**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<br>2 H-masers (18) | 1 H-maser (2)<br>+ microphase-stepper | *<br>(18) | * | * | * |
| APL | 4 Ind. Cs<br>3 H-masers | 1 H-maser<br>+ frequency synthesizer steered to UTC(APL) | | | * | |
| AUS | 5 Ind. Cs | 1 Cs | | * | * | * |
| BEV | 2 Ind. Cs<br>1 H-maser | 1 Cs | | * | * | |
| BFKH | 1 Ind. Cs | 1 Cs | | | * | |
| BIM | 2 Ind. Cs | 1 Cs | | | * | |
| BIRM (a) | 4 Ind. Cs<br>6 H-masers | 1 H-maser<br>+ microphase-stepper | | * | * | |
| BOM | 2 Ind. Cs | 1 Cs | | * | * | |
| BY | 7 H-masers | 3-6 H-masers<br>+ 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)<br>1 Ind. Cs (3)<br>4 H-masers | 1 H-maser (3)<br>+ frequency synthesizer<br>steered to UTC(CH.P) | * | * | * | * |
| CNES | 5 Ind. Cs (4)<br>3 H-masers | 1 H-maser (4)<br>+ microphase-stepper | | | * | |
| CNM | 3 Ind. Cs<br>1 H-maser | 1 H-maser<br>+ microphase-stepper | * | * | * | |
| CNMP (a) | 5 Ind. Cs | 1 Cs<br>+ frequency offset generator | | * | * | |
| DFNT | 2 Ind. Cs | 1 Cs | | | * | |
| DLR | 5 Ind. Cs<br>3 H-masers | 1 Cs<br>+ microphase-stepper | | * | * | |
| DMDM | 2 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| DTAG | 3 Ind. Cs | 1 Cs | | * | * | |
| EIM | 1 Ind. Cs | 1 Cs | | | * | |
| ESTC | 3 Ind. Cs<br>3 H-masers | 1 H-maser<br>+ microphase-stepper | | * | * | |
| HKO | 2 Ind. Cs | 1 Cs | | * | * | |
| ICE | 3 Ind. Cs | 1 Cs<br>+ 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 | Time transfer technique: TWSTFT |
|---|---|---|---|---|---|---|
| IFAG | 5 Ind. Cs<br>2 H-masers (5) | 1 Cs<br>+ microphase-stepper | | * | * | |
| IGNA (a) | 1 Ind. Cs | 1 Cs<br>+ time/frequency steering | | * | * | |
| IMBH | 2 Ind. Cs | 1 Cs<br>+ frequency offset generator | | * | * | |
| INCP | 2 Ind. Cs | 1 Cs | | | * | |
| INM | 3 Ind. Cs | 1 Cs<br>+ microphase-stepper | | | * | |
| INPL | 4 Ind. Cs | 1 Cs | | | * | |
| INTI | 3 Ind. Cs | 1 Cs | | * | * | |
| INXE | 1 Ind. Cs<br>1 Ind. Rb<br>1 Lab. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| IPQ | 3 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| IT | 4 Ind. Cs<br>4 H-masers<br>1 Lab. Cs<br>1 Lab. Yb | 1 H-maser<br>+ microphase-stepper<br>+ time scale switch | | * | * | * |
| JATC | 8 Ind. Cs<br>3 H-masers | 1 H-maser<br>+ microphase-stepper | * | | * | |
| JV | 3 Ind. Cs<br>1 H-maser | 1 Cs<br>+ microphase-stepper | | * | * | |
| KRIS | 2 Ind. Cs<br>4 H-masers | 1 H-maser<br>+ 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<br>+ microphase-stepper | | * | * | |
| LT | 2 Ind. Cs | 1 Cs | | * | * | |
| LUX | 2 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| LV | 2 Ind. Cs | 1 Cs | | | * | |
| MASM | 1 Ind. Cs | 1 Cs<br>+ time/frequency steering | | * | * | |
| MBM | 1 Ind. Cs | 1 Cs | | | * | |
| MIKE | 1 Ind. Cs<br>4 H-masers | 1 H-maser<br>+ microphase-stepper | | * | * | |
| MSL | 2 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| NAO | 4 Ind. Cs<br>1 H-maser | 1 Cs<br>+ microphase-stepper | | * | * | |
| NICT | 34 Ind. Cs<br>8 H-masers (7)<br>1 Lab. Cs<br>1 Lab. Sr (8) | 1 H-maser (9)<br>+ microphase-stepper | *<br>(10) | * | * | * |
| NIM | 7 Ind. Cs<br>13 H-masers<br>1 Lab. Cs | 1 H-maser<br>+ 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 | Time transfer technique: TWSTFT |
|---|---|---|---|---|---|---|
| NIMT | 4 Ind. Cs<br>1 H-maser | 1 Cs<br>+ microphase-stepper | | * | * | |
| NIS | 3 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| NIST | 1 Lab. Cs<br>1 Lab. Yb<br>13 Ind. Cs<br>13 H-masers | 4 Cs<br>7 H-masers<br>+ microphase-stepper | * | * | * | * |
| NMIJ | 1 Ind. Cs<br>1 Lab. Cs<br>2 H-masers<br>1 Lab. Yb (11) | 1 H-maser<br>+ microphase-stepper | | * | * | * |
| NMLS | 2 Ind. Cs | 1 Cs | | * | * | |
| NPL | 2 Ind. Cs<br>5 H-masers | 1 H-maser | | * | * | * |
| NPLI | 5 Ind. Cs<br>6 H-maser | 1 H-maser<br>+ microphase-stepper | | * | * | * |
