTC(NMIJ). This uncertainty was estimated with a method in Ref. [4]. $u_{A/Lab}$ also included the uncertainty of a frequency correction resulting from the dead time when the frequency steering of UTC(NMIJ) was carried out. $u_{A/Lab}$ varied from 8×10^{-17} to 4×10^{-16}.

$u_{B/Lab}$ arose from a microwave-optical link. For the reports in November and December 2020, $u_{B/Lab}$ was improved to 1.0×10^{-16} compared with an uncertainty of 2.2×10^{-16} in Ref. [2]. The previous uncertainty was mainly caused by frequency multiplication of a 10 MHz signal from UTC(NMIJ). Here we reduced this uncertainty by carefully stabilizing the temperature of a frequency multiplier.

Table 1. Up-to-date uncertainty budget of NMIJ-Yb1 in 1×10^{-17} for the report in December 2020

Effect	**Shift**	**Uncertainty**
Lattice light	5.9	4.5
Blackbody radiation	-267.0	20.6
Density	-1.1	0.7
Second order Zeeman	-5.1	0.3
Probe light	0.4	0.2
Servo error	-6.8	1.2
AOM switching	-	1
Line pulling	-	1
Total	-273.7	21.1
Gravitational redshift	229.4	6
Total (with gravitational redshift)	-44.3	22.0

[1] T. Kobayashi *et al.*, IEEE Trans. Ultrason., Ferroelectr., Freq. Control **65**, 2449-2458 (2018).

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[4] D.-H. Yu *et al.*, Metrologia **44**, 91-96 (2007).

Operation of the NPL-CsF2 primary frequency standard in 2020

The National Physical Laboratory in the UK currently operates one fully characterised and approved primary frequency standard, the caesium fountain NPL-CsF2. NPL-CsF2 was made operational and its accuracy evaluated for the first time in 2009. It was later reassessed in 2011, 2013 and 2015. Later, for a period of time, inconsistencies in both the short-term stability and accuracy of NPL-CsF2 were observed. After reconfiguring the grounding arrangement of the microwave synthesis chain, the physics package and associated devices, and removing a residual magnetisation of the magnetic shields near the cavity, this behaviour was no longer seen.

To regain confidence in the fountain's performance, it was operated for approximately a year starting in November 2019. The measurement data were initially only used internally for stability analysis of UTC(NPL). In October 2020, regular monthly submissions of data for TAI step interval measurements were reinstated. Including retrospective submissions, measurements were reported for 11 of the months in 2020.

The accuracy evaluation currently referenced in Circular-T was carried out in 2011, and an updated assessment was published in [1]. Following its reconfiguration in 2019, a revised accuracy evaluation of NPL-CsF2 was conducted in August 2020 and described in Circular-T 394. The table below summarises the results of this latest evaluation, which gives a total systematic uncertainty consistent with that in [1], together with typical values of the frequency biases that we now correct for.

	Typical bias / 10^{-16}	Uncertainty / 10^{-16}
Second order Zeeman	2475.0	0.8
Blackbody radiation	-164.0	1.0
AC Stark (lasers)		0.1
Microwave spectrum		0.1
Gravity	13.0	0.5
Cold collisions (typical)		0.4
Collisions with background gas		0.3
Rabi, Ramsey pulling		0.1
Cavity phase (distributed)	0.2	1.0
Cavity phase (dynamic)		0.1
Cavity pulling		0.6
Microwave leakage		0.6
Microwave lensing	0.6	0.3
Second-order Doppler		0.1
Total u_B (1σ)		**2.0**

A low noise microwave synthesiser referenced to an ultrastable laser, the stability of which is down-converted to the microwave domain via a frequency comb, has been implemented and routinely used as a local oscillator and microwave source. With this local oscillator, we can obtain short-term stabilities of 3.3×10^{-14} at 1 second. This new synthesiser is a shared resource and when it is unavailable a second synthesiser based on a BVA quartz crystal is used. With this system we obtain typical short-term stabilities of 1.2×10^{-13} at 1 second.

The temperature control of the fountain flight tube now relies on stabilisation of the room temperature rather than the active system with a water jacket that was previously used. We continually measure the flight tube temperature and compensate for the corresponding blackbody radiation shift. Thanks to the thermal insulation of the tube we do not observe any significant thermal gradients.

No other significant changes to the physics package of NPL-CsF2 or its control system have been introduced over the recent year.

[1] K. Szymaniec et al. J. Phys. Conf. Series 723 (2016) 012003.

Evaluations of PSFS for BIPM Annual Report 2020 - NRC-FCs2 Fountain Clock

The NRC-FCs2 PFS has been reported during 2020 with respect to a hydrogen maser 1400307 (BIPM code). The full evaluation of systematic uncertainties is described in detail in [1], the most recent evaluation, which is the reference listed for the 2020 reports to Circular T and is still up-to-date. Below, we will describe the evaluation of uA , uA/lab and uB/lab, as well as a typical error budget.

Short term stability and type A uncertainty - The typical short term stability of FCs2 for the collisional shift-corrected frequency was 1.7 x 10^{-13} after 1 second of averaging. The reported values of the type A uncertainty, uA, assume white FM as the dominant noise source during the averaging period. The averaging period is calculated as (reporting period – dead time).

Link to local timescale - The uncertainty of the link with our local timescale, ul_Lab, is the quadratic sum of two terms: the first term is the uncertainty in the frequency transfer between the maser 1400307 and FCs2, and the second term is the result of measurement dead time. In FCs2, the former uncertainty is attributed to phase fluctuations in cables between H-maser 1400307 and FCs2 and is estimated to be no larger than 10^{-16}.

The effects of measurement dead time arise due to both scheduled and unscheduled interruptions in the fountain operation. The unscheduled interruptions were rare, and generally caused by a failure in laboratory environmental control, or a broken laser lock. The contribution of dead time to the uncertainty is estimated using a numerical simulation that models the measurement noise as having two contributions: white FM (1.7 x 10^{-13} $\tau^{-1/2}$) and flicker FM (4.0 x 10^{-16}) [1].

Type B uncertainties - A detailed description of the evaluation of the systematic shifts and associated uncertainties is described in [1]. Table 1 shows a typical error budget, listing the main systematic effects and related type B uncertainties for the period of MJD 59149 – 59179.

Physical effect	Bias [10^{-16}]	Uncertainty [10^{-16}]
Zeeman effect	724.65	0.2
Blackbody radiation	-162.36	0.7
Gravitational redshift	104.52	0.03
Cold collisions	-	3.17
Background gas	-	< 0.1
AC Stark	-	< 0.1
Rabi, Ramsey pulling	-	< 0.1
Cavity pulling	-	< 0.1
Majorana transitions	-	< 0.1
DCP m=0	0.07	0.4
DCP m=1	-0.71	1.3
DCP m=2	0.040	0.2
Microwave lensing	0.60	0.2
Microwave leakage	0.10	1.0
Microwave spectrum	-	< 0.1
Synchronous phase transients	-	0.8
Total	666.9	3.8

Table 1. Contributions to type B uncertainty for FCs2 for period MJD 59149 - 59179. The bias due to cold collisions is corrected actively by toggling between high and low densities and extrapolating to zero.

References:

1. S. Beattie, B. Jian, J. Alcock, M. Gertsvolf, R. Hendricks, K. Szymaniec and K. Gibble, Metrologia, 57 (2020) 035010, DOI https://doi.org/10.1088/1681-7575/ab7c54

Operation of the SYRTE PSFS in 2020

In 2020, a total of 44 calibrations reports of the reference maser by the SYRTE fountains PSFS have been transmitted to BIPM to participate to the steering of TAI: 12 by the primary frequency standard (PFS) FO1, 12 by the PFS FO2-Cs, 12 by the secondary frequency standard (SFS) FO2-Rb, and 8 by the PFS FOM. The interval durations range from 10 to 35 d. The uptime of the fountains is typically 90% or higher. FO2-Cs and FO2-Rb are the 2 parts of the dual fountain FO2 which operates simultaneously with caesium and rubidium atoms. FO2-Rb calibrations are included in Circular T as SYRTE-FORb SFS.

The operation of the four fountains is similar. The microwave synthesizer of each fountain is referenced to the signal provided by an ultra-low phase noise cryogenic sapphire oscillator phase locked to a hydrogen maser, allowing to reach the quantum projection noise limit. The relative frequency instability in full atomic density is typically $\sigma_y(\tau) \sim 3\text{-}4 \times 10^{-14}\ \tau^{-1/2}$ for FO1, FO2-Cs and FO2-Rb. Because FOM uses optical molasses only, its relative frequency instability in full atomic density is limited to $\sigma_y(\tau) \sim 6\text{-}7 \times 10^{-14}\ \tau^{-1/2}$.

The typical uncertainty budgets are presented in Table 1 for the caesium fountains and in Table 2 for the rubidium fountain. As previously, the maser frequency is corrected from the quadratic Zeeman, the blackbody radiation, the cold collisions (+ cavity pulling), the first order Doppler, the microwave lensing shifts, and the redshift. The magnetic field and the temperature around the interrogation zone is measured every 1 hour or less in order to evaluate in real time the quadratic Zeeman and the blackbody radiation shift. To evaluate the cold collision shift and extrapolate to zero density, we alternate measurements between full and half atomic density either using the method proposed by K. Gibble [1] in FO1, FO2-Rb and FOM, or using the adiabatic passage method in FO2-Cs. The distributed cavity phase shift is verified from time to time with differential measurements alternating the cavity feeds [2]. Against possible residual microwave leakages, the microwave interrogation is pulsed and absence of synchronous phase transients is tested periodically. Improved relativistic redshift corrections with reduced uncertainties have been determined in the frame of the ITOC (International Timescales with Optical Clocks) project [3, 4]. This involved a combination of GNSS based height measurements, geometric levelling and a geoid model over Europe, refined by local gravity measurements, together with a fine determination of the average atomic trajectory with respect to the local reference points.
In the context of TAI calibrations, we use a conservative uncertainty of 2.5×10^{-17}.

The statistical uncertainty $u_{A/lab}$ of the link between the maser and the PSFS corresponds to the quadratic sum of two terms: the dead time uncertainty, which is estimated according to the method described in [5, 6], and the effect of possible phase fluctuations in the signal distribution between the maser and the PSFSs, which is expected to be lower than 5×10^{-17}.
The systematic uncertainty of the link $u_{B/lab}$ is expected to be negligible, because in the signal distribution chain between the maser and the fountain, all the intermediate oscillators are phase locked using proportional/integrator phase lock loops. In addition, the comparison between the maser and UTC(OP) is performed using a time interval counter.

