The generation of UTC and TAI

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Bureau International des Poids et Mesures

Presentation Plan

- Computation of UTC; atomic clocks, time transfer, Primary and Secondary Frequency Standard
- Publication of UTC and other related products
- UTCr, the rapid UTC
- New proposal for Uncertainties in Circular T

Computation of UTC (monthly) at the BIPM

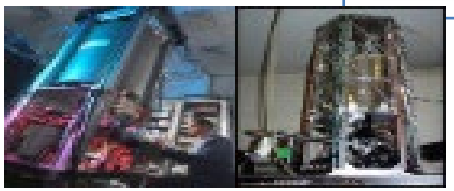
Similarly (weekly) for rapid UTC

≈ 420 atomic clocks in 85 laboratories

weighted average

EAL

Echelle Atomique Libre
freq stability
3×10^{-16}
@ 30-40 days



≈ 17 primary and secondary frequency standards

frequency steering

TAI

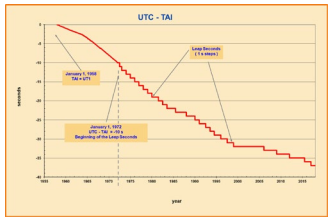
International Atomic Time
freq accuracy ~10^{-16}

Measurement of Earth's rotation (IERS)

leap seconds

UTC

Coordinated Universal Time



[UTC - UTC(k)] **BIPM *Circular T***

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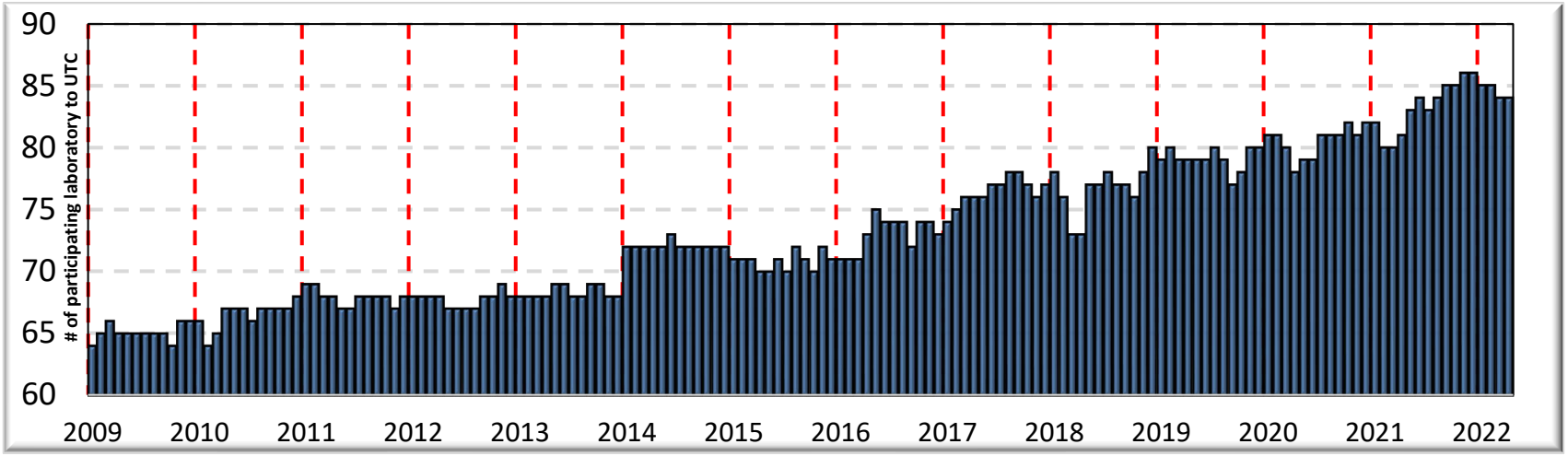
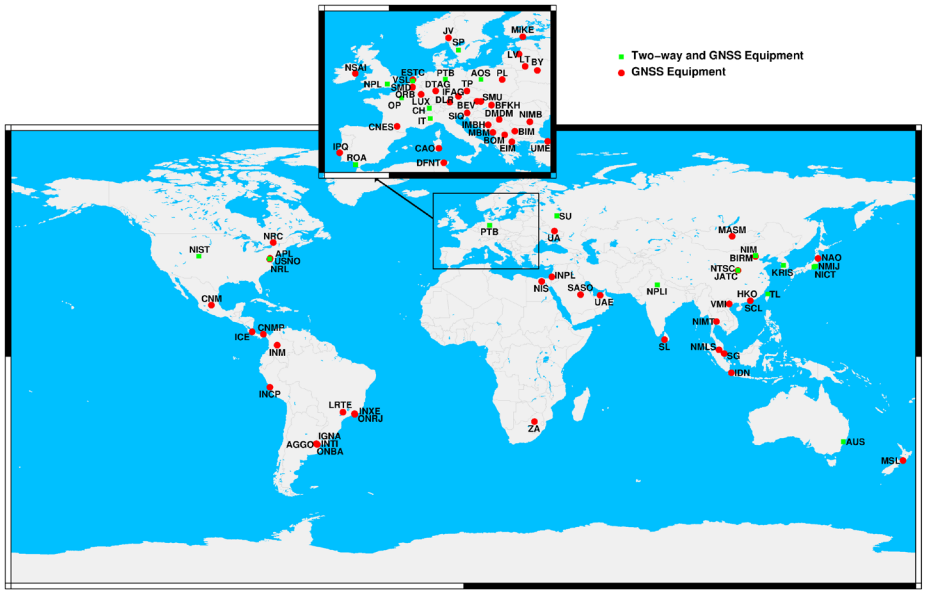
Number of laboratory distribution/geographical distribution



Even during the COVID-19 period the number of participating laboratories is continually increased.

Geographical distribution of the laboratories that contribute to TAI and time transfer equipment (2021)



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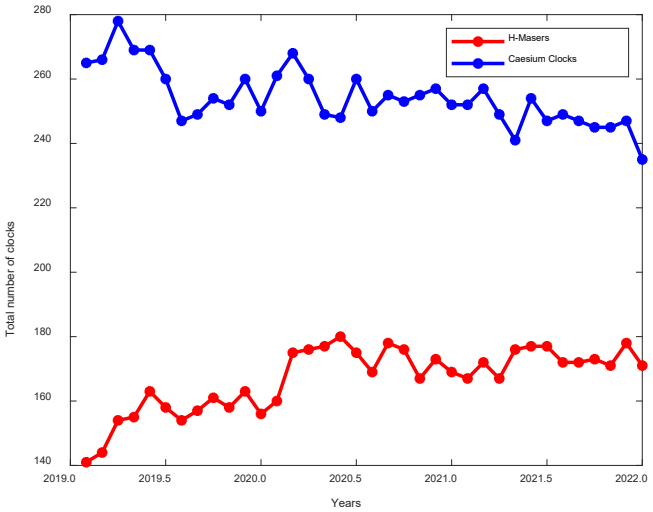
Status of atomic clocks in UTC

