CGSIC Timing Subcommittee

Introduction

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Prezented by Jerzy Nawrocki, Space Research Centre

AREAS BEING SERVED

- Coordinated Universal Time (UTC)
- International Timing Centers
- Global Navigation Satellite Systems
- Telecommunications Industries
- Two-Way Satellite Time Transfer (TWSTFT)
- Two-Way Optical Fiber Time Transfer (TWOTFT)
- Power Grids and other Industries
- As Research and Comparison Tool
- Other

Topics

- **Rapid UTC**
- **Fiber optic time transfer**
- **2017 CCTF Meeting**

Characteristics of BIPM UTCr

- **Based on daily data reported (daily) by contributing laboratories**
- **Weekly access to daily values of [*UTCr*-*UTC*(*k*)]**
- **Automatically generated weekly solution over four weeks of data (sliding solution)**

Implementation of BIPM UTCr

- **September 2011**: UTC contributing laboratories have been invited to participate on a voluntary basis to a pilot experiment.
- **January 2012**: Pilot experiment started, with the target of reporting to the CCTF in September 2012.
- **July 2013**: Operational production of UTCr.

Impact of a rapid realization of UTC

- **On UTC contributing laboratories:**
  - **More frequent assessing of the UTC(K) steering, and consequently better stability and accuracy of [UTC(k)];**
  - **Traceability to UTC is enhanced.**
- **On users of UTC(K):**
  - **Access to a better "local" reference, and indirectly, better traceability to the UTC "global" reference.**
- **On GNSS:**
  - **Better synchronization of GNSS times to UTC, through improved UTC and UTC(k) predictions: case of UTC(USNO) for GPS, UTC(SU) for GLONASS, UTC(k) used in the generation of Galileo ST, BeiDou ST and Gagan ST.**

Publication

- Every Wednesday before 18:00 UTC
- on
- ftp://tai.bipm.org/UTCr/Results/

UTCr_1211
2012 MARCH 21, 13h UTC

The results in this page are established by the BIPM Time Department in the frame of the pilot experiment on a rapid UTC, UTCr. The computed values [UTCr-UTC(k)] are reported.