The calibration values are given with typical uncertainties $u_A = 1.5 – 5.0 \times 10^{-16}$, and $0.5 – 2.1 \times 10^{-16}$ for the uncertainty due to the link between the reference maser and the standard. For FO1, FO2-Cs and FO2-Rb, the systematic uncertainty u_B is $\sim 2.1\text{-}3.5 \times 10^{-16}$, and for FOM, $\sim 6\text{-}7 \times 10^{-16}$.
The FO2-Rb SFS calibration reports were made using the 2017 recommended value (21st CCTF, [7]).

Throughout 2020, the frequency calibrations of the reference H-maser by the SYRTE fountains were also used to produce a daily steering of the H-maser output signal for the generation of the French timescale UTC(OP) [8].

Fountain	FO1		FO2-Cs		FOM	
Physical origin	Correction	Uncertainty	Correction	Uncertainty	Correction	Uncertainty
2nd order Zeeman	-1277.79	0.40	-1937.02	0.30	-314.42	1.90
Blackbody Radiation	169.97	0.60	172.26	0.80	166.50	2.30
Cold Collisions + cavity pulling	131.95	1.66	105.71	1.06	20.60	3.09
Distributed cavity phase shift	-0.07	2.40	-0.90	1.00	-0.70	2.75
Microwave lensing	-0.65	0.65	-0.70	0.70	-0.90	0.90
Microwave Leaks, spectral purity	0	1.00	0	0.50	0	1.50
Ramsey & Rabi pulling	0	0.20	0	0.10	0	0.10
Second order Doppler	0	0.10	0	0.10	0	0.10
Background gas collisions	0	0.30	0	1.00	0	1.00
Red shift	- 69.08	0.25	- 65.54	0.25	- 68.26	0.25
Total uncertainty u_B		**3.3**		**2.2**		**5.5**

Table 1: Typical accuracy budgets for the SYRTE PFS FO1, FO2-Cs and FOM adapted from those given in [9] and [10]. (Values given in units of 10^{-16})

Fountain	FO2-Rb	
Physical origin	Correction	Uncertainty
2nd order Zeeman	-3503.75	0.70
Blackbody Radiation	127.22	1.45
Cold Collisions + cavity pulling	4.34	1.26
First order Doppler	-0.35	1.00
Microwave lensing	-0.70	0.70
Microwave Leaks, spectral purity	0	0.50
Ramsey & Rabi pulling	0	0.10
Second order Doppler	0	0.10
Background gas collisions	0	1.00
Red shift	- 65.45	0.25
Total uncertainty u_B		**2.6**

Table 2: Typical accuracy budgets for the SYRTE SFS FO2-Rb adapted from those given in [9] and [10]. (Values given in units of 10^{-16})

The SYRTE Strontium optical lattice clocks SrB and Sr2 did not contribute to TAI in 2020, but are expected to provide new calibration values in 2021.

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Operation of the PTB primary clocks in 2020

PTB's primary clocks with a thermal beam

During 2020, PTB’s primary clocks CS1 and CS2 were operated almost continuously. Time differences UTC(PTB) - clock in the standard ALGOS format were reported to BIPM, so that $u_{\mathrm{l/lab}}$ is zero. The mean (MJD 58849 to 59214) relative frequency offset y(CS1 – CS2) amounted to -0.7×10^{-15}, which is compliant with the stated u_{B} values [1,2].

The clocks’ operational parameters were checked periodically and validated to estimate the clock uncertainty. These parameters are the Zeeman frequency, the temperature of the beam tube (vacuum enclosure), the line width of the clock transition as a measure of the mean atomic velocity, the microwave power level, the spectral purity of the microwave excitation signal, and some characteristic signals of the electronics. Using a high-resolution phase comparator, the 5 MHz output signals of both clocks have been continuously compared to 5 MHz of superior frequency instability to assess the frequency instability of CS1 and CS2, respectively. Data analysis has been made based on several 15 to 20-day batches distributed during 2020.

CS1

The CS1 relative frequency instability $\sigma_y(\tau = 5000\ \mathrm{s})$ was found to vary between 69×10^{-15} and 82×10^{-15} during 2020, generally in agreement with the prediction based on the prevailing parameters beam flux, clock transition signal and line width. With reference to TAI, the standard deviation of *d*(CS1) (Circular T Section 3, 12 months) was 6.5×10^{-15}, in agreement with the value $u_{\mathrm{A}}(\tau = 30\ \mathrm{d,\ CS1}) = 8\times10^{-15}$ stated in Circular T. During the year, two reversals of the beam direction were performed on CS1. No findings call for a modification of the previously stated relative frequency uncertainty u_{B}, which is 8×10^{-15} for CS1 [2]. This value complies with the mean offset between CS1 and TAI during 2020 (mean of the 12 *d*-values reported in Circular T) of -4.2×10^{-15}.

CS2

The relative CS2 frequency instability of $\sigma_y(\tau = 5000\ \mathrm{s})$ was measured between 52×10^{-15} and 66×10^{-15} during 2020, generally in agreement with the prediction based on the prevailing parameters beam flux, clock transition signal and line width. The standard deviation of the 12 *d*-values reported in Circular T for 2020 amounted to 2.9×10^{-15}. The scatter of data is lower than in previous years and is fully in line with the stated uncertainty contribution $u_{\mathrm{A}}(\tau = 30\ \mathrm{d,\ CS2}) = 5\times10^{-15}$ reported in Circular T. During the year, two reversals of the beam direction were performed on CS2.The uncertainty estimate as detailed in [1, 2] is considered as still valid, and the CS2 u_{B} is thus estimated as 12×10^{-15}. This value complies well with the mean offset between CS2 and TAI during 2020 (mean of the 12 *d*-values reported in Circular T) of -3.1×10^{-15}.

PTB’s primary caesium fountain clocks

In 2020 both caesium fountain clocks, CSF1 and CSF2, were operated regularly with a high duty cycle. The frequency synthesis for both fountains routinely makes use of an optically stabilized microwave oscillator [3-5] instead of employing quartz based microwave synthesis. Since March 2020 a new more robust frequency comb system, which is primarily dedicated to provide the microwave signal for the two fountain clocks, is in continuous use. In the new setup the microwave signal is obtained directly via a photodetector from the frequency-locked frequency comb. For the generation of UTC(PTB) the data of both fountains were routinely used for the steering of a hydrogen maser output frequency [6]. The steering data was obtained from the weighted average of the data of the two fountains, by taking the systematic and statistical uncertainties of either fountain data into account.

CSF1

In 2020 eleven measurements of the TAI scale unit of 10 (1×), 15 (1×), 25 (1×), 30 (7×) and 35 (1×) days duration were performed and reported to the BIPM. The difference between the mean fractional deviation *d* of the scale interval of TAI from that of TT, measured during 295 days by CSF1, and the mean BIPM estimate of *d* based on all simultaneous Primary and Secondary Frequency Standard measurements was less than 1.0×10^{-16}.

Dead times ranged from 2.5% to 11% of the nominal measurement duration, where about 1.5% dead time is caused by the periodic switching between low and high density operation modes and periodical magnetic field measurements. The resulting clock link uncertainty $u_{\mathrm{l/lab}}$ was in the range 0.1×10^{-16} to 0.6×10^{-16}.

The statistical uncertainty of CSF1 measurements was calculated with the assumption of white frequency noise during the measurement intervals. For the eleven TAI contributions in 2020 typically statistical uncertainties $u_{\mathrm{A}} < 1\times10^{-16}$ were achieved.

Below we compile typical frequency biases and the updated type B uncertainty budget of CSF1, valid for TAI scale unit measurements [7].

Physical effect	Bias / 10^{-16}	Type B uncertainty / 10^{-16}
Quadratic Zeeman shift	1078.73	0.10
Black body radiation shift	- 167.09	0.81
Relativistic redshift and Doppler effect	85.56	0.02
Collisional shift	15.0	2.3
Distributed cavity phase shift	0.04	0.93
Microwave lensing	0.4	0.2
AC Stark shift (light shift)		0.01
Rabi and Ramsey pulling		0.013
Microwave leakage		0.01
Electronics		0.1
Background gas collisions		0.4
Total type B uncertainty		2.7

CSF2

In 2020 thirteen measurements of the TAI scale unit of 15 (2×), 25 (1×), 30 (9×) and 35 (1×) days duration were performed and reported to the BIPM. The difference between the mean fractional deviation *d* of the scale interval of TAI from that of TT, measured during 360 days by CSF2, and the mean BIPM estimate of *d* based on all simultaneous Primary and Secondary Frequency Standard measurements was -1.0×10^{-16}.

The dead times of the above measurements were usually between 2%-6% of the nominal measurement duration, where about 1% dead time is caused by the periodic switching between low and high density operation modes and periodical magnetic field measurements. The resulting clock link uncertainty $u_{\mathrm{l/lab}}$ was $\leq 0.5\times10^{-16}$.

The statistical uncertainty of CSF2 measurements was calculated with the assumption of white frequency noise for the total measurement intervals and includes a statistical uncertainty contribution from the collisional shift evaluation [7]. For the thirteen TAI contributions in 2020 we arrived at statistical uncertainties u_{A} between $1.0\text{-}1.5\times10^{-16}$.

Below we compile typical frequency biases and an updated type B uncertainty budget of CSF2, valid for TAI scale unit measurements [7].

Physical effect	Bias / 10^{-16}	Type B uncertainty / 10^{-16}
Quadratic Zeeman shift	999.94	0.10
Black body radiation shift	- 165.93	0.63
Relativistic redshift and Doppler effect	85.45	0.02
Collisional shift	-68.4	0.3
Distributed cavity phase shift	0.28	1.52
Microwave lensing	0.7	0.2
AC Stark shift (light shift)		0.01
Rabi and Ramsey pulling		0.013
Microwave leakage		0.01
Electronics		0.1
Background gas collisions		0.1
Total type B uncertainty		1.7

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Table 7. Mean fractional deviation of the TAI scale interval from that of TT

The fractional deviation *d* of the scale interval of TAI from that of TT (in practice the SI second on the geoid), and its relative uncertainty, are computed by the BIPM for all the intervals of computation of TAI, according to the method described in 'Azoubib J., Granveaud M., Guinot B., *Metrologia* 1977, **13**, pp. 87-93', using all available measurements from the most accurate primary frequency standards (PFS) IT-CSF2, METAS-FOC2, NIM5, NPL-CsF2, NRC-FCs2, PTB-CS1, PTB-CS2, PTB-CSF1, PTB-CSF2, SU-CSFO2, SYRTE-FO1, SYRTE-FO2, SYRTE-FOM and secondary frequency standard (SFS) IT-Yb1, NICT-Sr1, NIST-Yb1, NMIJ-Yb1, SYRTE-FORb, SYRTE-SR2 and SYRTE-SrB consistently corrected for the black-body radiation shift.