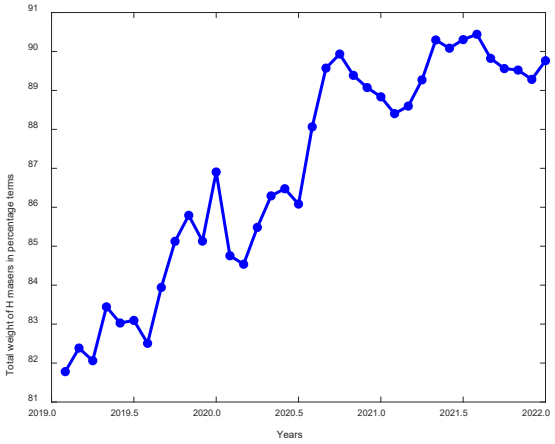
420 atomic clocks contributing to UTC of which:

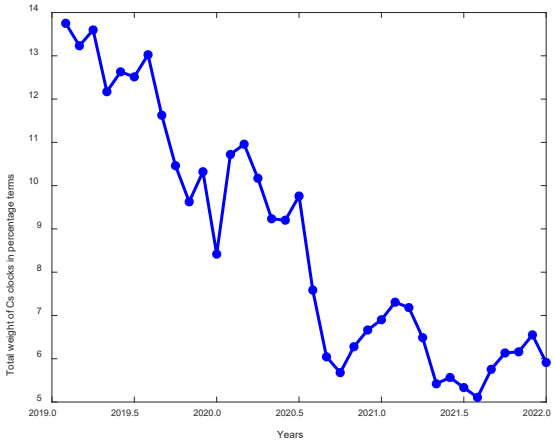
- ~180 H-Masers (from 140 to 180 in 2 years)
- ~230 Cs-clocks (from 270 to 230)

The weight of the clocks:

- ~ 90 % is assigned to H-masers
- ~ 7 % to Cs-clocks







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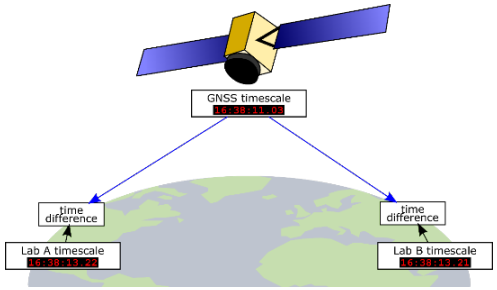
Clocks in different laboratories are compared by suitable time and frequency transfer techniques

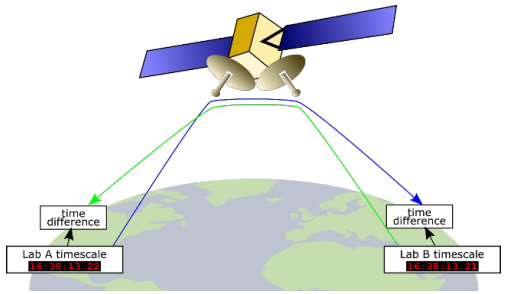
Global Navigation Satellite Systems (GNSS)

GNSS are based on time broadcasting from satellites to ground receivers (one-way time transfer). Distant labs equipped with GNSS receivers periodically compare their clocks to the broadcasted time and send the result to the BIPM. Typical algorithms are All in View, Common View, and Precise Point Positioning



Two-Way Satellite Time & Freq. Transfer (TWSTFT)

dedicated ground terminals simultaneously receive and transmit time transfer signals (two-way time transfer) on geostationary telecom satellites. Two-way method cancels out (at first order) the propagation time of the signal.



Progress in GNSS measures

GPS+ GLONASS + Beidou + Galileo

IPPP : Precise Point Positioning with integer ambiguity resolution

Progress in TWSTFT

Software Designed Radio and TWSTFT Carrier Phase

In development : Optical Fiber links

A growing number of UTC laboratories are gaining access to fiber links dedicated to time and frequency. Although few of them are currently interconnected by operational, high-duty cycle links, this number is expected to grow quickly during the next decade.

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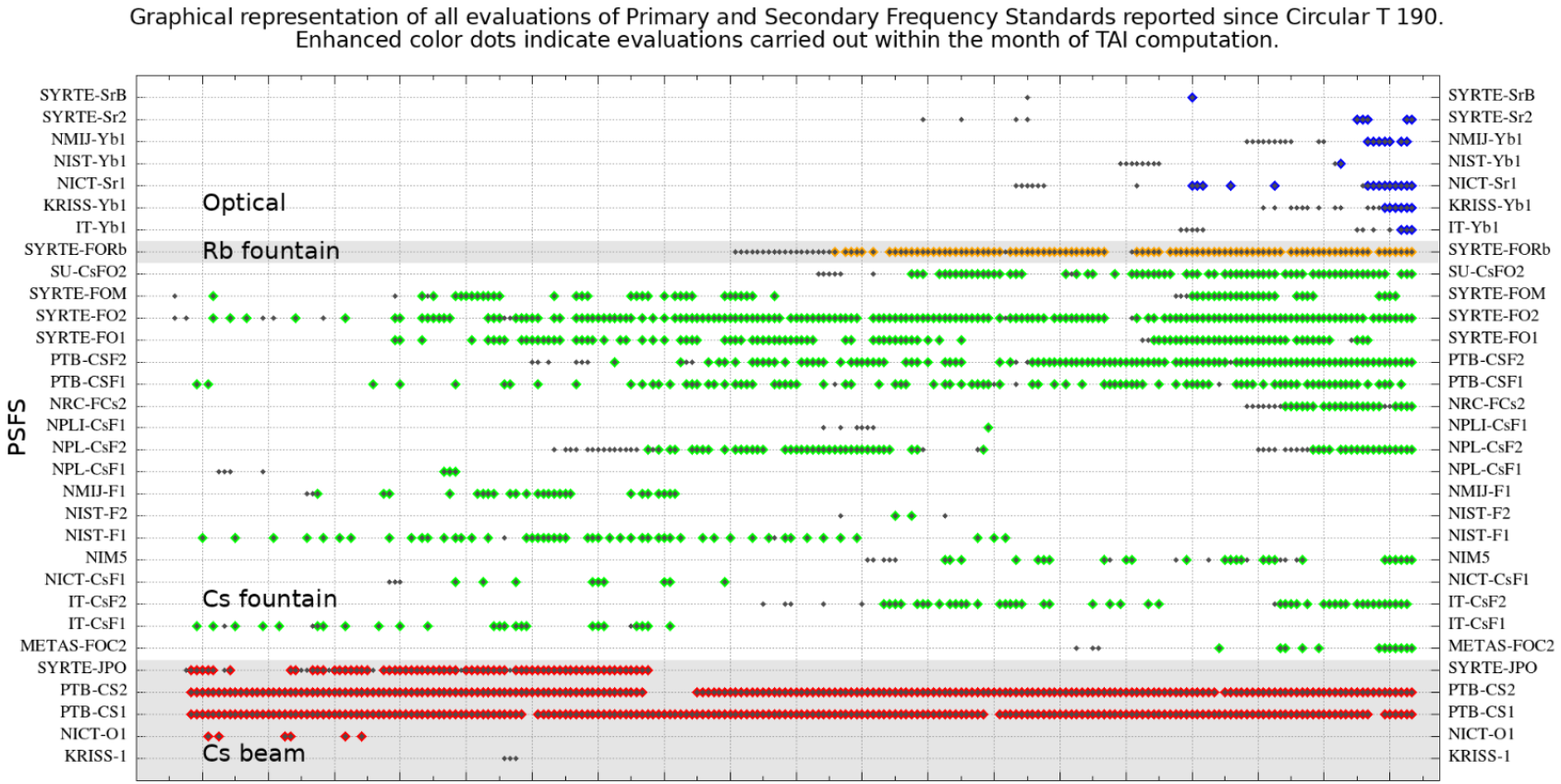
Primary and Secondary standards contributing to UTC