| NRC | 1 Lab. Cs (12)<br>6 Ind. Cs (13)<br>2 H-masers | 1 H-maser<br>+ microphase-stepper | * | * | * | |
| NRL | 1 Ind. Cs<br>8 H-masers | 1 H-maser<br>+ Auxiliary Output Generator steered to UTC(NRL) | | * | * | |
| NSAI | 1 Ind. Cs | 1 Cs | | * | * | |
| NTSC | 24 Ind. Cs<br>8 H-masers | 1 H-maser<br>+ microphase-stepper | * | * | * | * |
| ONBA | 2 Ind. Cs | 1 Cs | | | * | |
| ONRJ | 7 Ind. Cs<br>2 H-masers | 7 Cs<br>2 H-masers<br>+ 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<br>3 Lab. Cs<br>1 Lab. Rb<br>2 Lab. Sr<br>5 H-masers | 1 H-maser (15)<br>+ microphase-stepper | *<br>(16) | * | * | * |
| ORB | 3 Ind. Cs<br>2 H-maser | 1 H-maser<br>+ femtostepper | | * | * | |
| PL | 12 Ind. Cs<br>5 H-masers | 1 H-maser (17)<br>+ femtostepper | *<br>(18) | * | * | *<br>(19) |
| PTB | 3 Ind. Cs<br>4 Lab. Cs (20)<br>6 H-masers | 1 H-maser (21)<br>+ microphase-stepper | *<br>(22) | * | * | * |
| ROA | 6 Ind. Cs (23)<br>2 H-masers | 1 H-maser (24)<br>+ frequency synthesizer<br>steered to UTC(ROA) | | * | * | * |
| SASO (a) | 5 Ind. Cs | 1 Cs | | * | * | |
| SCL | 2 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| SG | 5 Ind. Cs<br>1 H-maser | 1 H-maser<br>+ microphase-stepper | | * | * | |
| SIQ | 1 Ind. Cs | 1 Cs | | | * | |
| SL | 1 Ind. Cs | 1 Cs | | * | * | |
| SMD | 4 Ind. Cs<br>1 H-maser | 1 H-maser<br>+ microphase-stepper | | * | * | |
| SMU | 1 Ind. Cs | 1 Cs<br>+ output frequency steering | | | * | |
| SP | 16 Ind. Cs (25)<br>10 H-masers | 1 H-maser<br>+ 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)<br>4 Lab. Rb (27)<br>16 H-masers | 8-14 H-masers (28) | *<br>(29) | * | * | *<br>(30) |
| TL | 6 Ind. Cs<br>3 H-masers | 1 H-maser (31)<br>+ microphase-stepper | *<br>(31) | * | * | * |
| TP | 4 Ind. Cs<br>2 H-maser | 1 Cs<br>+ output frequency steering | | * | * | |
| UA | 2 Ind. Cs + (1 Ind. CS (32))<br>4 H-masers<br>2 Lab. Rb (32) | 2 Cs<br>2 H-masers<br>+ microphase-stepper | * | | * | |
| UAE | 3 Ind. Cs | 3 Cs (33) | | | * | |
| UME | 5 Ind. Cs<br>1 H-maser | 1 H-maser<br>+ frequency offset generator | | * | * | |
| USNO (a) | 62 Ind. Cs<br>35 H-masers<br>6 Lab. Rb | 1 H-maser (34)<br>+ frequency synthesizer<br>steered to create UTC(USNO) | *<br>(34) | * | * | * |
| VMI | 3 Ind. Cs | 1 Cs<br>+ microphase-stepper | | * | * | |
| VSL | 3 Ind. Cs<br>1 H-maser | 1 Cs<br>+ 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.<br>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).<br>In addition to the Ind. Cs, there is one active hydrogen maser and three passive hydrogen masers.<br>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.<br>The paper time scale is steered weekly to track UTC.<br>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).<br>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:<br><br>*Kazakhstan Institute for Metrology (Astana) — 4 Cs<br>*South-Kazakhstan branch of Kazakhstan Institute for Metrology (Almaty) — 1 Cs |
| (7) | NICT | The standards are located as follows:<br><br>* Koganei Headquarters — 18 Cs, 6 H-masers<br>* Ohtakadoya-yama LF station — 6 Cs<br>* Hagane-yama LF station — 6 Cs<br>* 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.<br>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.<br>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.<br>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:<br><br>* Real Observatorio de la Armada en San Fernando — 5 Cs, 2 H-maser<br>* 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:<br><br>* RISE Research Institutes of Sweden (RISE, Borås) — 3 Cs, 4 H-masers<br>* RISE Research Institutes of Sweden (RISE, Stockholm) — 5 Cs, 2 H-masers<br>* STUPI AB (Stockholm) — 7 Cs, 2 H-masers<br>* Onsala Space Observatory (Onsala) — 1 Cs, 2 H-masers |
| (26) | SU | CsFO1 and CsFO2 are fountain frequency standards using laser cooled caesium atoms.<br>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.<br>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.