In this computation, the uncertainty of the link to TAI has been computed using the standard uncertainty of [UTC-UTC(*k*)], following the recommendation of the CCTF working group on PFS. The model for the instability of EAL has been expressed as the quadratic sum of three components: a white frequency noise $1.7 \times 10^{-15}/\sqrt{(\tau)}$ in 2013 and 2014 and $1.4 \times 10^{-15}/\sqrt{(\tau)}$ from 2015 to 2020, a flicker frequency noise 0.35×10^{-15} in 2013 and 2014 and 0.3×10^{-15} in from 2015 to 2017 and 0.2×10^{-15} from 2018 to 2020 and a random walk frequency noise $0.4 \times 10^{-16} \mathrm{x} \sqrt{(\tau)}$ in 2013 and $0.2 \times 10^{-16} \mathrm{x} \sqrt{(\tau)}$ from 2014 to 2020, with τ in days. The relation between EAL and TAI is given in the following https://webtai.bipm.org/ftp/pub/tai/other-products/ealtai/feal-ftai.

Month	Interval	$d/10^{-15}$	uncertainty/10^{-15}
Jan. 2018	58114-58149	-0.09	0.20
Feb. 2018	58149-58174	0.01	0.17
Mar. 2018	58174-58204	-0.15	0.17
Apr. 2018	58204-58234	0.03	0.17
May 2018	58234-58269	0.33	0.17
Jun. 2018	58269-58299	0.46	0.19
Jul. 2018	58299-58329	0.64	0.23
Aug. 2018	58329-58359	0.50	0.22
Sep. 2018	58359-58389	0.66	0.16
Oct. 2018	58389-58419	0.39	0.18
Nov. 2018	58419-58449	0.60	0.16
Dec. 2018	58449-58479	0.63	0.13
Jan. 2019	58479-58514	0.57	0.13
Feb. 2019	58514-58539	0.56	0.15
Mar. 2019	58539-58569	0.51	0.16
Apr. 2019	58569-58599	0.44	0.16
May 2019	58599-58634	0.57	0.14
Jun. 2019	58634-58664	0.59	0.14
Jul. 2019	58664-58694	0.55	0.16
Aug. 2019	58694-58724	0.31	0.13
Sep. 2019	58724-58754	-0.10	0.13
Oct. 2019	58754-58784	-0.36	0.12
Nov. 2019	58784-58814	-0.38	0.12
Dec. 2019	58814-58844	-0.67	0.13
Jan. 2020	58844-58879	-0.60	0.12
Feb. 2020	58879-58904	-0.49	0.14
Mar. 2020	58904-58939	-0.49	0.12
Apr. 2020	58939-58969	-0.43	0.13
May 2020	58969-58999	-0.46	0.12
Jun. 2020	58999-59029	-0.59	0.13
Jul. 2020	59029-59059	-0.59	0.11
Aug. 2020	59059-59089	-0.65	0.13
Sep. 2020	59089-59119	-0.57	0.12
Oct. 2020	59119-59149	-0.29	0.12
Nov. 2020	59149-59179	-0.02	0.12
Dec. 2020	59179-59214	-0.19	0.14

Independent local atomic time scales

Local atomic time scales are established by the time laboratories which contribute with the appropriate clock data to the BIPM. Starting on 1 January 1998, the differences between TAI and the atomic scale maintained by each laboratory have been available on the Publications page of the Time Department's FTP Server, including the relevant notes. For each time laboratory 'lab' a separate file TAI-lab is provided; it contains the respective values of the differences [*TAI - TA(lab)*] in nanoseconds, for the standard dates.

For dates from January 1982 to December 1992 and from January 1993 to December 1998, the differences between TAI and the atomic scale maintained by each laboratory are available on the Scales page of the Time Department's FTP server including relevant notes. The values of [*TAI - TA(lab)*] are given in yearly files. Note that the formats of the [TAI – TA(lab)] files are different in the two intervals.

Local representations of UTC

The time laboratories which submit data to the BIPM keep local representations of UTC. Starting on 1 January 1998, the computed differences between UTC and each local representation are available on the Publications page of the Time Department's FTP Server including the relevant notes. For each time laboratory 'lab' a separate file UTC-lab is provided; it contains the values of the differences [*UTC - UTC(lab)*] in nanoseconds, for the standard dates.

For dates from January 1990 to December 1992 and from January 1993 to December 1998, the computed differences between UTC and each local representation maintained by each laboratory are available on the Scales page of the Time Department's FTP server including the relevant notes. The values of [*UTC - UTC(lab)*] are given in yearly files. Note that the formats of the files [*UTC* – *UTC*(*lab*)] are different in the two intervals.

Starting on MJD 56467 daily values of the differences [*UTCr-UTC(lab)*] in nanoseconds are given in one file per laboratory. The results during the UTCr Pilot Experiment (February 2012-June 2013) are also available.

Relations of UTC and TAI with GPS time, GLONASS time, UTC(USNO)_GPS and UTC(SU)_GLONASS

(File available at https://webtai.bipm.org/ftp/pub/tai/other-products/utcgnss/utc-gnss)

[*TAI - GPS time*] and [*UTC - GPS time*]

The GPS satellites disseminate a common time scale designated 'GPS time'. The relation between GPS time and TAI is:

$$[TAI\text{ - }GPS\ time] = 19\text{ s} + C_0,$$

where the time difference of 19 seconds is kept constant and C_0 is a quantity of the order of tens of nanoseconds, varying with time.

The relation between GPS time and UTC involves a variable number of seconds as a consequence of the leap seconds of the UTC system and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[UTC\text{ - }GPS\ time] = -18\text{ s} + C_0$,

Here C_0 is given at 0 h UTC every day.

C_0 is computed as follows. The GPS data recorded at the Paris Observatory for highest-elevation satellites are first corrected for precise satellite ephemerides and for ionospheric delays derived from IGS maps, and then smoothed to obtain daily values of [*UTC*(*OP*) - *GPS time*] at 0 h UTC. Daily values of C_0 are then derived by linear interpolation of [*UTC* - *UTC*(*OP*)].

The standard deviation σ_0 characterizes the dispersion of individual measurements for a month. The actual uncertainty of user’s access to GPS time may differ from these values. N_0 is the number of measurements.

[*TAI – UTC(USNO)_GPS*] and [*UTC – UTC(USNO)_GPS*]

The GPS satellites broadcast a prediction of UTC(USNO) calculated at the USNO, indicated by UTC(USNO)_GPS. The relation between UTC(USNO)_GPS and TAI involves a variable number of seconds as a consequence of the leap seconds of the UTC system, and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[TAI – UTC(USNO)\_GPS] = 37\text{ s} + C_0'$

Here C_0' is given at 0 h UTC every day.

C_0' is computed using the values of [*UTC* - *UTC*(*OP*)] similarly than the computation of C_0.

The relation between UTC(USNO)_GPS and UTC is $[UTC– UTC(USNO)\_GPS] = 0\text{ s} + C_0'$

The standard deviation σ_0' characterizes the dispersion of individual measurements for a month. The actual uncertainty of user’s access to UTC(USNO)_GPS may differ from these values. N_0' is the number of measurements.

Relations of UTC and TAI with GPS time, GLONASS time, UTC(USNO)_GPS and UTC(SU)_GLONASS (Cont.)

(File available at https://webtai.bipm.org/ftp/pub/tai/other-products/utcgnss/utc-gnss)

[*UTC* - *GLONASS time*] and [*TAI* - *GLONASS time*]

The GLONASS satellites disseminate a common time scale designated 'GLONASS time'. The relationship between GLONASS time and UTC is

$$[UTC - GLONASS\ time] = 0\ \mathrm{s} + C_1,$$

where the time difference 0 s is kept constant by the application of leap seconds so that GLONASS time follows the UTC system, and C_1 is a quantity of the order of tens of nanoseconds (tens of microseconds until 1 July 1997), which varies with time.

The relation between GLONASS time and TAI involves a variable number of seconds and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[TAI - GLONASS\ time] = 37\ \mathrm{s} + C_1$.

Here C_1 is given at 0 h UTC every day.

C_1 is computed as follows. The GLONASS data recorded at the Astrogeodynamical Observatory, Borowiec, Poland for the highest-elevation satellites are smoothed to obtain daily values of [*UTC*(*AOS*) - *GLONASS time*] at 0 h UTC. Daily values of C_1 are then derived by linear interpolation of [*UTC* - *UTC*(*AOS*)].

To ensure the continuity of C_1 estimates, the following corrections are applied:

+1285 ns from 1 January 1997 (MJD 50449) to 22 March 1999 (MJD 51259)
+107 ns for 23 March 1999 and 24 March (MJD 51260 and MJD 51261)
0 ns since 25 March 1999, (MJD 51262).

The standard deviation σ_1 characterizes the dispersion of individual measurements for a month. The actual uncertainty of user's access to GLONASS time may differ from these values. N_1 is the number of measurements.

[*TAI – UTC(SU)_GLONASS*] and [*UTC – UTC(SU)_GLONASS*]

The satellites broadcast a prediction of UTC(SU) calculated at the SU, indicated by UTC(SU)_GLONASS. The relation between UTC(SU)_GLONASS and TAI involves a variable number of seconds as a consequence of the leap seconds of the UTC system, and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[TAI – UTC(SU)\_GLONASS] = 37\ \mathrm{s} + C_1'$

Here C_1' is given at 0 h UTC every day.

C_1' is computed using the values of [*UTC* - *UTC*(*AOS*)] similarly than the computation of C_1.

The relation between UTC(SU)_GLONASS and UTC is $[UTC– UTC(SU)\_GLONASS] = 0\ \mathrm{s} + C_1'$

The standard deviation σ_1' characterizes the dispersion of individual measurements for a month. The actual uncertainty of user's access to UTC(SU)_GPS may differ from these values. N_1' is the number of measurements.

Clocks contributing to TAI in 2020

Clock characteristics

The annual tables of clock weight, rate, and drift, are no longer published, the information can be found in the reported links in the monthly files.
YY represents the last two digits of the year (20YY) and MM represents the month number of the year (1-12).

Relative clock weights for intervals of one month

Monthly clock weights are available in file wYY.MM in https://webtai.bipm.org/ftp/pub/tai/other-products/weights/.

Monthly rates of TAI- clocks for intervals of one month

Monthly clock rates are available in file rYY.MM in https://webtai.bipm.org/ftp/pub/tai/other-products/rates/.

Frequency drifts of the clocks using a monthly realization of TT(BIPM) as reference

Monthly clock frequency drifts are available in file dYY.MM in https://webtai.bipm.org/ftp/pub/tai/other-products/clkdrifts/.

Table 8 reports the statistical data on the weights attributed to the clocks in 2020.