Date 2012	0h UTC	MAR 12	MAR 13	MAR 14	MAR 15	MAR 16	MAR 17	MAR 18
MJD		55998	55999	56000	56001	56002	56003	56004
Laboratory k				[UTCr-UTC(k)]/ns				
AOS	(Borowiec)	-2.6	-2.4	-1.9	-1.3	-1.9	-1.9	-1.2
BEV	(Wien)	11.9	11.3	10.3	6.5	0.4	-2.3	-5.7
CAO	(Cagliari)	-6291.7	-6290.8	-6293.1	-6291.4	-6298.8	-6308.3	-6300.0
CH	(Bern)	-12.5	-12.3	-12.0	-10.9	-9.8	-9.2	-9.3
CNM	(Queretaro)	-13.8	-15.0	-15.5	-14.9	-17.3	-18.4	-17.1
CNMP	(Panama)	75.8	81.4	85.5	83.1	83.8	83.0	88.0
DTAG	(Frankfurt/M)	6.8	5.1	5.8	5.7	6.8	6.4	7.7
IFAG	(Wettzell)	-620.2	-619.1	-623.8	-627.3	-627.8	-626.7	-627.4
IGNA	(Buenos Aires)	6691.8	6700.6	6711.9	6724.6	6737.0	6747.7	6762.6
INTI	(Buenos Aires)	-26.4	-32.2	-32.6	-32.7	-32.5	-31.6	-36.7
IPQ	(Caparica)	-23.1	-29.1	-27.5	-24.7	-22.6	-16.5	-12.5
IT	(Torino)	1.2	2.3	2.6	3.0	3.4	3.8	4.0
KRIS	(Daejeon)	-8.3	-8.7	-9.4	-	-	-	-
LT	(Vilnius)	42.4	39.1	32.9	35.0	30.1	37.5	43.8
MSL	(Lower Hutt)	67.0	61.2	55.3	-	-	-	-
NAO	(Mizusawa)	54.8	49.9	52.4	54.7	50.1	49.0	50.8
NICT	(Tokyo)	2.5	2.7	2.6	3.1	3.4	3.2	3.2
NIM	(Beijing)	-7.1	-7.5	-8.3	-8.9	-9.8	-9.8	-10.7
NIMT	(Pathumthani)	987.6	1008.5	1026.4	1042.7	1058.3	1074.2	1090.9
NIS	(Cairo)	-782.1	-784.0	-783.8	-786.8	-794.0	-797.0	-799.5
NIST	(Boulder)	-4.1	-5.0	-4.2	-3.9	-6.6	-6.3	-5.2
NMIJ	(Tsukuba)	-8.7	-8.4	-8.5	-8.2	-7.7	-8.0	-8.2
NMLS	(Sepang)	-664.4	-665.1	-667.1	-667.0	-670.4	-672.4	-674.5
NRC	(Ottawa)	-18.1	-14.2	-15.1	-13.9	-13.8	-14.0	-13.6
NTSC	(Lintong)	0.8	2.2	2.1	5.0	4.3	4.5	3.8
ONRJ	(Rio de Janeiro)	-12.3	-9.7	-6.9	-7.5	-7.8	-4.7	-1.9
OP	(Paris)	-24.5	-22.8	-23.7	-21.8	-21.4	-21.8	-24.5
ORB	(Bruxelles)	-0.4	-0.1	0.5	0.0	0.4	-0.5	-1.0
PL	(Warszawa)	15.8	16.5	18.1	16.1	15.0	12.4	12.8
PTB	(Braunschweig)	-3.2	-3.4	-3.6	-3.5	-4.0	-4.0	-4.6
ROA	(San Fernando)	-2.8	-2.2	-2.7	-3.1	-3.5	-3.8	-4.4
SCL	(Hong Kong)	13.8	11.5	5.2	5.5	2.8	-5.8	-2.0
SG	(Singapore)	9.6	9.3	7.5	7.8	7.8	7.4	6.6
SP	(Boras)	-15.7	-15.6	-15.5	-15.6	-15.5	-15.6	-16.0
SU	(Moskva)	1.4	1.2	2.0	2.2	0.6	0.3	0.9
TL	(Chung-Li)	6.4	6.5	5.5	4.9	4.2	2.7	1.3
UME	(Gebze-Kocaeli)	103.3	100.2	104.3	109.5	107.7	105.3	107.1
USNO	(Washington DC)	-0.7	-1.1	-1.2	-1.3	-1.5	-1.5	-1.5
VSL	(Delft)	10.0	8.1	3.6	3.2	4.4	4.5	4.6

These results should not be used as a prediction of UTC.
UTC remains available from the monthly Circular T at
(http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication).

Oncoming Optical Fibre - TWOTFT

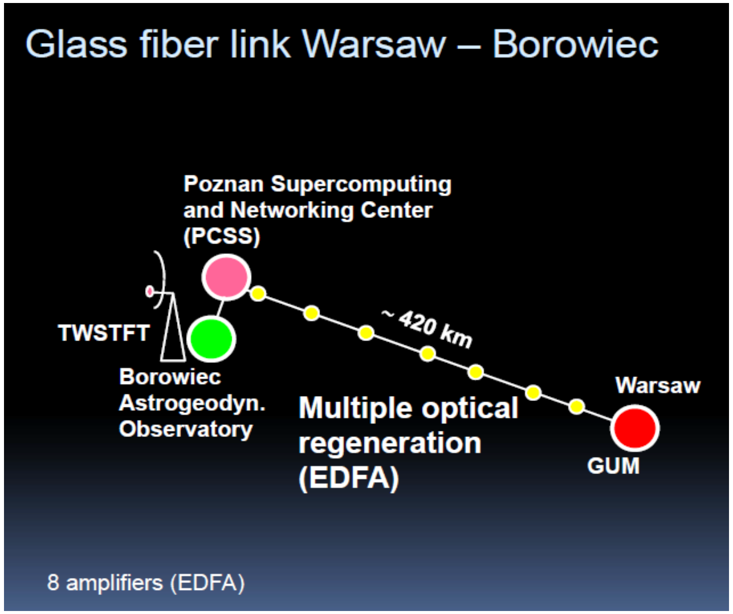
- Long-term goal: Compare the optical clocks ~10^{-18}@day
- More than 14 UTC laboratories actively involved
- Already operational UTC(AOS)-UTC(PL) by AGH
- Immediate Applications in UTC:
  - Validate the BIPM GNSS calibrator with u_B ~ 200 ps
  - Validate the new GNSS and TW**S**TFT techniques
- **New challenges**
  - the theoretical issues
  - the practical issues: data processing, format, programs …