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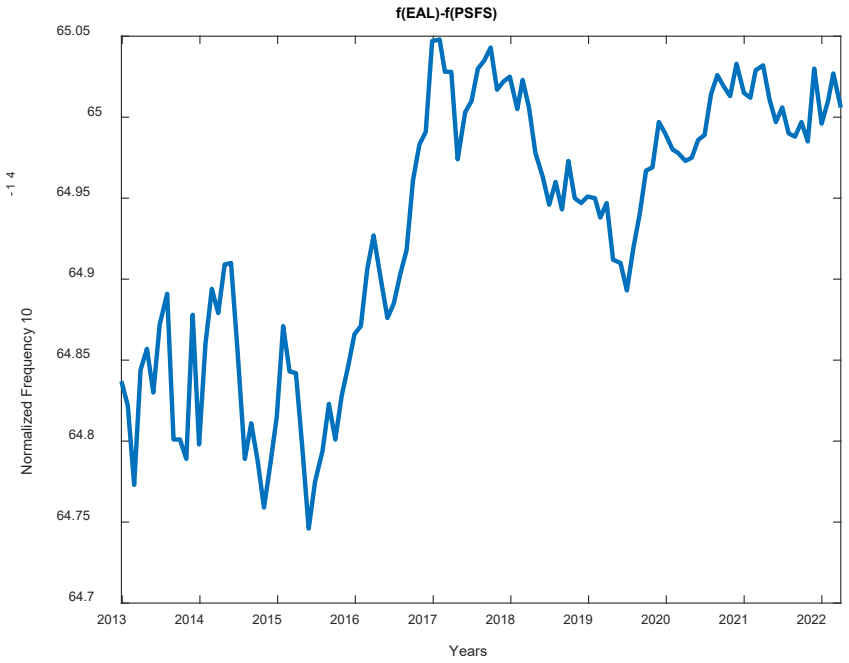
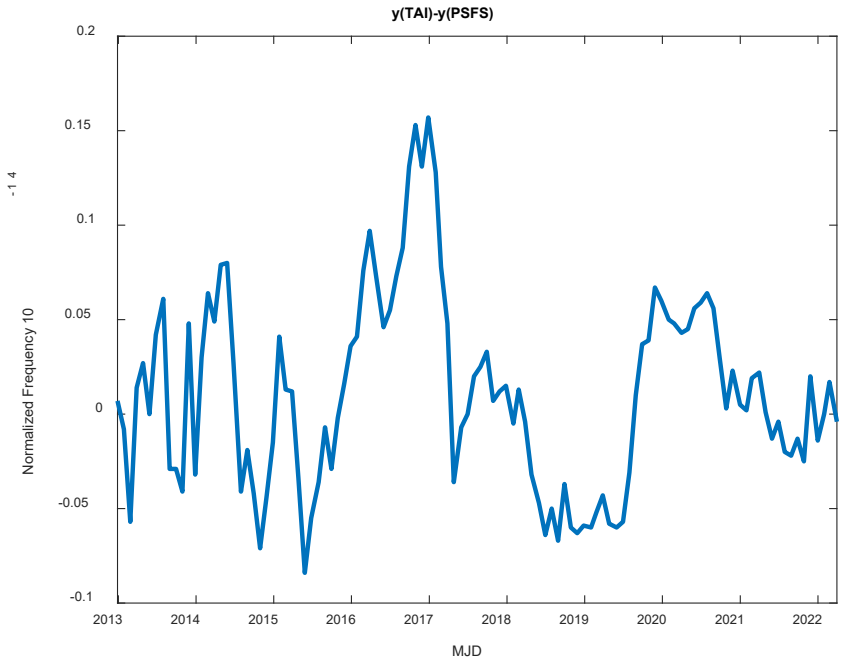
EAL and TAI versus PSFS

The Primary and secondary frequency standards (PFSF) are also used to evaluate the behaviour of EAL and TAI. After each calculation month we plot the f(EAL-PSFS) and f(TAI-PSFS) to check and verify them.





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Circular T

The laboratories have direct access to UTC through your local realization of UTC, so called ‘UTC(k)’, via the **BIPM *CircularT*** monthly publication: differences [*UTC-UTC(k)*] are published, with time spacing of 5 days.

CIRCULAR T 412 ISSN 1143-1393
2022 MAY 12, 12h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES
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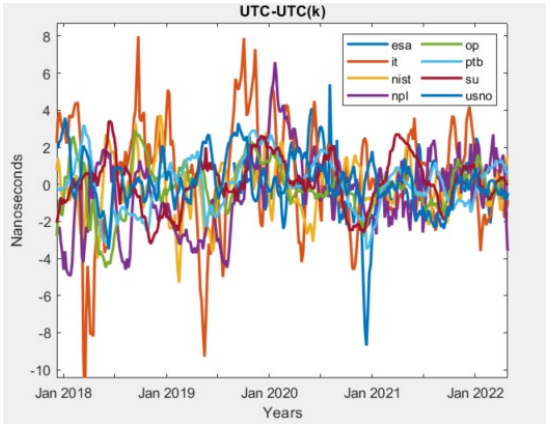
The contents of the sections of BIPM Circular T are fully described in the document "Explanatory supplement to BIPM Circular T" available at https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties.
From 2017 January 1, 0h UTC, TAI-UTC = 37 s.