Table 8: Statistical data on the weights attributed to the clocks in 2020

		Number of Clocks			Number of clocks with a given weight									
					Weight = 0*			Weight = 0**			Max weight			Max relative weight
Interval		HM	5071A	Total	HM	5071A	Total	HM	5071A	Total	HM	5071A	Total	
2020	Jan.	160	223	429	19	40	69	4	4	12	62	0	66	1.111
2020	Feb.	175	229	451	32	45	88	4	4	11	60	0	64	1.102
2020	Mar.	176	226	444	28	35	68	6	6	16	61	0	65	1.064
2020	Apr.	177	218	434	30	32	68	6	7	17	59	0	63	1.093
2020	May	180	219	435	27	24	57	8	6	16	63	0	67	1.058
2020	June	175	222	443	12	21	48	10	6	19	64	0	68	1.013
2020	July	169	216	427	13	24	50	4	4	10	61	0	65	1.061
2020	Aug.	178	214	441	24	24	67	5	4	11	60	0	64	1.070
2020	Sep.	176	213	437	22	24	62	5	4	12	59	0	63	1.067
2020	Oct.	167	213	430	18	19	49	7	4	15	60	0	64	1.050
2020	Nov.	173	218	438	20	21	50	7	6	16	64	0	68	1.031
2020	Dec.	169	214	429	11	19	37	7	6	17	61	0	65	1.020

Wmax=A/N, here N is the number of clocks, excluding those with a priori null weight, A=4.00.

* A priori null weight (test interval of new clocks).

** Null weight resulting from the statistics.

HM designates hydrogen masers and 5071A designates Hewlett-Packard 5071A units with high performance tube.

Clocks with missing data during a one-month interval of computation are excluded.

TIME SIGNALS

The time signal emissions reported here follow the UTC system, in accordance with Recommendation 460-6 of the Radiocommunication Bureau (RB) of the International Telecommunication Union (ITU) unless otherwise stated.

Their maximum departure from Universal Time UT1 is thus 0.9 seconds.

The following tables are based on information received at the BIPM between March and May 2021.

AUTHORITIES RESPONSIBLE FOR TIME SIGNAL EMISSIONS

Signal	**Authority**
ALS162 (previoulsy TDF)	France Horlogerie (previously CFHM : Chambre française de l’horlogerie et des microtechniques) 22 avenue Franklin Roosevelt 75008 Paris, France and ANFR Agence nationale des fréquences 78, avenue du général de Gaulle 94704 Maisons-Alfort, France and LNE Laboratoire national de métrologie et d’essais 1 rue Gaston Boissier 75724 Paris Cedex 15, France
BPC, BPL, BPM	National Time Service Center, NTSC Chinese Academy of Sciences 3 East Shuyuan Rd, Lintong District, Xi’an Shaanxi 710600, China
CHU	National Research Council of Canada Metrology Frequency and Time Standards Bldg M-36, 1200 Montreal Road Ottawa, Ontario, K1A 0R6, Canada
DCF77	Physikalisch-Technische Bundesanstalt Time and Frequency Department, WG 4.42 Bundesallee 100 D-38116 Braunschweig Germany
HLA	Center for Time and Frequency Division of Physical Metrology Korea Research Institute of Standards and Science 267 Gajeong-Ro, Yuseong, Daejeon 34113 Republic of Korea
JJY	Space-Time Standards Laboratory National Institute of Information and Communications Technology 4 -2- 1, Nukui-kitamachi Koganei, Tokyo 184-8795 Japan

Signal	**Authority**
LOL	Servicio de Hidrografía Naval Observatorio Naval Buenos Aires Av. España 2099 C1107AMA – Buenos Aires, Argentina
MIKES	VTT Technical Research Centre of Finland Ltd Centre for Metrology MIKES P.O. Box 1000, FI-02044 VTT, Finland
MSF	National Physical Laboratory Time and Frequency Department Hampton Road Teddington, Middlesex TW11 0LW United Kingdom
RAB-99, RBU, RJH-63, RJH-69, RJH-77, RJH-86, RJH-90,RTZ,RWM	All-Russian Scientific Research Institute for Physical Technical and Radiotechnical Measurements FGUP “VNIIFTRI” Meendeleevo, Moscow Region 141570 Russia
WWV, WWVB, WWVH	Time and Frequency Division, 688.00 National Institute of Standards and Technology - 325 Broadway Boulder, Colorado 80305, U.S.A.

TIME SIGNALS EMITTED IN THE UTC SYSTEM

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
ALS162 (previously TDF)	Allouis France 47° 10'N 2° 12'E	162	Continuous, except every Tuesday from 8 h to12 h (French legal time)	Phase modulation of the carrier by +1 and -1 rad in 0.1 s every second except the 59th second of each minute. This modulation is doubled to indicate binary 1. The numbers of the minute, hour, day of the month, day of the week, month and year are transmitted each minute from the 21st to the 58th second, in accordance with the French legal time scale. In addition, a binary 1 at the 17th second indicates that the local time is 2 hours ahead of UTC (summer time); a binary 1 at the 18th second indicates that the local time is 1 hour ahead of UTC (winter time); a binary 1 at the 14th second indicates that the current day is a public holiday (Christmas, 14 July, etc...); a binary 1 at the 13th second indicates that the current day is a day before a public holiday.
BPC	Shangqiu China 34° 27'N 115° 50'E	68.5	00 h 00 m to 21 h 00 m	UTC second pulse modulation of the phase shift keying of the carrier. The additional pulse width modulation includes calendar and local time information.
BPL	Pucheng China 34° 56'N 109° 32'E	100	Continuous	The BPL time signals are generated by NTSC and are in accordance with the legal time of China which is UTC(NTSC)+8 . The BPL system is the same as the Loran-C system, utilizing the multi-pulse phase coding scheme. Carrier Frequency of 100KHz. The information that BPL broadcasts contains minutes, seconds, year, month, day, and other information. Using pulse shift modulation.
BPM	Pucheng China 35° 0'N 109° 31'E	2 500 5 000 10 000 15 000	7 h 30 m to 1 h Continuous Continuous 1 h to 9 h	The BPM time signals are generated by NTSC and are in accordance with UTC(NTSC)+8 h. Signals emitted in advance on UTC by 20 ms. Second pulses of 10 ms duration with 1 kHz modulation. Minute pulses of 300 ms duration with 1 kHz modulation. UTC time signals are emitted from minute 0 to 10, 15 to 25, 30 to 40, 45 to 55. UT1 time signals are emitted from minute 25 to 29, 55 to 59.
CHU	Ottawa Canada 45° 18'N 75° 45'W	3 330 7 850 14 670	Continuous	Second pulses of 300 cycles of a 1 kHz modulation, with 29th and 51st to 59th pulses of each minute omitted. Minute pulses are 0.5 s long. Hour pulses are 1.0 s long, with the following 1st to 9th pulses omitted. A bilingual (Fr. Eng.) announcement of time (UTC) is made each minute following the 50th second pulse. FSK code (300 bps, Bell 103) after 10 cycles of 1 kHz on seconds 31 to 39. Year, DUT1, leap second information, TAI-UTC and Canadian daylight saving time format on 31, and time code on 32-39. Broadcast is single sideband; upper sideband with carrier reinsert. DUT1 : ITU-R code by double pulse.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
DCF77	Mainflingen Germany 50° 1'N 9° 0'E	77.5	Continuous	The DCF77 time signals are generated by PTB and are in accordance with the legal time of Germany which is UTC(PTB)+1 h or UTC(PTB)+2 h. At the beginning of each second (except in the last second of each minute) the carrier amplitude is reduced to about 15 % for a duration of 0.1 or 0.2 s corresponding to “binary 0” or “binary 1”, respectively, referred to as second marks 0 to 59 in the following. The number of the minute, hour, day of the month, day of the week, month and year are transmitted in BCD code using second marks 20 to the 58, including overhead. Information emitted during minute n is valid for minute n+1. The information transmitted during the second marks 1 to the 14 is provided by third parties. Information on that additional service can be obtained from PTB. To achieve a more accurate time transfer and a better use of the frequency spectrum available an additional pseudo-random phase shift keying of the carrier is superimposed on the AM second markers. No transmission of DUT1.
HLA	Daejeon Rep. of Korea 36° 23'N 127° 22'E	5 000	Continuous	Second pulses of 9 cycles of 1 800 Hz tones. 29th and 59th second pulses omitted. Hour identified by 0.8 s long 1 500 Hz tones. Beginning of each minute identified by 0.8 s long 1 800 Hz tones. BCD time code given on 100 Hz subcarrier.
JJY	Tamura-shi Fukushima Japan 37° 22'N 140° 51'E	40	Continuous	A1B type 0.2 s, 0.5 s and 0.8 s second pulses, spacings are given by the reduction of the amplitude of the carrier. Coded announcement of hour, minute, day of the year, year, day of the week and leap second. Transmitted time refers to UTC(NICT) + 9 h.
JJY	Saga-shi Saga Japan 33° 28'N 130° 11'E	60	Continuous	A1B type 0.2 s, 0.5 s and 0.8 s second pulses, spacings are given by the reduction of the amplitude of the carrier. Coded announcement of hour, minute, day of the year, year, day of the week and leap second same as JJY(40). Transmitted time refers to UTC(NICT) + 9 h.
LOL	Buenos Aires Argentina 34° 37'S 58° 21'W	10 000	11 h to 12 h except Saturday, Sunday and national holidays.	Second pulses of 5 cycles of 1000 Hz modulation. Second 59 is omitted. Announcement of hours and minutes every 5 minutes, followed by 3 minutes of 1000 Hz or 440 Hz modulation. DUT1: ITU-R code by lengthening.
MIKES	Espoo Finland 60° 11'N 24° 50'E	25 000	Continuous	Modulation as in DCF77, but with 1 kHz amplitude modulation added and without pseudo-random phase shift keying of the carrier. Time code in UTC.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
MSF	Anthorn United Kingdom 54° 54'N 3° 16'W	60	Continuous, except for interruptions for maintenance from 10 h 0 m to 14 h 0 m on the second Thursday of December and March, and from 09 h 0 m to 13 h 0 m on the second Thursday of June and September. A longer period of maintenance during the summer is announced annually.	The carrier is interrupted for 0.1 s at the start of each second, except during the first second of each minute (second 0) when the interruption is 0.5 s. Two data bits are transmitted each second (except second 0): data bit “A” between 0.1 and 0.2 s after the start of the second and data bit “B” between 0.2 and 0.3 s after the start of the second. Presence of the carrier represents “binary 0” and an interruption represents “binary 1”. The values of data bit “A” provide year, month, day of the month, day of the week, hour and minute in BCD code. The time represented is UTC(NPL) in winter and UTC(NPL)+1h when DST is in effect. The values of data bit “B” provide DUT1 and an indication whether DST is in effect. The information transmitted applies to the following minute. DUT1: ITU-R code by double pulse.
RAB-99	Khabarovsk Russia 48° 30'N 134° 50'E	25.0 25.1 25.5 23.0 20.5	02 h 06 m to 02 h 36 m 06 h 06 m to 06 h 36 m	A1N type signals are transmitted between minutes 9 and 20 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 9 and 11; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 11 and 20.
RBU	Moscow Russia 56° 44'N 37° 40'E	200/3	Continuous	DXXXW type 0.1 s signals. The numbers of the minute, hour, day of the month, day of the week, month, year of the century, difference between the universal time and the local time, TJD and DUT1+dUT1 are transmitted each minute from the 1st to the 59th second. DUT1+dUT1 : by double pulse.
RJH-63	Krasnodar Russia 44° 46'N 39° 34'E	25.0 25.1 25.5 23.0 20.5	11 h 06 m to 11 h 40 m	A1N type signals are transmitted between minutes 9 and 20 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 9 and 11 ; 0.1 second pulses of 25 ms duration, 10 second pulses of 1 s duration and minute pulses of 10 s duration are transmitted between minutes 11 and 20.
RJH-69	Molodechno Belarus 54° 28'N 26° 47'E	25.0 25.1 25.5 23.0 20.5	07 h 06 m to 07 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.
RJH-77	Arkhangelsk Russia 64° 22'N 41° 35'E	25.0 25.1 25.5 23.0 20.5	09 h 06 m to 09 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
RJH-86	Bishkek Kirgizstan 43° 03'N 73° 37'E	25.0 25.1 25.5 23.0 20.5	04 h 06 m to 04 h 47 m 10 h 06 m to 10 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.
RJH-90	Nizhni Novgorod Russia 56° 11'N 43° 57'E	25.0 25.1 25.5 23.0 20.5	08 h 06 m to 08 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.
RTZ	Irkutsk Russia 52° 26'N 103° 41'E	50	00 h 00 m to 19 h 00 m 20 h 00 m to 24 h 00 m	DXXXW type 0.1 s signals. The numbers of the minute, hour, day of the month, day of the week, month, year of the century, difference between the universal time and the local time, TJD and DUT1+dUT1 are transmitted each minute from the 1st to the 59th second. DUT1+dUT1: by double pulse.
RWM (1)	Moscow Russia 56° 44'N 37° 38'E	4 996 9 996 14 996	The station operates simultaneously on the three frequencies.	A1X type second pulses of 0.1 s duration are transmitted between minutes 10 and 20, 40 and 50. The pulses at the beginning of the minute are prolonged to 0.5 s. A1N type 0.1 s second pulses of 0.02 s duration are transmitted between minutes 20 and 30. The pulses at the beginning of the second are prolonged to 40 ms and of the minute to 0.5 ms. DUT1+dUT1: by double pulse.
WWV	Fort-Collins CO, USA 40° 41'N 105° 3'W	2 500 5 000 10 000 15 000 20 000 25 000	Continuous	Second pulses are 1 000 Hz tones, 5 ms in duration. 29th and 59th second pulses omitted. Hour is identified by 0.8 second long 1 500 Hz tone. Beginning of each minute identified by 0.8 second long 1 000 Hz tones. DUT1: ITU-R code by double pulse. BCD time code given on 100 Hz subcarrier, includes DUT1 correction.
WWVB	Fort-Collins CO, USA 40° 41'N 105° 3'W	60	Continuous	Second pulses given by reduction of the amplitude, reversal of phase, and by binary phase shift keying of the carrier, AM, PM and BPSK coded announcement of the date, time, DUT1 correction, daylight saving time in effect, leap year and leap second.
WWVH	Kauai HI, USA 21° 59'N 159° 46'W	2 500 5 000 10 000 15 000	Continuous	Second pulses are 1 200 Hz tones, 5 ms in duration. 29th and 59th second pulses omitted. Hour is identified by 0.8 second long 1 500 Hz tone. Beginning of each minute identified by 0.8 second long 1 200 Hz tones. DUT1: ITU-R code by double pulse. BCD time code given on 100 Hz subcarrier, includes DUT1 correction.

