CGSIC Timing Subcommittee

Introduction

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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
- Caesium Fountains for GNSS

Characteristics of BIPM UTCr

- **Based on 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 assessment 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
- Link comparing UTC(AOS)-UTC(PL) is now operational
- 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 …

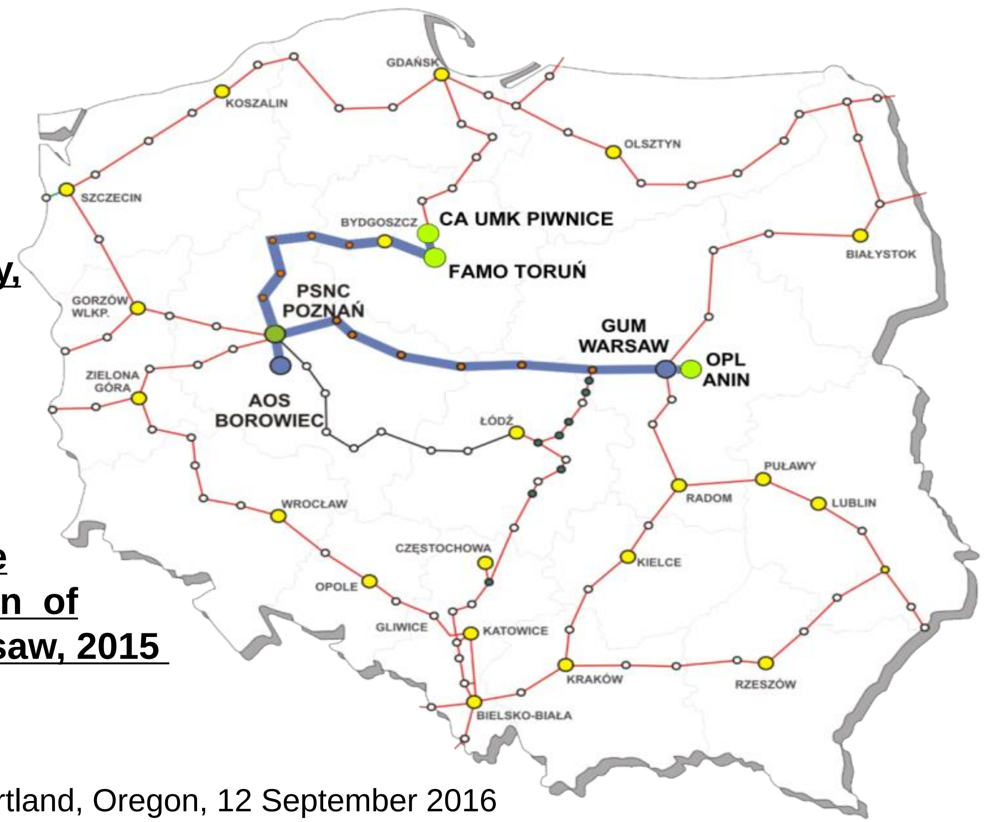
Configuration of permanent T&F optical fibre links in Poland

- **<u>421,4 km fiber-optic connection between Central Office of Measures (GUM) in Warsaw and the Astrogeodynamic Observatory (AOS), from 27th January 2012.</u>**

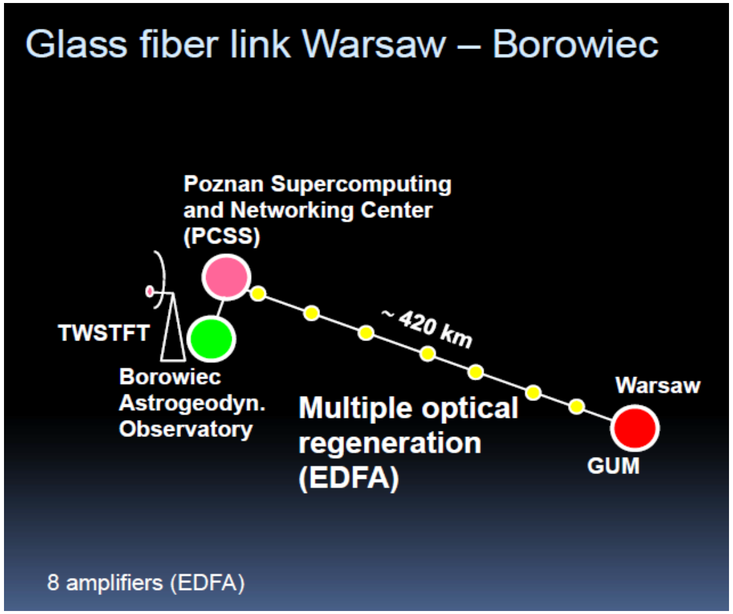
- **<u>330 km optical line from the Astrogeodynamic Observatory (AOS) to the National Laboratory of Atomic, Molecular and Optical Physics inTorun, operational from December 2014</u>**