Date 2022 0h UTC	MAR 31	APR 5	APR 10	APR 15	APR 20	APR 25	APR 30	Uncertainty/ns			Notes
MJD	59669	59674	59679	59684	59689	59694	59699	uA	uB	u	
Laboratory k	[UTC-UTC(k)]/ns										
AGGO (La Plata)	545.4	554.5	549.5	559.6	597.3	606.7	612.7	1.0	20.0	20.0	
AOS (Borowiec)	-3.0	-2.2	-1.4	-0.8	-0.5	0.2	0.4	0.3	3.1	3.1	
APL (Laurel)	-0.2	-1.2	-1.4	-1.2	-1.4	-1.9	-2.5	0.3	19.7	19.7	
AUS (Sydney)	-539.4	-547.1	-538.9	-534.2	-525.3	-523.7	-514.9	0.3	11.2	11.2	
BEV (Wien)	-14.1	-18.1	-24.9	-38.7	-45.1	-47.6	-47.6	0.3	2.6	2.6	
BFKH (Budapest)	4569.6	4603.9	4638.6	4666.4	4699.0	4737.9	4768.8	1.5	20.0	20.1	
BIM (Sofiya)	16011.5	16022.9	16040.0	16057.5	16064.5	16094.8	16119.3	0.3	7.1	7.1	
BIRM (Beijing)	0.0	-1.4	-3.8	-7.0	-7.0	-0.5	9.5	0.3	3.0	3.0	
BOM (Skopje)	-	-	-	-	-	-	-				
BY (Minsk)	0.5	1.3	0.9	0.7	0.3	0.5	-0.1	1.5	2.8	3.2	
CAO (Cagliari)	-	-34953.1	-35068.3	-35185.6	-35298.0	-35412.7	-35526.8	1.5	20.0	20.1	
CH (Bern-Wabern)	-1.4	-1.0	-0.8	-0.7	0.4	1.3	1.7	0.3	1.5	1.6	
CNES (Toulouse)	-11.1	-13.8	-14.6	-14.2	-9.1	-2.3	2.1	0.3	2.6	2.6	
CNM (Queretaro)	0.7	3.4	0.8	-4.0	3.4	-2.4	6.6	1.5	4.0	4.2	
CNMP (Panama)	17.5	18.7	6.0	14.6	15.9	6.7	12.0	0.7	5.2	5.3	
DFNT (Tunis)	1793.2	1899.4	1991.2	2086.8	2177.8	2271.9	2375.0	0.7	20.0	20.0	
DLR (Oberpfaffenhofen)	-7.8	-7.5	-7.2	-7.2	-6.7	-7.0	-7.6	0.7	2.6	2.7	
DMDM (Belgrade)	25.7	18.5	-	-	-	-	-	0.3	3.5	3.5	
DTAG (Frankfurt/M)	-47.9	-44.6	-31.9	-25.4	-16.1	-15.1	-15.0	0.3	3.0	3.0	
EIM (Thessaloniki)	7.1	7.5	6.8	6.1	13.2	10.0	7.4	4.0	11.2	11.9	
ESA (Noordwijk)	-0.8	-0.5	-0.5	-0.7	-1.1	-0.6	-0.2	0.3	2.7	2.7	
HKO (Hong Kong)	100.0	105.3	107.5	108.2	110.3	115.9	-	0.7	3.2	3.3	
ICE (San Jose)	98.9	90.3	92.5	94.1	92.6	105.8	123.7	2.5	7.2	7.7	
IDN (Serpong-Tangerang)	1659.8	1683.8	1698.8	1698.2	1733.6	1756.7	1768.1	0.3	3.0	3.0	
IFAG (Wettzell)	-829.4	-829.3	-832.1	-829.0	-823.3	-825.9	-830.4	0.3	2.7	2.7	
IGNA (Buenos Aires)	-962.0	-1097.8	-1243.5	-20.7	-60.0	-89.5	-	0.3	20.0	20.0	(1)
IMBH (Sarajevo)	1.9	-0.4	-1.9	2.8	-3.0	-3.3	0.1	0.3	3.0	3.0	
INCP (Lima)	1246.3	1366.8	1466.5	677.1	15.1	121.3	346.7	5.0	20.0	20.6	(2)
INM (Bogota D.C.)	534.5	510.5	498.4	470.2	449.6	438.2	411.7	1.5	20.0	20.1	
INPL (Jerusalem)	10.6	18.4	16.9	13.2	20.6	23.9	23.8	0.3	7.4	7.4	



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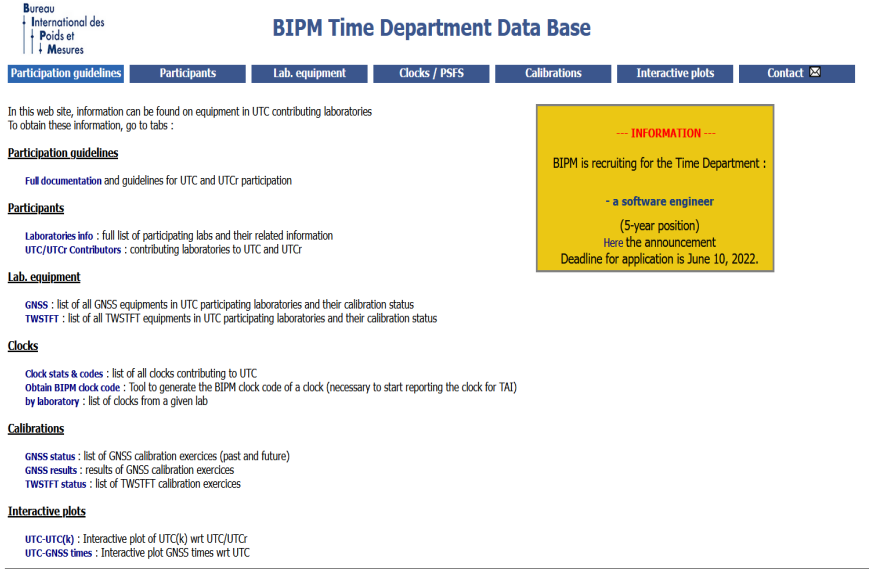
UTC data available on the BIPM web site

http://webtai.bipm.org/database/ and *https://www.bipm.org/en/time-ftp*



- UTC-UTC(k), UTCr-UTC(k)
- Several plots and data of time transfer links UTC(j)-UTC(k)
- Comparison between techniques
- Integer Precise Point Positioning (for some links), Galileo links
- UTC-GNSS Times
- Weights, frequency, frequency drifts of the clocks