(1) RWM is the radiostation emitting DUT1 information in accordance with the ITU-R code and also giving the additional information, dUT1, which specifies more precisely the difference UT1-UTC down to multiples of 0.02 s, the total value of the correction being DUT1+dUT1.

Positive values of dUT1 are transmitted by the marking of *p* second markers within the range between the 21st and 24th second so that dUT1 = +*p* x 0.02 s.

Negative values of dUT1 are transmitted by the marking of *q* second markers within the range between the 31st and 34th second, so that dUT1 = -*q* x 0.02 s.

ACCURACY OF THE CARRIER FREQUENCY

Station	Relative uncertainty of the carrier frequency in 10^{-10}	
ALS162	**0.02**	**(previously TDF)**
BPM	**0.01**	
CHU	**0.05**	
DCF77	**0.02**	
HLA	**0.02**	
JJY	**0.01**	
LOL	**0.1**	
MIKES	**0.01**	
MSF	**0.02**	
RAB-99,RJH-63	**0.05**	
RBU,RTZ	**0.02**	
RJH-69, RJH-77	**0.05**	
RJH-86, RJH-90	**0.05**	
RWM	**0.05**	
WWV	**0.01**	
WWVB	**0.01**	
WWVH	**0.01**	

TIME DISSEMINATION SERVICES

The following tables are based on information received at the BIPM between March and May 2021.

AUTHORITIES RESPONSIBLE FOR TIME DISSEMINATION SERVICES

AOS
Astrogeodynamical Observatory
Borowiec near Poznan
Space Research Centre P.A.S.
PL 62-035 Kórnik - Poland

AUS
Electricity Section
National Measurement Institute
36 Bradfield Rd
Lindfield NSW 2070 - Australia

BelGIM
Belarussian State Institute of Metrology
National Standard for Time, Frequency and
Time-scale of the Republic of Belarus
Minsk, Minsk Region – 220053 Belarus

BEV
Bundesamt für Eich- und Vermessungswesen
Arltgasse 35
A-1160 Wien, Vienna - Austria

BoM
Ministry of economy - Bureau of metrology
Jane Sandanski 109a
1000 Skopje, Macedonia

CENAM
Centro Nacional de Metrología
Dirección de Tiempo y Frecuencia
km. 4.5 carretera a Los Cués
El Marqués, Querétaro 76246, México.

CENAMEP
Centro Nacional de Metrología de Panamá AIP
CENAMEP AIP
Ciudad del Saber
Edif. 206 Panama

DMDM
Directorate of Measures and Precious Metals
Section for electrical quantities, time and frequency
Mike Alasa 14
11000 Belgrade
Serbia

EIM
Hellenic Institute of Metrology
Electrical Measurements Department
Block 45, Industrial Area of Thessaloniki
PO 57022, Sindos
Thessaloniki, Greece

GUM
Time and Frequency Laboratory
Główny Urząd Miar – Central Office of Measures
ul. Elektoralna 2
PL 00 – 139 Warszawa, Poland

HKO
Hong Kong Observatory
134A, Nathan Road
Kowloon, Hong Kong, China

ICE	Instituto Costarricense de Electricidad ICE San Jose Costa Rica
IGNA	Instituto Geográfico Nacional Argentino Servicio Internacional de la Hora General Manuel N. Savio 1898 B1650KLP – Villa Maipú, Provincia de Buenos Aires, Argentina
ILNAS	Bureau Luxembourgeois de Métrologie Laboratoire Temps Fréquence 22 avenue des Hauts Fourneaux L-4362 Esch-sur-Alzette, Luxembourg
IMBH	Institute of Metrology of Bosnia and Herzegovina (IMBH) Laboratory for time and frequency Augusta Brauna 2 71000 Sarajevo, Bosnia and Herzegovina
INACAL	Instituto Nacional de Calidad Calle De La Prosa 150 Código postal 15034 San Borja, Lima 41, Peru
INM	Instituto Nacional de Metrología de Colombia Avenida Carrera 50 No. 26 – 55 Interior 2 Bogotá D.C. – Colombia
INPL	National Physical Laboratory of Israel Ministry of Economy and Industry Bank of Israel Street, 5, Jerusalem 9103101 P.O.B. 3166; Tel.: +972-(0)74-7215923 Israel
INRIM	Istituto Nazionale di Ricerca Metrologica Strada delle Cacce, 91 I – 10135 Turin, Italy
INTI	Instituto Nacional de Tecnología Industrial Av. General Paz Nº 5445 B1650WAB San Martín Buenos Aires, Argentina
JV	Justervesenet Norwegian Metrology Service PO Box 170 2027 Kjeller, Norway
KRISS	Center for Time and Frequency Division of Physical Metrology Korea Research Institute of Standards and Science 267 Gajeong-Ro, Yuseong Daejeon 34113 Republic of Korea
KZ	Kazakhstan Institute of Metrology Orynbor str., 11 Astana, Republic of Kazakhstan

LNE-SYRTE Laboratoire National de Métrologie et d’Essais
Systèmes de Référence Temps-Espace
Observatoire de Paris
61, avenue de l’Observatoire, 75014 Paris – France

LRTE Laboratório de Referências de Tempo e Espaço
Grupo de Óptica
University of São Paulo
Av. Trabalhador Saocarlense, 400
13566-590 São Carlos, Brazil

LT Time and Frequency Standard Laboratory
Center for Physical Sciences and Technology
Savanoriu av. 231
Vilnius LT-02300, Lithuania

MASM Time and Frequency Standard Laboratory
Mongolian Agency for Standardization and Metrology
Peace avenue 46A, Bayanzurkh district, Ulaanbaatar 13343 Mongolia

METAS Federal Institute of Metrology
Sector Length, Optics and Time
Lindenweg 50
CH-3003 Bern-Wabern
Switzerland

MIKES VTT Technical Research Centre of Finland Ltd
Centre for Metrology MIKES
P.O. Box 1000, FI-02044 VTT, Finland

MSL Measurement Standards Laboratory
Callaghan Innovation
69 Gracefield Road
PO Box 31-310
Lower Hutt – New Zealand

NAO Time Keeping Office
Mizusawa VLBI Observatory
National Astronomical Observatory of Japan
2-12, Hoshigaoka, Mizusawa, Oshu, Iwate 023-0861
Japan

NICT Space-Time Standards Laboratory
National Institute of Information and Communications Technology
4 -2 -1, Nukui-kitamachi
Koganei, Tokyo 184-8795 - Japan

NIM Time & Frequency Division
National Institute of Metrology
No. 18, Bei San Huan Dong Lu
Beijing 100029 - People’s Republic of China