Optical Fiber Links: realized long hauls

Location	Length	Performance (*)
Check Rep/Austria	550 km	TT, evaluating accuracy 30 ps/20s
China	50 km	FT $20\times10^{-15}/\tau$
Finland	900 km	TT 1 ns
France-Germany	1400 km	FT $1\times10^{-16}/\tau$
France-UK	800 km	FT $\times10^{-15}/\tau$
Italy	1284 km	FT $0.2\times10^{-15}/\tau$
Japan	120 km	FT $0.8\times10^{-15}/\tau$
Poland	420 km	TT 70 ps - FT $35\times10^{-15}/\tau$

(*) accuracy for Time Transfer (TT)
Allan deviation for frequency Transfer (FT), extrapolated to 100 km (scaling law L3/2).
[*adapted from D. Calonico et al., European Phys Lett, 110 40001 (2015)*]

Optical Fibre - TWOTFT



	determined quantity	estimate	sensitivity coefficient	standard uncertainty	uncertainty contribution
1	$\tau_{UTC(PL)\rightarrow REF}$ (a)	420.17 ns	1	100 ps	100 ps
2	$\tau_{REF\rightarrow RET}$ (a)	4 093 944.73 ns	0.5	100 ps	50 ps
3	$\tau_{\Delta\lambda}$ (b)	2.950 ns	0.5	19 ps	9.5 ps
4	τ_{S} (c)	-1.686 ns	0.5	5 ps	2.5 ps
5	τ_{B} (d)	0 ns	0.5	1.2 ps	0.6 ps
6	τ_{H} (e)	26.565 ns	0.5	8.8 ps	4.4 ps
	$\tau_{UTC(PL)\rightarrow OUT}$	2 047 406.45 ns	complex uncertainty:		112.3 ps

First Operational Optical Fibre Time Link
420 km between UTC Laboratories AOS-PL
Combined uncertainty **112 ps**

In conclusion Optical Fiber Links :

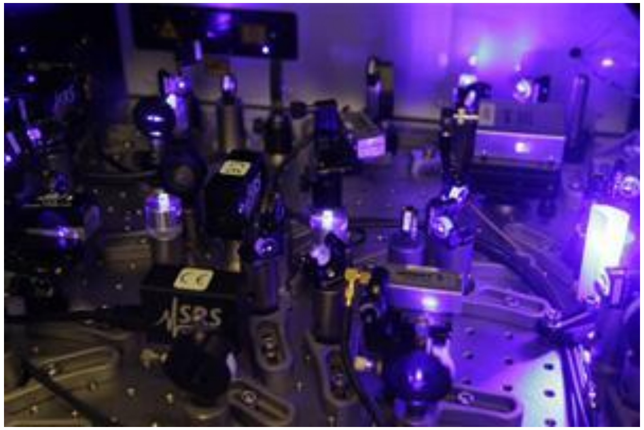
- The Optical Fiber Links techniques have grown fast. Over thousands of kilometres, a coherent fibre link can compare clocks with an uncertainty of few parts in 1e18 in 1000-10000 s.

- But, only one laboratory in Europe, the AOS, regularly reports data to BIPM connecting a remote atomic clock. The implementation of fibre links reporting data to BIPM shall be encouraged and pursued more carefully in the past to take benefit of a widespread optical fibre network.

- Fibre links comparisons demonstrated to be the only suitable means to compare remote optical frequency standards. More comparisons shall now be realized in order to achieve the identified in the roadmap for the possible redefinition of the SI second, collecting more and more comparison of optical frequency standards with an uncertainty of parts in 1e18.