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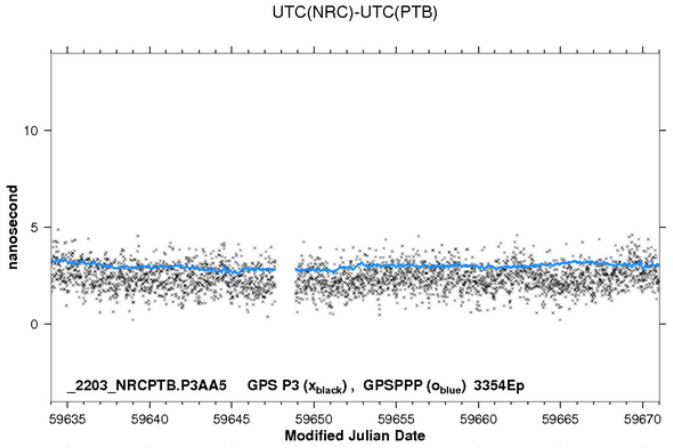
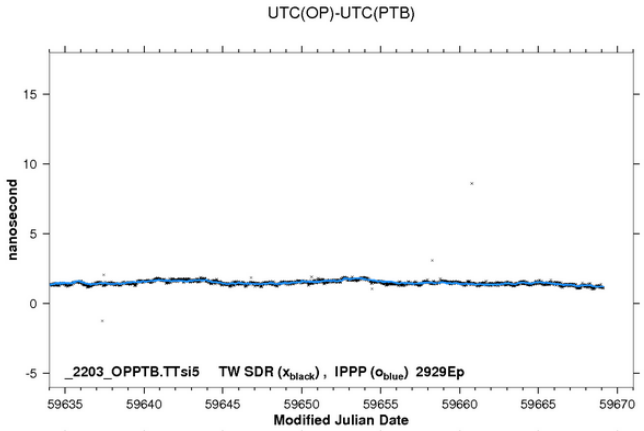
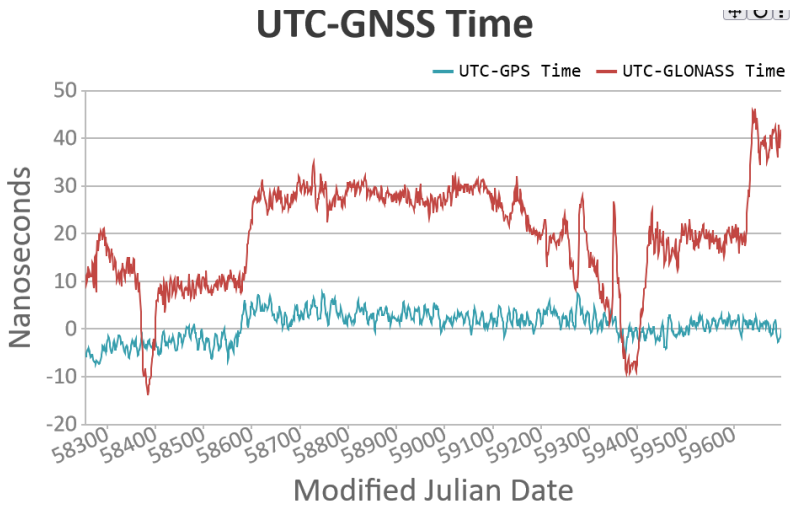
Publication examples – graphical representation

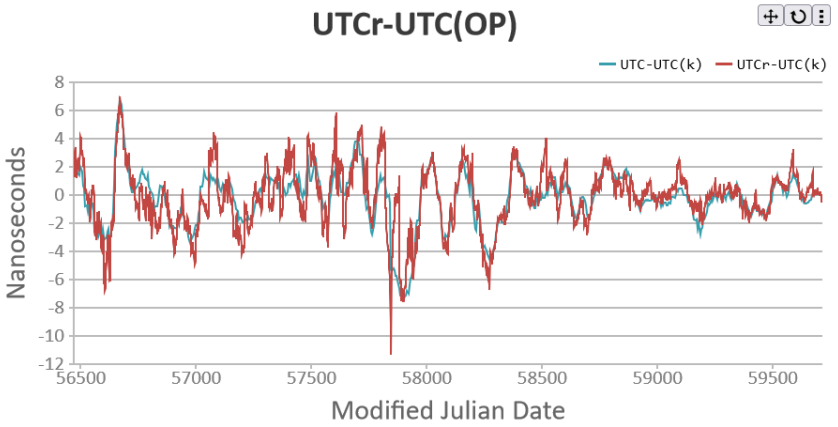


Link comparisons

- GPS P3 and GPS PPP
- TW SDR and IPPP
- UTC-UTC(k)
- UTC-UTCr(k)
- UTC-GNSS Time







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Publication exemples - Data availability - Digitalisation

- An important amount of data are published and are used by the time laboratories for internal generation of their time scale.

MJD	[UTC-UTC(NRC)]/ns	uA/ns	uB/ns	u/ns
50814	9			
50819	54			
50824	117			
50829	13			
50834	14			
50839	17			
50844	17			
50849	20			
50854	22			
50859	24			
50864	29			
50869	26			
50874	24			
50879	18			
50884	16			

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INTERNATIONAL ATOMIC TIME

MONTHLY RATES OF TAI-CLOCK
FOR INTERVALS OF ONE MONTH ENDING AT THE GIVEN DATES

(UNIT IS ns/day , 0.00 DENOTES THAT THE CLOCK WAS NOT USED)

LAB.	CLOCK	59544	59579	59609	59634	59669	59699
AGGO	35 768	0.00	3.22	1.77	2.41	1.75	2.24
AGGO	40 8620	0.00	-11.47	-11.46	-11.28	-6.55	-3.03
AGGO	35 1881	0.00	-0.37	-0.34	0.19	0.96	0.59
APL	35 1264	-1.94	-1.94	-1.12	-2.59	-2.84	-2.45
APL	35 1791	1.53	1.00	1.33	1.05	1.24	2.08
APL	35 3842	1.27	1.94	1.99	2.06	2.04	3.01
APL	40 3107	57.49	57.68	58.48	58.94	59.43	59.89
APL	40 3108	684.68	687.02	689.42	690.97	692.31	693.45
APL	40 3109	20.56	20.54	20.72	20.81	20.92	20.96
AUS	36 2269	-0.43	0.22	0.56	0.69	-0.38	0.82
AUS	36 3814	0.70	0.74	0.93	1.97	0.85	2.65
AUS	36 340	6.70	7.20	6.43	7.37	8.39	6.02
AUS	36 654	-24.20	-24.40	-23.71	-24.55	-25.24	-25.12
BEV	35 3009	-1.39	-1.17	1.81	1.30	1.24	0.49
BEV	40 3452	-23.66	-20.12	-17.65	-15.29	-13.12	-10.59

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INTERNATIONAL ATOMIC TIME

FREQUENCY DRIFTS OF THE CLOCKS USING A MONTHLY REALIZATION OF TT(BIPM)
AS REFERENCE FOR INTERVALS OF THREE MONTHS ENDING AT THE GIVEN DATE
UNIT IS ns/day/30days

(********* DENOTES THAT CLOCK WAS MISSING)

LAB.	CLOCK	59544	59579	59609	59634	59669	59699
APL	35 1264	-0.1752	-0.1384	0.3015	-0.2833	-0.8140	0.0110
APL	35 1791	-0.1833	-0.0788	-0.1065	0.1010	-0.0323	0.5154
APL	35 3842	0.2303	0.3345	0.2278	-0.0148	0.0214	0.3841
APL	40 3107	0.3453	0.2380	0.4937	0.6770	0.4807	0.4640
APL	40 3108	2.0108	2.0690	2.1986	2.0262	1.4907	1.1896
APL	40 3109	-0.0388	-0.0906	0.0716	0.1333	0.0875	0.0728
AUS	36 2269	0.5353	0.3471	0.5836	0.2306	-0.5457	0.0312
AUS	36 3814	0.0325	-0.0319	0.1647	0.4176	0.0289	0.4621
AUS	36 0340	-0.4554	-0.3940	-0.1027	-0.0455	0.8141	-0.5880
AUS	36 0654	-0.1879	-0.3203	0.0678	-0.2462	-0.8862	-0.3119
BEV	35 3009	-0.2629	0.1331	1.4172	1.2959	-0.1979	-0.4485
BEV	40 3452	2.8572	3.0895	2.7549	2.3953	2.3305	2.2538
BEV	35 1793	-0.0633	-0.0165	0.2426	0.3578	0.6813	0.1187
BFKH	35 3543	*********	*********	*********	-2.2842	0.3950	0.1969
BIM	18 8058	-0.3712	0.3048	-0.4911	-0.3777	-0.3341	-0.2314
BIRM	35 3447	*********	*********	*********	*********	*********	3.7773
BIRM	35 3689	*********	*********	*********	*********	*********	6.9110
BY	40 4227	*********	*********	*********	*********	33.2125	4.2657
BY	40 4222	*********	*********	*********	*********	0.1268	-1.2629
BY	41 5105	*********	*********	*********	*********	0.0796	0.1079