NIMB Time and Frequency Laboratory
National Institute of Metrology
Sos. Vitan - Barzesti, 11
042122 Bucharest, Romania

NIMT
Time and Frequency Laboratory
National Institute of Metrology (Thailand)
3/5 Moo 3, Klong 5, Klong Luang,
Pathumthani 12120, Thailand

NIST
National Institute of Standards and Technology
Time and Frequency Division, 688.00
325 Broadway
Boulder, Colorado 80305, USA

NMIJ
Time Standards Group
National Metrology Institute of Japan (NMIJ), AIST
Umezono 1-1-1, Tsukuba, Ibaraki 305-8563, Japan

NMISA
Time and Frequency Laboratory
National Metrology Institute of South Africa
Private Bag X34
Lynnwood Ridge 0040, Pretoria - South Africa

NMLS
Time and Frequency Laboratory
National Metrology Institute of Malaysia
Lot PT 4803, Bandar Baru Salak Tinggi,
43900 Sepang - Malaysia

NPL
National Physical Laboratory
Time and Frequency Department
Hampton Road
Teddington, Middlesex TW11 0LW
United Kingdom

NPLI
Time and Frequency Metrology Section
CSIR-National Physical Laboratory
Dr.K.S.Krishnan Road
New Delhi 110012 - India

NRC
National Research Council of Canada
Metrology
Frequency and Time Standards
Bldg M-36, 1200 Montreal Road
Ottawa, Ontario, K1A 0R6, Canada

NSC IM
Time and Frequency Section
National Scientific Center "Institute of Metrology"
Kharkov - Ukraine Str. Mironositska 42
Region – 61002 Ukraine

NTSC
National Time Service Center
Chinese Academy of Sciences
3 East Shuyuan Rd, Lintong District, Xi’an
Shaanxi 710600, China

ONBA
Servicio de Hidrografía Naval
Observatorio Naval Buenos Aires
Servicio de Hora
Av. España 2099
C1107AMA – Buenos Aires, Argentina

ONRJ
Observatorio Nacional (MCTIC)
Divisão Serviço da Hora
Rua General José Cristino, 77 São Cristovão
20921-400 Rio de Janeiro, Brazil

ORB
Royal Observatory of Belgium
Avenue Circulaire, 3
B-1180 Brussels, Belgium

PTB
Physikalisch-Technische Bundesanstalt
Time and Frequency Department, WG 4. 42
Bundesallee 100
D-38116 Braunschweig, Germany

RISE
RISE Research Institutes of Sweden
Box 857
S-501 15 Borås
Sweden

ROA
Real Instituto y Observatorio de la Armada
Plaza de las Tres Marinas s/n
11.100 San Fernando
Cádiz, Spain

SG
National Metrology Centre
Agency for Science, Technology and Research (A*STAR)
1 Science Park Drive
118221 Singapore

SIQ
SIQ Ljubljana
Metrology department
Mašera-Spasićeva ulica 10
1000 Ljubljana
Slovenia

SL
Measurement Units, Standards and Services Department (MUSSD),
Mahenawatta, Pitipana,
Homagama, - Sri Lanka

SMD
FPS Economy
Directorate-General
Quality and Safety
Metrology
North Gate
Boulevard du Roi Albert II 16
1000 Brussels, Belgium

SNSU-BSN
Standar Nasional Satuan Ukuran --
Badan Standardisasi Nasional
National Measurement Standards --
National Standardization Agency
(SNSU-BSN)
Kawasan PUSPIPTEK Gedung 420
Serpong Tangerang 15314 Banten - Indonesia

TL
National Standard Time and Frequency Laboratory
Telecommunication Laboratories
Chunghwa Telecom. Co., Ltd.
No. 99, Dianyan Road
Yang-Mei, Taoyuan, 32661 Taiwan
Chinese Taipei

TP	Institute of Photonics and Electronics Czech Academy of Sciences Chaberská 57, 182 51 Praha 8 Czech Republic
UME	Ulusal Metroloji Enstitüsü Baris Mah. Dr. Zeki Acar Cad. No: 1 41470 Gebze - Kocaeli Turkey
USNO	U.S. Naval Observatory 3450 Massachusetts Ave., N.W. Washington, D.C. 20392-5420 USA
VMI	Laboratory of Time and Frequency (TFL) Vietnam Metrology Institute (VMI) No 8, Hoang Quoc Viet Rd, Cau Giay Dist., Hanoi Vietnam.
VNIIFTRI	All-Russian Scientific Research Institute for Physical Technical and Radiotechnical Measurements, Moscow Region 141570 Russia
VSL	VSL Dutch Metrology Institute Postbus 654 2600 AR Delft Netherlands

TIME DISSEMINATION SERVICES

AOS (1)	AOS Computer Time Service: vega.cbk.poznan.pl (150.254.183.15) Synchronization: NTP V3 primary (Caesium clock), PC Pentium, RedHat Linux Service Area: Poland/Europe Access Policy: open access Contact: Jerzy Nawrocki (nawrocki@cbk.poznan.pl) Robert Diak (kondor@cbk.poznan.pl)
AUS	Network Time Service Computers connected to the Internet can be synchronized to UTC(AUS) using the NTP protocol. The NTP servers are referenced to UTC(AUS) either directly or via a GPS common view link. Please see http://www.measurement.gov.au/Services/Pages/TimeandFrequencyDisseminationService.aspx for information on access or contact time@measurement.gov.au Dial-up Computer Time Service Computers can also obtain time via a modem connection to our dial-up timeserver. For further information, please see our web pages as above.
BelGIM	Internet Time Service: BelGIM operates one time server Stratum 1 using the “Network Time Protocol” (NTP). The server host name is: http://www.belgim.by (Stratum 1)
BEV	Three NTP servers are available; addresses: bevtime1.metrologie.at bevtime2.metrologie.at time.metrologie.at more information on http://www.metrologie.at Provides a time dissemination service via phone and modem to synchronize PC clocks. Uses the Time Distribution System from TUG. It has a baud rate of 1200 and everyone can use it with no cost. Access phone number is +43 1 21110 826381 The system will be updated periodically (DUT1, Leap Second…).
BoM	Internet Time Service BoM operates two Stratum 1 NTP servers referenced to UTC(BoM). BoM also operates one time server Stratum 2 using the “Network Time Protocol” (NTP). Server Host Name: time.bom.gov.mk
CENAM	CENAM operates a telephone voice system that provides the local time for time zones in Mexico. Phone numbers and zones: +52 (442) 211 0505 → Southeast Time +52 (442) 211 0506 → Central Time +52 (442) 211 0507 → Pacific Time +52 (442) 211 0508 → Northwest Time +52 (442) 211 0509 → UTC(CNM) Telephone Code CENAM provides a telephone code for setting time in computers. For more information about this service please contact tiempo@cenam.mx

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(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

	Network Time Protocol (NTP) Operates two time servers using NTP (located at CENAM). Further information at http://www.cenam.mx/hora_oficial/ Web-based time-of-day clock which displays local time for all Mexican time zones. Referenced to CENAM Internet Time Service. Available at http://www.cenam.mx/hora_oficial/
CENAMEP (1)	Network Time Server A Stratum 1 time server is used to synchronize computer networks of the government institutions and companies in the private sector using the NTP protocol. To access the Network time service, send an email to servicios@cenamep.org.pa Web Clock A web clock is used to display the time of day in real time. To access the Web Clock, enter the link http://horaexacta.cenamep.org.pa/ Voice Time Server An assembly of computers provides the local time. To access the service, call the telephone numbers (507) 5173201, (507) 5173202 and (507) 5173203
DMDM	Internet Time Service (ITS) DMDM operates two Stratum 1 time servers using the “Network Time Protocol” (NTP), synchronized to UTC(DMDM). Access policy: restricted. DMDM also operates two Stratum 2 NTP servers: vreme1.dmdm.rs or vreme1.dmdm.gov.rs vreme2.dmdm.rs or vreme2.dmdm.gov.rs Access policy: free. Web-based time-of-day clock that displays local time for Serbia referenced to the DMDM ITS. Available at the web page: http://www.dmdm.rs/en/index.php
EIM	Internet Time Service EIM operates a time server using the “Network Time Protocol” (NTP). The address hercules.eim.gr is also accessible through IP address 83.212.233.6. This route is offered under a restricted access policy. The server uses the 10 MHz signal from our primary standard as reference and is synchronized to UTC(EIM).
GUM	Telephone Time Service providing the European time code by telephone modem for setting time in computers. Includes provision for compensation of propagation time delay. Access phone number : +48 22 654 88 72 Network Time Service Two NTP servers are available: tempus1.gum.gov.pl tempus2.gum.gov.pl with an open access policy. It provides synchronization to UTC(PL). Contact: time@gum.gov.pl Web Clock A web clock is used to display the local time in Poland referred to the GUM NTP servers. Available at the web page: http://czas.gum.gov.pl

(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

HKO	Internet Clock Services HKO operates time-of-day clocks that display Hong Kong Standard Time (=UTC(HKO) + 8 h) Available as web clock at https://www.hko.gov.hk/en/gts/time/clock_e.html Speaking Clock Service HKO operates an automatic “Dial-a-weather System” that provides a voice announcement of Hong Kong Standard Time. Access phone number: +852 1878200 (when connected, press “3”, “6”, “1” in sequence) Network Time Service HKO operates network time service using Network Time Protocol (NTP). Host names of the NTP servers: stdtime.gov.hk; time.hko.hk (for IPv6 users) Further information at https://www.hko.gov.hk/en/nts/ntime.htm
ICE	Network Time Server A Stratum 1 time server is used to synchronize computer networks of the government institutions and companies in the private sector using the NTP protocol. To access the Network time service, send an email to ofallasc@ice.go.cr Web Clock A web clock is used to display the time of day in real time. To access the Web Clock, enter the link: https://www.grupoice.com/wps/portal/ICE/Electricidad/servicios-especiales/laboratorios
IGNA (1)	GPS common-view data GPS common-view data using CGGTTS format referred to UTC(IGNA) is available through our website at http://www.ign.gob.ar/NuestrasActividades/Geodesia/ServicioInternacionalHora/TransferenciaDeTiempo
ILNAS	Network Time Service via NTP Protocol Stratum-1 time server with monitoring (restricted access) Host names: ntp1.ilnas.blm.lu ntp2.ilnas.blm.lu ntp3.ilnas.blm.lu Further information at: https://portail-qualite.public.lu/fr/metrologie/etalonnages.html
IMBH	Internet Time Service IMBH operates several Stratum 1 time servers using the NTP protocol. These servers are directly synchronized to UTC(IMBH). The servers are available at IP addresses: 185.12.78.85 and 77.78.199.17 Common-view data GPS and GLONASS common-view data using CGGTTS format referred to UTC(IMBH) are available at request. Further information can be found at: http://met.gov.ba

