Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019

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 (15)	1 H-maser (2) + microphase-stepper	* (15)	*	*	*
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		*	*	
BIM	2 Ind. Cs	1 Cs			*	
BIRM	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	2 Ind. Cs	1 Cs			*	
CH	2 Ind. Cs (3) 3 H-masers	1 H-maser (3) + frequency synthesizer steered to UTC(CH.P)	*	*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
CNES	5 Ind. Cs (4) 3 H-masers	1 H-maser (4) + microphase-stepper			*	
CNM	4 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper	*	*	*	
CNMP	5 Ind. Cs	1 Cs + frequency offset generator		*	*	
DFNT	2 Ind. Cs	1 Cs			*	
DLR (a)	3 Ind. Cs 3 H-masers	1 Cs		*	*	
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	3 Ind. Cs	1 Cs			*	
IFAG	5 Ind. Cs 2 H-masers	1 Cs + microphase-stepper		*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
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	2 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	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
IT	6 Ind. Cs 4 H-masers 2 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 (a)	3 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
KEBS	3 Ind. Cs	1 Cs + reference generator			*	
KRIS	5 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 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
KZ (a)	5 Ind. Cs (5)	1 Cs + microphase-stepper			*	
LRTE	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
LT	2 Ind. Cs	1 Cs		*	*	
LUX	2 Ind. Cs	1 Cs + microphase-stepper			*	
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		*	*	
MKEH	1 Ind. Cs	1 Cs			*	
MSL	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
MTC (a)	11 Ind. Cs	1 Cs		*	*	
NAO	4 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	
NICT	37 Ind. Cs 8 H-masers (6) 1 Lab. Cs 1 Lab. Sr (7)	1 H-maser (8) + microphase-stepper	* (9)	*	*	*
NIM	7 Ind. Cs 13 H-masers 1 Lab. Cs	1 H-maser + microphase-stepper		*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
NIMB (a)	2 Ind. Cs	1 Cs		*	*	
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 4 H-masers	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 5 H-maser	1 H-maser + microphase-stepper		*	*	*
NRC	6 Ind. Cs (10) 2 H-masers	1 Cs + microphase-stepper	*	*	*	
NRL	1 Ind. Cs 8 H-masers	1 H-maser + steered by AOG to UTC(NRL)		*	*	
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	* (11)	*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (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 4 H-masers	1 H-maser (12) + microphase-stepper	* (13)	*	*	*
ORB	3 Ind. Cs 2 H-maser	1 H-maser + femtostepper		*	*	
PL	12 Ind. Cs 4 H-masers	1 H-maser (14) + femtostepper	* (15)	*	*	* (16)
PTB	3 Ind. Cs 4 Lab. Cs (17) 5 H-masers	1 H-maser (18) + microphase-stepper	* (19)	*	*	*
ROA	6 Ind. Cs (20) 2 H-masers	1 H-maser (21) + 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 (a)	1 Ind. Cs	1 Cs + output frequency steering			*	
SP	18 Ind. Cs (22) 10 H-masers	1 H-maser + microphase-stepper		*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
SU	1 Lab. Cs (23) 4 Lab. Rb (24) 14-15 H-masers	10-14 H-masers (25)	* (26)	*	*	* (27)
TL	6 Ind. Cs 4 H-masers	1 H-maser (28) + microphase-stepper	* (28)	*	*	*
TP	5 Ind. Cs 1 H-maser	1 Cs + output frequency steering		*	*	
UA	1 Ind. Cs + (2 Ind. CS (29)) 4 H-masers 2 Lab. Rb (29)	1 Cs 3 H-masers + microphase-stepper	*		*	
UAE	3 Ind. Cs	3 Cs (30)			*	
UME	5 Ind. Cs	1 Cs		*	*	
USNO	62 Ind. Cs 35 H-masers 6 Lab. Rb	1 H-maser (31) + frequency synthesizer steered to create UTC(USNO)	* (31)	*	*	*
VMI	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
VSL	4 Ind. Cs	1 Cs + microphase-stepper		*	*	*
ZA	5 Ind. Cs 3 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 1 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). Since November 2007, UTC(CH) is defined in real time by a hydrogen maser steered to the paper time scale UTC(CH.P) which is defined as a weighted average of all the clocks, steered to UTC. TA(CH) is also a weighted average of all the clocks, but free running.
(4)	CNES	All the standards are located in Toulouse at CNES (French Space Agency). UTC(CNES) is defined in real time by a H-Maser steered to an ensemble of industrial high-performance Cs clocks. UTC(CNES) is steered monthly on UTC.
(5)	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
(6)	NICT	The standards are located as follows: * Koganei Headquarters — 20 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
(7)	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 a NICT's hydrogen maser.
(8)	NICT	UTC(NICT) is generated from the output of a hydrogen maser, steered to TA(NICT) regularly, and steered to UTC if necessary.
(9)	NICT	The NICT atomic timescale TA(NICT) is computed from the weighted average of 18 commercial Cs clocks at the Koganei HQ.
(10)	NRC	The standards are located as follows: * NRC Metrology (Ottawa) — 4 Cs, 2 H-masers * CHU Time signal radio station (Ottawa) — 2 Cs
(11)	ONRJ	The Brazilian atomic time scale TA(ONRJ) is computed by the National Observatory Time Service Division in Rio de Janeiro with data from 7 industrial caesium clocks and 2 hydrogen masers.
(12)	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.

Notes (Cont.)

(13) OP The French atomic time scale TA(F) is computed by the LNE-SYRTE with data from up to 22 industrial caesium clocks in 2019 located as follows :

* Direction Générale de l'Armement (DGA, Rennes)	2 Cs
* Centre National d'Etudes Spatiales (CNES, Toulouse)	6 Cs
* Orange Labs réseaux (Lannion)	1 Cs
* Observatoire de la Côte d'Azur (OCA, Grasse)	1 Cs
* Observatoire de Paris (LNE-SYRTE, Paris)	3 Cs
* Observatoire de Besançon (OB, Besançon)	3 Cs
* Marine Nationale (Brest)	5 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.

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

(15) PL The Polish atomic timescale TA(PL) is computed by the AOS and GUM with data from 12 caesium clocks and 4 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
* 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.

(16) 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 fiber link, with stabilized propagation delay, of c. 30 km long.

(17) 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 four active masers and one passive masers

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

(19) 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.

Notes (Cont.)

(20)	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
(21)	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.	
(22)	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)	6 Cs, 2 H-masers
		* STUPI AB (Stockholm)	8 Cs, 2 H-masers
		* Onsala Space Observatory (Onsala)	1 Cs, 2 H-masers

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

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

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

(26) 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.

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

(28) TL TA(TL) is generated from a 4-caesium-clock + 5-hydrogen-maser hybrid ensemble from January 2019.
UTC(TL) is steered according to UTCr, UTC, and TA(TL).

(29) UA 2 Ind. Cs, 2 Lab. Rb were tested and left in reserve for use when necessary.

(30) 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.

(31) 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 ftp://ftp2.bipm.org/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.