- UTC-UTC(k)
- Rates and drifts of the clocks

API development in progress

Allow machines and applications to collect data according to custom requests :
- Customized period
- Customized output file format (JSON, CSV, Text)

Currently, only :
- [UTC-UTC(k)]
- [UTCr-UTC(k)]
- [UTC-GNSS times] are proposed.

But the service is planned to provide a larger variety of data in the future.

The API is still in testing version…

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https://webtai.bipm.org/api/v0.2-beta/

UTCr – the rapid realization of UTC

Since 2013 a rapid evaluation of UTC is available, UTCr.

The data are on daily batches and published each week, the Wednesday.

The number of participating laboratories is slightly increased in the last years.

UTCr_2215
2022 APRIL 20, 08h UTC

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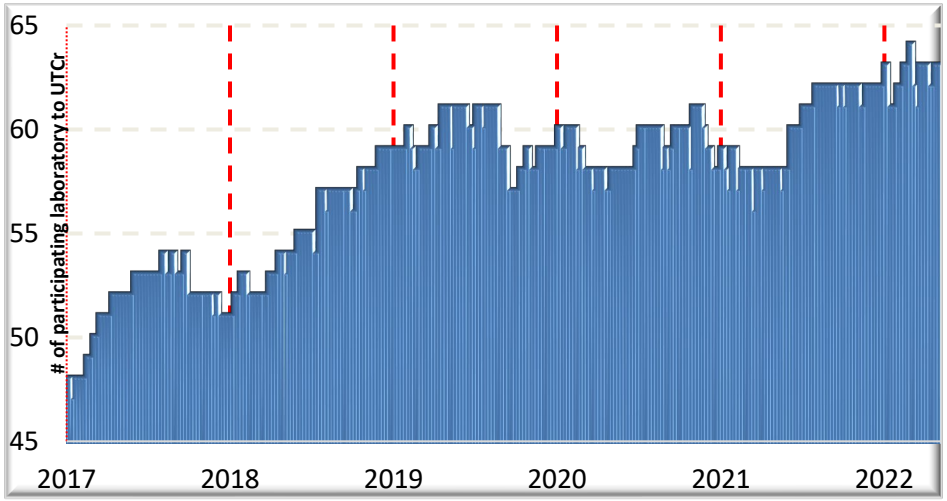
Computed values of [UTCr-UTC(k)]

Date 2022 0h UTC	APR 11	APR 12	APR 13	APR 14	APR 15	APR 16	APR 17
MJD	59680	59681	59682	59683	59684	59685	59686
Laboratory k	[UTCr-UTC(k)]/ns						
AOS (Borowiec)	-1.2	-1.1	-0.9	-0.8	-1.0	-0.8	-0.8
AUS (Sydney)	-542.6	-535.2	-532.6	-535.9	-533.8	-537.3	-532.2
BEV (Wien)	-28.3	-30.8	-34.2	-38.8	-39.0	-40.9	-41.2
BIRM (Beijing)	-5.3	-5.8	-6.0	-7.0	-6.9	-6.7	-7.6
CH (Bern-Wabern)	-0.9	-1.1	-1.0	-1.2	-0.9	-0.7	-0.5
CNM (Queretaro)	5.4	10.5	7.9	2.2	-3.0	1.5	7.0
CNMP (Panama)	4.8	3.6	1.6	11.6	14.3	10.8	18.4
DLR (Oberpfaffenhofen)	-7.1	-7.1	-7.0	-7.0	-7.3	-7.2	-7.2
DTAG (Frankfurt/M)	-28.3	-26.1	-25.6	-24.8	-24.6	-24.7	-21.3
ESA (Noordwijk)	-0.5	-0.5	-0.7	-0.6	-0.8	-1.0	-1.0
HKO (Hong Kong)	107.1	110.6	107.5	108.6	108.0	106.0	105.8
ICE (San Jose)	97.4	97.5	99.4	102.2	93.5	87.6	93.3
IFAG (Wettzell)	-830.1	-832.7	-831.8	-830.9	-	-	-
IGNA (Buenos Aires)	-1268.2	-1294.5	-11.8	-5.7	-11.5	-21.3	-28.1
IMBH (Sarajevo)	-3.8	-1.3	0.2	2.0	2.1	1.6	1.0
INTI (Buenos Aires)	212.7	216.9	205.8	204.6	204.7	206.5	203.9