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(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

INACAL	Network Time Server A time server is used to synchronize computer networks of the government institutions and companies in the private sector using the NTP protocol. To access the Network time enter the link https://www.inacal.gob.pe/metrologia/categoria/sincronizacion-de-sistemas-de-computo Web Clock A web clock is used to display the time of day in real time. To access the Web Clock, enter the link https://www.inacal.gob.pe/
INM	Network Time Protocol Operates a time server using the “Network Time Protocol”, it is located at the Instituto Nacional de Metrología de Colombia, Bogotá D.C., Colombia. Further information at: http://www.inm.gov.co/index.php/servicios-inm/hora-legal Web Clock Service A web clock is used to display the time of day in real time. The web clock is available at: http://horalegal.inm.gov.co/ 186.155.28.147 Voice Time Service Telephone voice announcements are followed by a tone to indicate the local time. The service is available to the public in Spanish by calling the telephone number (+571) 2542222 option 1.
INPL	Time dissemination service is performed in Israel by telecommunication companies, whose time and frequency standards are traceable to local UTC(INPL) time and are calibrated regularly once a year against the Israeli Time and Frequency National Standard kept by INPL.
INRIM	CTD Telephone Time Code Time signals dissemination, according to the European Time code format, available via modem on regular dial-up connection. Access phone numbers : 0039 011 3919 263 and 0039 011 3919 264. Provides a synchronization to UTC(IT) for computer clocks without compensation for the propagation time. Internet Time Service INRIM operates two time servers using the "Network Time Protocol" (NTP); host names of the servers are ntp1.inrim.it and ntp2.inrim.it. More information on this service can be found on the web pages: http://rime.inrim.it/labtf/ntp/. Web-based time-of-day clock that displays UTC or local time for Italy (Central Europe Time), referenced to INRIM Internet Time Service. Provides a snapshot of time with any web browser. A continuous time display requires a web browser with Java plug-in installed: http://rime.inrim.it/labtf/tempo-legale-italiano/. Fiber based PTP time signal distribution to linked users.
INTI	Network Time Service: INTI operates an open access NTP server referenced to UTC(INTI). Server Host Name: ntp.inti.gob.ar

JV	Network Time Protocol JV operates an open access stratum 1 server referenced to UTC(JV) ntp.justervesenet.no By special arrangement customers may get direct access to PPS from UTC(JV) as a reference for customer's own NTP-server(s) hosted at JV. PTP White Rabbit services are currently running on an experimental basis over dedicated link(s).
KRISS	Telephone Time Service Provides digital time code to synchronize computer clocks to Korea Standard Time (=UTC(KRIS) + 9 h) via modem. Access phone number: + 82 42 868 5116 Network Time Service KRISS operates three time servers using the NTP to synchronize computer clocks to Korea Standard Time via the Internet. Host name of the server: time.kriss.re.kr (210.98.16.100). Software for the synchronization of computer clocks is available at http://www.kriss.re.kr
KZ (1)	Network Time Service Stratum-1 time server using the "Network Time Protocol" (NTP). Restricted access and free access ip 89.218.41.170 Stratum-2 time server using the "Network Time Protocol" (NTP). Free access. Stratum-2 is available: ip 88.204.171.178 Web-based Time Services: A real-time clock aligned to UTC(KZ) and corrected for internet transmission delay. "Six-pip time signals" are broadcast by FM radio stations hourly every day.
LNE-SYRTE	LNE-SYRTE operates several time servers using the "Network Time Protocol" (NTP) : Stratum-1 time server: ntp-p1.obspm.fr (restricted access) Stratum-2 time server: ntp.obspm.fr (free access) Futher information at: http://syrte.obspm.fr/informatique/ntp_infos.php
LRTE	Internet Time Service LRTE operates Stratum 1 and Stratum 2 time servers using the NTP protocol. The servers are directly synchronized to UTC(LRTE). The servers are available on free access at hostnames/ip : lrte.ntp.ifsc.usp.br / 143.107.229.211 -> stratum 1 ntp1.ifsc.usp.br / 143.107.229.210 -> stratum 2 Further information available at http://lrte.ntp.ifsc.usp.br/ https://www.ntppool.org/scores/143.107.229.211 https://www.ntppool.org/scores/143.107.229.210 https://thingspeak.com/channels/691405
LT	Network Time Service via NTP protocol NTP v3 Host name: laikas.pfi.lt Directly referenced to UTC(LT) System: Datum TymeServe 2100 NTP server Access policy: free Further information available at https://www.ftmc.lt/time-and-frequency-standard-laboratory

(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

MASM	Network Time Service via NTP It provides synchronization to UTC(MASM) Address: ntp.mn System: LANTIME M600 Access policy: free
METAS	Internet Time Service METAS operates three public stratum 1 NTP servers in open access policy, namely: ntp11.metas.ch ntp12.metas.ch ntp13.metas.ch The alias ntp.metas.ch points to one of the above servers. More information available at http://www.metas.ch/metas/en/home/fabe/zeit-und-frequenz/time-dissemination.html
MIKES	VTT MIKES provides an official stratum-1 level NTP service to paying organizations and institutions. Stratum-2 level NTP service is freely available to everyone. Both NTP services are provided over public internet. PTP and PTP White Rabbit services are provided to individual customers over dedicated links. Further information can be found at http://www.mikes.fi/ntp-palvelu/
MSL	Network Time Service Computers connected to the Internet can be synchonized to UTC(MSL) using the NTP protocol. Access is available for users within New Zealand. Servers are available at pool.msltime.measurement.govt.nz and msltime1.measurement.govt.nz Speaking Clock A speaking clock gives New Zealand time. Because it is a pay service, access is restricted to callers within New Zealand. Further information about these services can be found at http://measurement.govt.nz/about-us/official-new-zealand-time
NAO	Network Time Service Three stratum 2 NTP servers are available. The NTP servers internally refer stratum 1 NTP server that is linked to UTC(NAO). One of the three stratum 2 NTP servers are selected automatically by a round-robin DNS server to reply for an NTP access. The server host name is s2csntp.miz.nao.ac.jp.
NICT	Telephone Time Service (TTS) NICT provides digital time code accessible by computer at 300/1200/2400 bps, 8 bits, no parity. Access number to the lines: + 81 42 327 7592. Optical IP Telephone Time Service (OTTS) NICT provides digital time code accessible by computer using Network Time Protocol, on Specific Optical IP Telephone lines and available only to agreement users. Network Time Service (NTS) NICT operates three Stratum 1 NTP time servers linked to UTC(NICT) through a leased line. Internet Time Service (ITS) NICT operates five Stratum 1 NTP time servers linked to UTC(NICT) through the Internet, where one server is located in Kobe branch. Host name of the servers: ntp.nict.jp (Round robin).

	GPS common view data NICT provides the GPS common view data based on UTC(NICT) to the time business service in Japan.
NIM (1)	Telephone Time Service The coded time information generated by NIM time code generator, referenced to UTC(NIM). Telephone Code provides digital time code at 1200 to 9600 bauds, 8 bits, no parity, 1 stop bit. Access phone number: 8610 6422 9086. Network Time Service Provides digital time code across the Internet using NTP server via free IP access: ntp1.nim.ac.cn ntp2.nim.ac.cn
NIMB	1 NTP server is available: Address: ntp.inm.ro (STRATUM 1) with an open access policy Server is referenced to UTC(NIMB).
NIMT	Internet Time Services NIMT operates 3 NTP servers at: time1.nimt.or.th time2.nimt.or.th time3.nimt.or.th The NTP servers are referenced to UTC(NIMT). FM/RDS Radio Transmission The time code is applied to the sub-carrier frequency of 57 kHz using the Radio Data System protocol. The accuracy of time transmission is around 30 ms of UTC(NIMT) depending on the internet traffic. The time code is broadcast via 40 radio stations across the country.
NIST	Automated Computer Time Service (ACTS) Provides digital time code by telephone modem for setting time in computers. Free software and source code available for download from NIST. Includes provision for calibration of telephone time delay. Access phone numbers : +1 303 494 4774 (4 phone lines) and +1 808 335 4721 (2 phone lines). Further information at https://www.nist.gov/pml/time-and-frequency-division/services/automated-computer-time-service-acts Web-based time-of-day clock: https://time.gov Internet Time Service (ITS) Provides digital time code across the Internet using three different protocols: Network Time Protocol (NTP), Daytime Protocol, and Time Protocol. (Time Protocol is not supported by all servers) Geographically distributed set of multiple time servers at multiple locations within the United States of America. For most current listing of time servers and locations, see: http://tf.nist.gov/tf-cgi/servers.cgi Free software and source code available for download from NIST. Further information at https://www.nist.gov/pml/time-and-frequency-division/services/internet-time-service-its Telephone voice announcement: Audio portions of radio broadcasts from time and frequency stations WWV and WWVH can be heard by telephone: +1 303 499 7111 for WWV and +1 808 335 4363 for WWVH. For more information see: https://www.nist.gov/pml/time-and-frequency-division/radio-stations/wwv/telephone-time-day-service

(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

	Time Measurement and Analysis Service (TMAS) and NIST Disciplined Clock (NISTDC) Subscription-based calibration services that utilize GPS common-view measurements and can either measure a clock with respect to UTC(NIST), or discipline an atomic clock to agree with UTC(NIST) with an uncertainty of ~10 ns (*k* = 2). The NISTDC can be either a rubidium clock supplied by NIST or a cesium clock supplied by the customer. For more information see: https://www.nist.gov/programs-projects/time-measurement-and-analysis-service-tmas
NMIJ	GPS common-view data GPS common-view data using CGGTTS format referred to UTC(NMIJ) are available through the NMIJ's web site for the remote frequency calibration service.
NMISA	Network Time Service One open access NTP server is available at address time.nmisa.org. More information is available at http://time.nmisa.org/
NMLS	Web-based time-of-day clock A web clock is used to display the local time for Malaysia. The service is available at http://mst.sirim.my. Network Time Service The NTP time information is referenced to UTC(NMLS) and is currently generated by Stratum-1 NTP servers, made available to the public freely. The NTP server host names are ntp1.sirim.my and ntp2.sirim.my.
NPL	Internet Time Service Two servers referenced to UTC(NPL) provide Network Time Protocol (NTP) time code across the internet. More information is available from the NPL web site at www.npl.co.uk/time. The server host names are: ntp1.npl.co.uk ntp2.npl.co.uk
NPLI	Web clock Web-based time-of-day clock that displays Indian Standard Time (IST) and UTC(NPLI). It also displays local time in user's time zone, time-of-day of the user's device clock and its difference. Available at the web page: http://www.nplindia.in/clockcode/html/index.php Internet Time Service Multiple Stratum 1 NTP servers referenced to UTC(NPLI) provide time service. The server host names are: time1.nplindia.org time2.nplindia.org time.nplindia.org (Round Robbin) time.nplindia.in (Round Robbin)
NRC	Telephone Code Provides digital time code by telephone modem for setting time in computers. Access phone number: +1 613 745 3900. https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/computer-time-date Talking Clock Service Voice announcements of Eastern Time are at ten-second intervals followed by a tone to indicate the exact time.