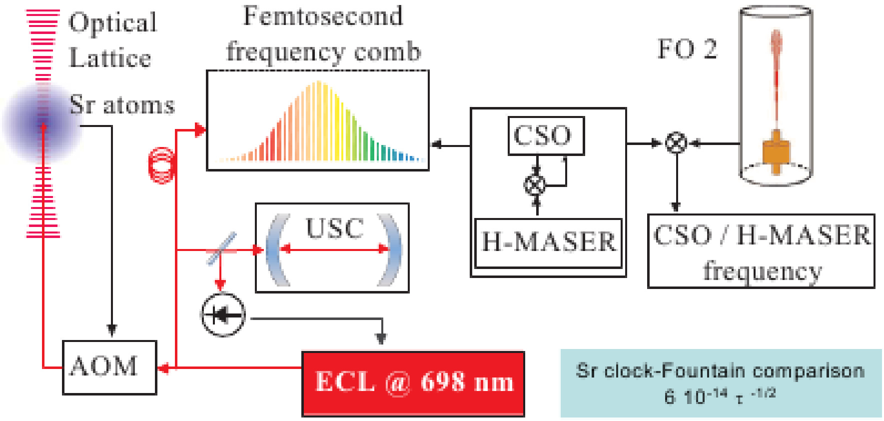
Polish Optical Clock - FAMO

National Laboratory of Atomic, Molecular and Optical Physics

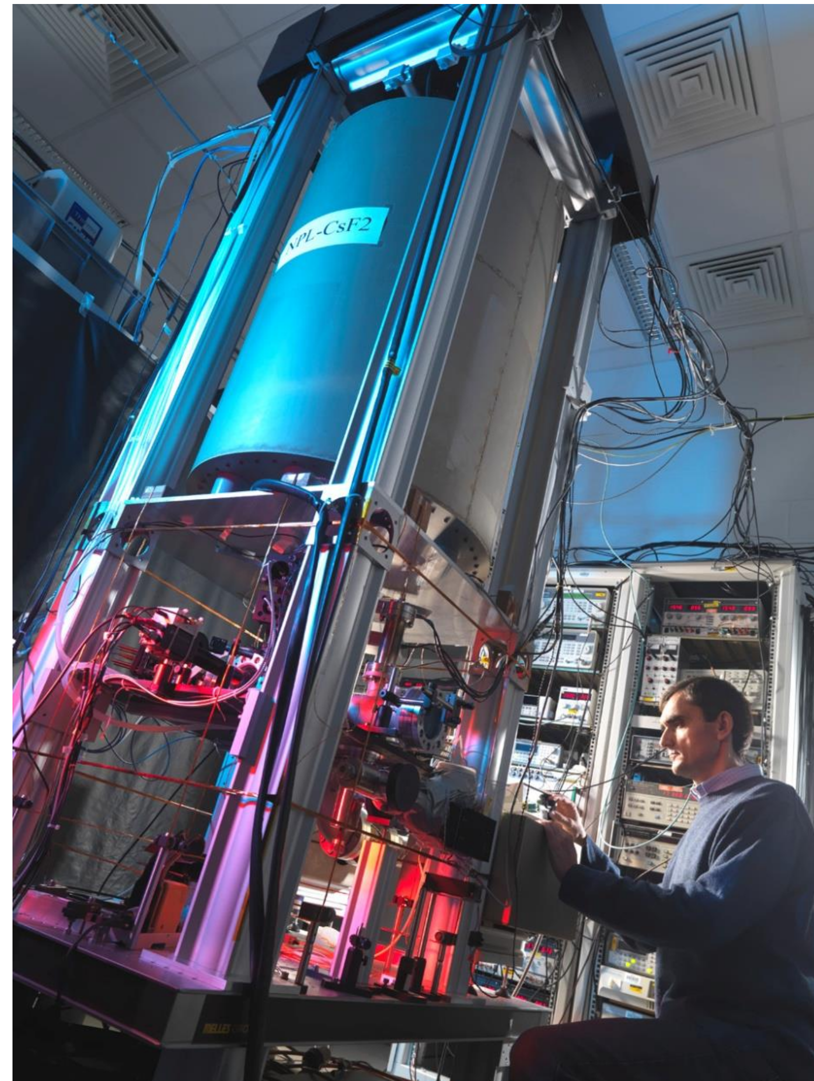


A system of two independent strontium optical lattice clocks.
The system consists of two atomic standards interrogated by a shared ultra-narrow laser, pre-stabilised to a high-Q optical cavity and an optical frequency comb

Expected future stability
~10^{-18}



Two Caesium Frequency Standards



Under construction
in cooperation with
British NPL

CsF-1, December 2016

CSF-2, November 2017

21st Meeting of the Consultative Committee for Time and Frequency BIPM, 8-9 June 2017

Recommendations

(*excerpts*)

RECOMMENDATION CCTF (2017)

on recommended frequency standard values for applications including the practical realisation of the metre and secondary representations of the second

The CCTF, considering that

- **a list of Secondary Representations of the Second (SRS) has been maintained following the recommendations of the CIPM**

….