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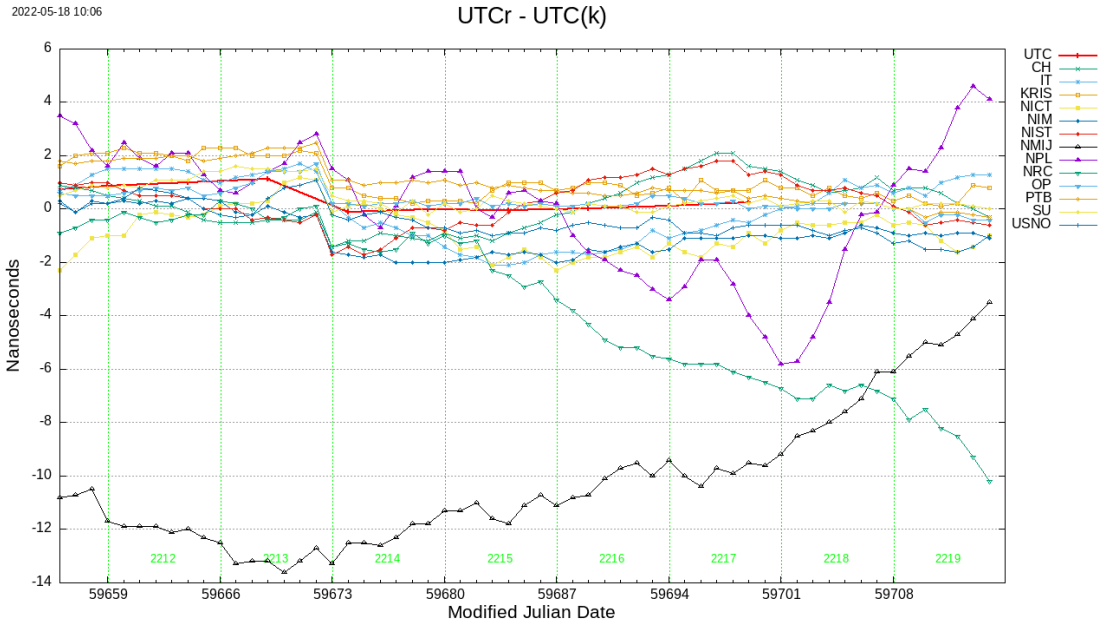
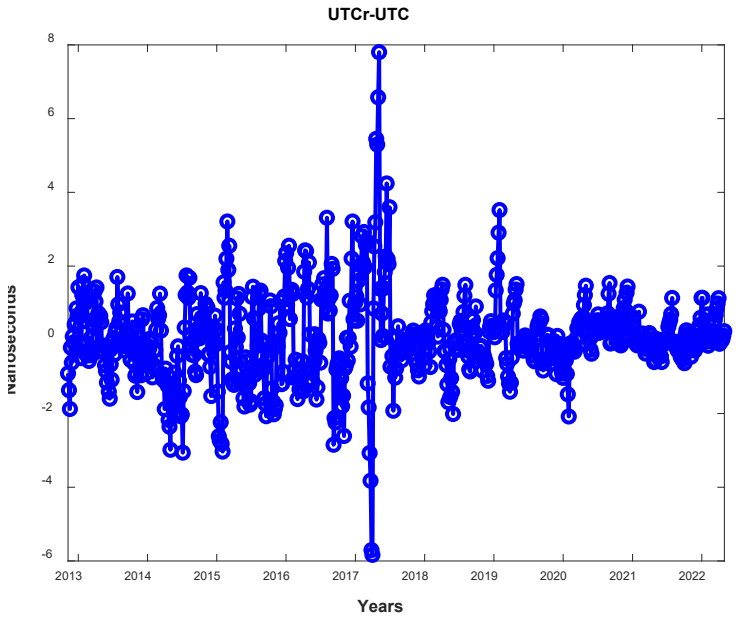
UTCr versus UTC

For the week 2219 for example we had 62 participating laboratories with 270 atomic clocks.

Concerning the time links we apply the following politics:

- if in UTC the combination of TW and GPS PPP is used ➡ in UTCr the TW
- If in UTC we use GPS PPP ➡ in UTCr GPS P3





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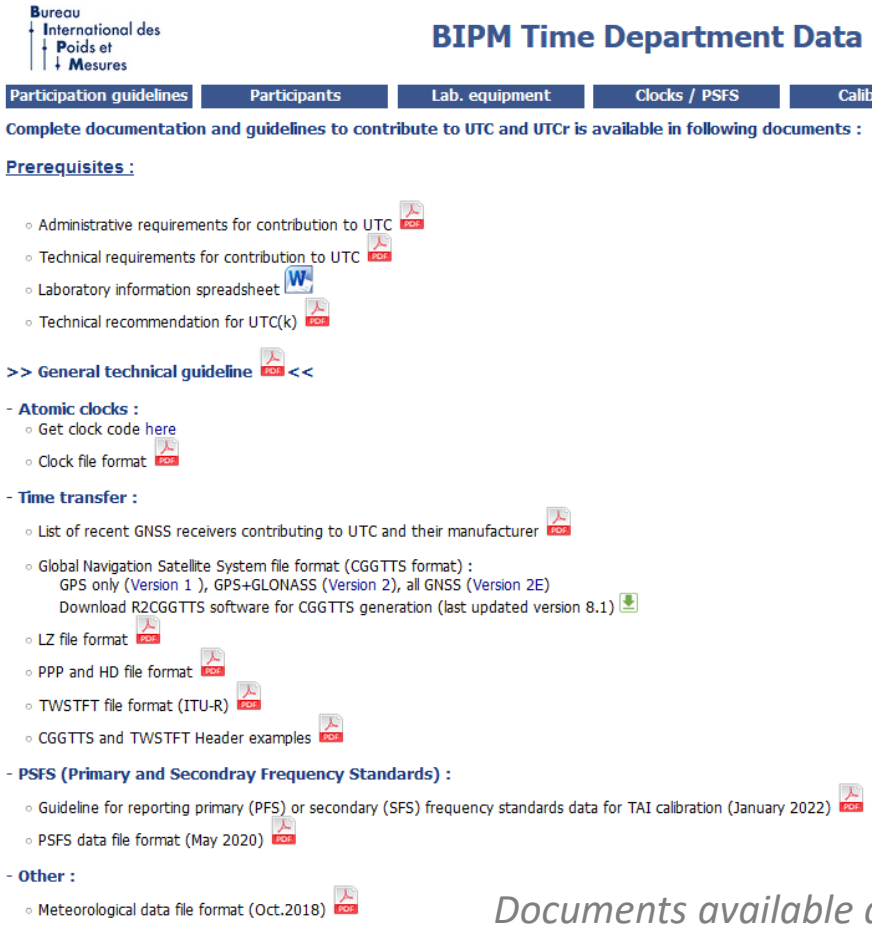
Participation to UTC and UTCr



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BIPM Time Department Data Base

Participation guidelines | Participants | Lab. equipment | Clocks / PSFS | Calibrations | Interactive plots | Contact

Complete documentation and guidelines to contribute to UTC and UTCr is available in following documents :

Prerequisites :

- Administrative requirements for contribution to UTC
- Technical requirements for contribution to UTC
- Laboratory information spreadsheet
- Technical recommendation for UTC(k)

>> General technical guideline <<

- Atomic clocks :
- Get clock code here
- Clock file format

- Time transfer :
- List of recent GNSS receivers contributing to UTC and their manufacturer
- Global Navigation Satellite System file format (CGGTTS format) :
  GPS only (Version 1), GPS+GLONASS (Version 2), all GNSS (Version 2E)
  Download R2CGGTTS software for CGGTTS generation (last updated version 8.1)
- LZ file format
- PPP and HD file format
- TWSTFT file format (ITU-R)
- CGGTTS and TWSTFT Header examples

- PSFS (Primary and Secondray Frequency Standards) :
- Guideline for reporting primary (PFS) or secondary (SFS) frequency standards data for TAI calibration (January 2022)
- PSFS data file format (May 2020)

- Other :
- Meteorological data file format (Oct.2018)

- Requirements are described in CCTF Guidance documents from the WG on MRA :
  - Guideline 6: Requirements for participation in the computation of UTC at the BIPM
  - Guideline 8: Technical requirements for the time laboratories for the participation in UTC

Documents available at:
https://webtai.bipm.org/database/guidelines.html
https://www.bipm.org/en/committees/cc/cctf/wg/cctf-wgmra