	The service is available to the public in English at +1 613 745 1576 and in French at +1 613 745 9426. For more information see: https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/telephone-talking-clock Web Clock Service The Web Clock shows dynamic clocks in each Canadian Time zone, for both Standard time and daylight saving time. The web page is at: https://nrc.canada.ca/en/web-clock/ Short Wave Radio CHU radio station broadcasts the time of day with voice announcements in English and French and time code at three different frequencies: 3.330 MHz, 7.850 MHz and 14.670 MHz. Further information at: https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/nrc-shortwave-station-broadcasts-chu Network Time Protocol Operates multiple time servers using the " Network Time Protocol " at different locations and on two networks. Host names: time.nrc.ca and time.chu.nrc.ca. Further information at: https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/network-time-protocol-ntp The official website for the Frequency and Time group is: https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time The contact email is: MSS-SMETime@nrc-cnrc.gc.ca
NSC IM	Network Time Service. National Science Center Institute of Metrology (Kharkiv, Ukraine) operates time server Stratum 1 using the “Network Time Protocol” (NTP). Stratum-1 time server using the "Network Time Protocol" (NTP). Free access. ip 81.17.128.133 ip 31.202.14.125 ip 31.202.14.124 PTP services are provided to individual customers over dedicated links. The server host name is: http://www.metrology.kharkov.ua/
NTSC	Network Time Service (NTS) NTSC operates a time server directly referenced to UTC(NTSC). Software for the synchronization of computer clocks is available on the NTSC Time and Frequency web page: http://www.ntsc.ac.cn/ Access Policy: free Contact: Shaowu DONG (sdong@ntsc.ac.cn).
ONBA	Speaking clock access phone number 113 (only accessible in Argentina). Hourly and half hourly radio-broadcast time signal. Internet time service at web site http://www.hidro.gov.ar/observatorio/lahora.asp
ONRJ	Telephone Voice Announcer (55) 21 25806037. Telephone Code (55) 21 25800677 provides digital time code at 300 bauds, 8 bits, no parity, 1 stop bit (Leitch CSD5300) Internet Time Service at the address : 200.20.186.75 and 200.20.186.94 SNTP at port 123 Time/UDP at port 37 Time/TCP at port 37 Daytime/TCP at port 13

WEB-based Time Services:
1) A real-time clock aligned to UTC(ONRJ) and corrected for internet transmission delay.
Further information at: http://200.20.186.71/asp/relogio/horainicial.asp
2) Voice Announcer, in Portuguese, each ten seconds, after download of the Web page at: http://200.20.186.71.

Broadcast Brazilian legal time (UTC – 3 hours) announced by a voice starting with “Observatório Nacional” followed by the current time (hh:mm:ss) each ten seconds with a beep for each second with a 1KHz modulation during 5ms and a long beep with 1KHz modulation during 200ms at the 58 , 59 and 00 seconds. The signal is transmitted every day of the year by the radio station PPE, whose signal is at 10 MHz with kind of modulation A3H and HF transmission power of 1 kW.

ORB

Network Time Service via NTP protocol
Hostname : ntp1.oma.be and ntp2.oma.be
Access policy : free
Synchronization to UTC(ORB)
Contact : ntp-as@oma.be

ORB provides a time dissemination via phone and modem to synchronize PC clocks on UTC(ORB). The system used is the Time Distribution System from TUG, which produces the telephone time code mostly used in Europe.
The baud rate used is 1200. The access phone number is 32 (0) 2 373 03 20. The system is updated periodically with DUT1 and leap seconds

PTB

Contact : time@ptb.de
Information on the web pages
https://www.ptb.de/time

Telephone Time Service
The coded time information is referenced to UTC(PTB) and generated by a TUG type time code generator using an ASCII-character code.
The time protocols are sent in a common format, the “European Telephone Time Code”. Access phone number: +49 531 51 20 38.

Internet Time Service
The PTB operates three time servers using the “ Network Time Protocol “ (NTP), see https://www.ptb.de/cms/en/ptb/fachabteilungen/abtq/gruppe-q4/ref-q42/time-synchronization-of-computers-using-the-network-time-protocol-ntp.html for details and explanations.

The hostnames of the servers are:
ptbtime1.ptb.de
ptbtime2.ptb.de
ptbtime3.ptb.de

Since 2020 PTB enhanced these time servers by Network Time Security (NTS). NTS is a security protocol specified in RFC 8915, which provides a scalable approach to protect NTP packets. PTB’s time servers provide NTS secured NTP service on network port 123.
PTB also provides a fee-based authenticated NTP service based on the NTP’s pre-shared key approach specified in RFC 5905. In 2018, the IETF published RFC 8673, which deprecates the usage of MD5 for the pre-shared key approach and replaces it with a message authentication code based on AES-CMAC as specified in RFC 4493. PTB’s authenticated time service has been enhanced in order to comply to RFC 8673.
The hostnames of the servers are:
ntpsmgw1.ptb.de
ntpsmgw2.ptb.de

PTB created a new service to distribute legal time via the WWW. The PTB clock is completely programmed in pure Hypertext Markup Language (HTML). The time queries at the PTB server are performed via WebSocket (WS), a supplement to the established Hypertext Transfer Protocol (HTTP) specified by the Internet Engineering Taskforce (IETF).
URL: https://uhr.ptb.de

RISE

The coded time information is referenced to UTC(SP) and generated by several NTP servers using the Network Time Protocol (NTP) for both IPv4 and IPv6.
Access host names: ntp1.sptime.se, ntp2.sptime.se, ntp3.sptime.se and ntp4.sptime.se

Speaking Clock
The speaking clock service is operated by Telia AB in Sweden.
The time announcement is referenced to UTC(SP) and disseminated from a computer-based system operated and maintained at RISE.
Access phone number : 90510 (only accessible in Sweden).
Access phone number : +4633 90510 (from outside Sweden).

More information about these services are found on the web site www.ri.se

ROA (1)

Telephone Code
The coded time information is referenced to UTC(ROA) and generated by a TUG type time code generator using an ASCII-character code. The time protocols are sent in a common format, the "European Telephone Time Code". Access phone number : +34 956 599 429

Network Time Protocol
More information is available from the ROA web site at www.roa.es
Host names of the servers:
hora.roa.es
minuto.roa.es

SG

Network Time Service (NeTS)
Transmit digital time code via the Internet using three protocols - Time Protocol, Daytime Protocol and Network Time Protocol.
Operate one time server at domain name: nets.org.sg

Automated Computer Time Service (ACTS)
Transmit digital time code (NIST format) via telephone modem for setting time in computers. The coded time information is referenced to UTC(SG).
Include provision for correcting telephone time delay.
Access phone number: +65 67799978.

SIQ

Internet Time Service (Network Time Protocol)
One server referenced to UTC(SIQ) provides Network Time Protocol (NTP) time code across the internet.
There is free access to the server for all users.
The server host names are: ntp.siq.si or time.siq.si
(two URL’s for the same server; IP: 153.5.147.30)
New IP for NTP server on new location

SL

Network Time Service
Computers connected to the Internet can be synchronized to UTC(SL)
Using the NTP protocol using NTP Time Server at http://www.sltime.org.
For more information please visit http://www.sltime.org and http://www.measurementsdept.gov.lk or contact through email; adelec@measurementsdept.gov.lk.

(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

SMD	Network Time Service Disseminate time, UTC(SMD), through NTP protocol. URL’s: ntp1.economie.fgov.be ntp2.economie.fgov..be ntp3.economie.fgov.be. All users have free access.
SNSU-BSN	Network Time Service The NTP time information referenced to UTC(IDN) is generated by Stratum-1 NTP server at URL: ntp.bsn.go.id Access Policy : free
TL	Speaking Clock Service Traceable to UTC(TL). Broadcast through PSTN (Public Switching Telephone Network) automatically and provides an accurate voice time signal to public users. Local access phone number: 117. The Computer Time Service Provides ASCII time code by telephone modem for setting time in computers. Access phone number: +886 3 4245117. NTP Service TL operates the network time service using the "Network Time Protocol” (NTP). Host name of the server: time.stdtime.gov.tw, further information in http://www.stdtime.gov.tw/english/e-home.aspx
TP	Internet Time Service UFE operates time servers directly referenced to UTC(TP). Time information is accessible through Network Time Protocol (NTP). Server host name: ntp2.ufe.cz More information at http://www.ufe.cz/
UME	Network Time Service UME operates an NTP server referenced to UTC(UME). Server Host Name: time.ume.tubitak.gov.tr
USNO (1)	Telephone Voice Announcer +1 202 762-1401 Backup voice announcer: +1 719 567-6742 Backup voice announcer: +1 202-762-1069 GPS via subframe 4 page 18 of the GPS broadcast navigation message Web site for time and for data files: https://www.usno.navy.mil/USNO/time Network Time Protocol (NTP) see https://www.usno.navy.mil/USNO/time/ntp for software and site closest to you.
VMI	Network Time Service VMI operates one time server Stratum 1 using the Network Time Protocol (NTP). For information on access to the website, please contact phuongtv@vmi.gov.vn. The server host name is: http://standardtime.vmi.gov.vn/ or IP: 113.160.59.166 port 123

(1) Information based on the Annual Report 2019, not confirmed by the Laboratory.

VNIIFTRI	Internet Time Service VNIIFTRI operates eight time servers Stratum 1 and one time server Stratum 2 using the “Network Time Protocol” (NTP). The server host names are: ntp1.vniiftri.ru (Stratum 1) ntp2.vniiftri.ru (Stratum 1) ntp3.vniiftri.ru (Stratum 1) ntp4.vniiftri.ru (Stratum 1) ntp1. niiftri.irkutsk.ru (Stratum 1) ntp2. niiftri.irkutsk.ru (Stratum 1) vniiftri.khv.ru (Stratum 1) vniiftri2.khv.ru (Stratum 1) ntp21.vniiftri.ru (Stratum 2).
VSL	Internet Time Service VSL operates a time server directly referenced to UTC(VSL). Time information is accessible through Network Time Protocol (NTP). The URLs for the NTP server are: ntp.vsl.nl ntp1.vsl.nl ntp2.vsl.nl