- **the Working Group on Strategic Planning of the CCTF has prepared a roadmap for a future**
- **redefinition of the second using optical frequency standards;**

recommends that

- **the institutes put effort into operating their frequency standards as secondary representations of the second in such a way that they routinely contribute to TAI via reporting to the BIPM,**
- **the best optical standards be compared with uncertainties that are comparable to the uncertainties of the standards themselves,**

…

CCTF RECOMMENDATION
On improving Two-Way Satellite Time and Frequency Transfer (TWSTFT) for UTC Generation

The CCTF **realizing**

- that atomic frequency standards have achieved unprecedented precision and accuracy, and that further rapid advances in this field are underway ….

considering

- that the experiment of using Software Defined Radio (SDR) receivers in the Asia-Pacific region showed the SDR TWSTFT significantly reduced the diurnal and measurement noise …

recommends

- that the laboratories operating TWSTFT stations continue to study the SDR TWSTFT technique by maintaining SDR operation or installing SDR systems in stations, and providing SDR TWSTFT data to the BIPM in parallel to the data from the currently used TWSTFT equipment …

CCTF RECOMMENDATION
On the utilization and monitoring of redundant time transfer equipment in the timing laboratories contributing to UTC

The CCTF **realizing** that

- atomic frequency standards have achieved unprecedented precision and accuracy, and that further rapid advances in this field are underway **….**

recommends

- that laboratories participating in UTC-generation maintain at least two (three in the case of G1 labs) independent GNSS systems, some of which being state-of-the-art if resources are available …
- record and maintain both external and relevant internal temperature and humidity information and report to the BIPM, calibrate at least one operational link every two years

- continue to study the use of redundant time transfer systems in UTC generation; add in the timing data base the station temperature and humidity information …

CCTF Recommendation on the definition of time-scales

The CCTF **considering that**

- Resolution 1 of the 14th CGPM (1971) requested the CIPM to give a definition of International Atomic Time (TAI);
- no complete self-contained definition of TAI has been officially provided by the CIPM …

recognizing that

- the CGPM is responsible for defining metrological standards, while the IAU) and the IUGG) with the IAG are responsible for defining reference frames for Earth and space applications, and the ITU is responsible for coordinating the dissemination of time and frequency signals and making relevant recommendations …

recommends the following definitions of UTC

- Coordinated Universal Time (UTC) is a time-scale produced by the BIPM, based on TAI. UTC has the same rate as TAI, but differs from TAI by an integral number of seconds. The procedure for UTC adjustment is described in an ITU Recommendation. The difference TAI-UTC is published by the BIPM …

and further recommends that

- all relevant unions and organizations consider these definitions and work together to develop a common understanding …
- all relevant unions and organizations work together to further improve the accuracy of the prediction of DUT1 …

Obituary Notice

Bernard Guinot (1925 – 2017)

passed away on March 6, 2017, at the age of 91.
Officer in the shipping department, he become an astronomer at the Paris Observatory in 1952;
In 1958, he obtained his doctoral thesis on the Danjon astrolabe, an instrument used for observations used for polar motion and Earth rotation determination;
Director of the Bureau International de l’Heure between 1965 and 1985, located at Paris Observatory in the Department of Fundamental Astronomy, today SYRTE;
He officially transferred the BIH activity on time scales to the BIPM in 1985, organized and headed the Time Section.

He made made outstanding contributions to space and time metrology

– He designed newalgorithms for the calculationofUT1and the polar coordinates,
– Hecontributed to the transiton from optical measurements to space geodesy techniques, and proposer their use for the measurement of the Earth’s rotation and the maintenance of the global geodetic system,
– He proposed in 1979 the definition of a new equatorial origin which was adopted by the IAU in 2000,
– He created the algorithm for TAI,«ALGOS»;he was strongly involved in the establishment of UTC, and he strongly supported to stop leap second insertions.

– He had anextraordinary clarity for presenting his ideas. His book,co-authored with Claude Audoin, « The measurement of time », is a clear and exhaustive compendium of time and frequency metrology at about 2000.
– He was a member of the CCDS (today CCTF) between 1978 and 1984, and a member of the CIPM.

His competence, his rigor and his scentific authority have been unanimously recognized. We have lost with him a prominent personality

Thank you !