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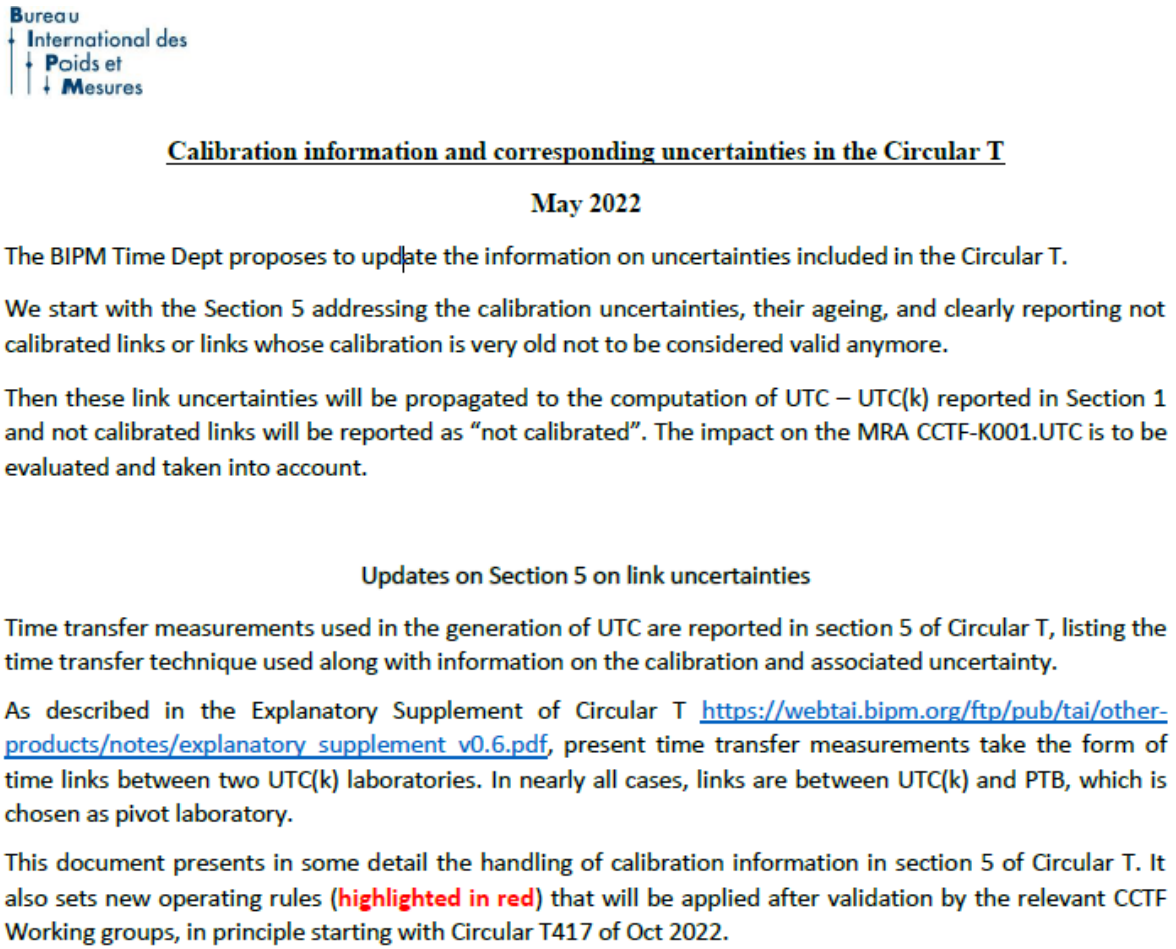
Proposals to be discussed – Uncertainties

- The document « Calibration information and corresponding uncertainties in the Circular T » will be discussed in all relevant CCTF working groups



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Calibration information and corresponding uncertainties in the Circular T

May 2022

The BIPM Time Dept proposes to update the information on uncertainties included in the Circular T.

We start with the Section 5 addressing the calibration uncertainties, their ageing, and clearly reporting not calibrated links or links whose calibration is very old not to be considered valid anymore.

Then these link uncertainties will be propagated to the computation of UTC – UTC(k) reported in Section 1 and not calibrated links will be reported as "not calibrated". The impact on the MRA CCTF-K001.UTC is to be evaluated and taken into account.

Updates on Section 5 on link uncertainties

Time transfer measurements used in the generation of UTC are reported in section 5 of Circular T, listing the time transfer technique used along with information on the calibration and associated uncertainty.

As described in the Explanatory Supplement of Circular T https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf, present time transfer measurements take the form of time links between two UTC(k) laboratories. In nearly all cases, links are between UTC(k) and PTB, which is chosen as pivot laboratory.

This document presents in some detail the handling of calibration information in section 5 of Circular T. It also sets new operating rules (**highlighted in red**) that will be applied after validation by the relevant CCTF Working groups, in principle starting with Circular T417 of Oct 2022.

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Proposal 1: Not Calibrated Laboratories

- Currently, uncalibrated equipment are assigned a uCal value of 20 ns. This translates to a total uncertainty of [UTC – UTC(k)] in section 1 of about 20 ns. This is too optimistic as unknown calibration delays can be quite larger.
- We propose that labs without recognized calibration appear as « Not Calibrated » in section 1.

➢NC stands for no valid calibration available.

➢NC_Al indicates that the BIPM needed to compute and apply a correction to align the current link to the previously used link, which was non-calibrated.

A laboratory linked by a NC or NC_AL link will appear as Not Calibrated in section 1. No uncertainty can be assigned to the access to UTC through such a UTC(k).

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Proposal 2: Ageing and validity of old calibration

- Currently, the ageing uncertainty set to 10 ns after 10 years, without specified duration limit for an old calibration.
- We expect to stimulate labs with very old calibration to take action towards a new calibration by severing a bit the ageing uncertainty and setting a 12-year validity limit for a calibration.

A calibrated link is characterized by a standard calibration uncertainty under the heading *uCal* and an ageing uncertainty under the heading *uAg*. The ageing uncertainty depends on the technique and increases with time elapsed since the calibration. **The ageing uncertainty increases to a conventional fixed value of 10 ns when 8 years have elapsed since calibration. When 12 years have elapsed, the calibration is considered invalid, and the link will be considered Not Calibrated**.

➢NA stands for no availability of the calibration report. This refers to some calibrations performed before the definition of Calibration identifiers in 2015. **When 12 years have elapsed since calibration, the calibration is considered invalid, and the link will be considered Not Calibrated.**

Proposal 3: Temporary alignments

- Currently, in case of problem with an equipment discovered at Circular T computation, and if an alternative exists, the BIPM aligns the alternative link to the previous link, saving the continuity and the previous calibration.
- This procedure is expected to be temporary, however may remain in place for years if no action is taken.
- We propose to stimulate laboratories to regain the control of their calibration information by setting a time limit to the procedure of « alignment by the BIPM »

➢NA_Al indicates that the BIPM needed to compute and apply a correction to align the current link to the previously used link, which was calibrated. The value of the correction and the month of alignment are indicated under the headings Al/ns and YYMM. **This procedure allows temporary saving the calibration uncertainty of the link, for a maximum period of 12 months, after which the link will be considered Not Calibrated. The laboratory can provide new calibration information, see "Restore calibration after a set-up change".**

Conclusions

UTC, UTCr and published products

Status of clocks, PFSF, time links in UTC and in UTCr

Proposals for uncertainties in Circular T