- **<u>15.5 km line connected KL FAMO Laboratory in Torun to Center for Astronomy of Nicolaus Copernicus University, Piwnice, where there is one of The biggest Polish radio Telescopes, 2015.</u>**

- **<u>40 km line connected Central Office of Measures (GUM) with the Centre of Network Synchronization of Orange Polska , in Anin near Warsaw, 2015</u>**



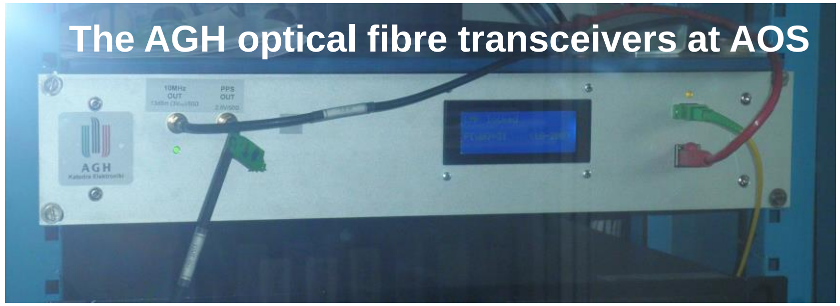
Optical Fibre - TWOTFT

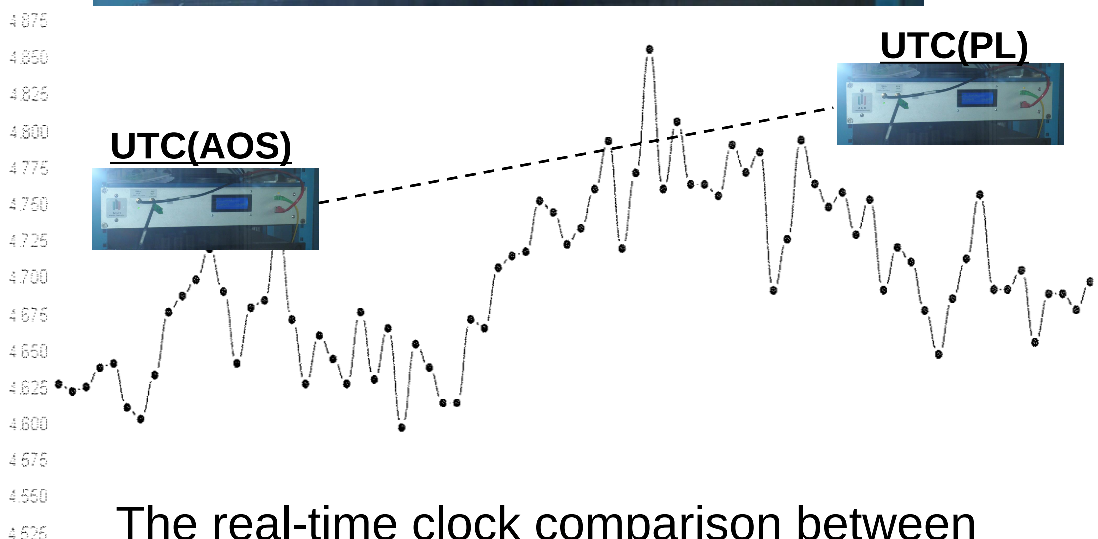


	determined quantity	estimate	sensitivity coefficient	standard uncertainty	uncertainty contribution
1	$\tau_{UTC(PL)\to REF}$ (a)	420.17 ns	1	100 ps	100 ps
2	$\tau_{REF\to RET}$ (a)	4 093 944.73 ns	0.5	100 ps	50 ps
3	$\tau_{\Delta\lambda}$ (b)	2.950 ns	0.5	19 ps	9.5 ps
4	τ_S (c)	-1.686 ns	0.5	5 ps	2.5 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
	$\tau_{UTC(PL)\to OUT}$	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**

Optical Fibre - TWOTFT



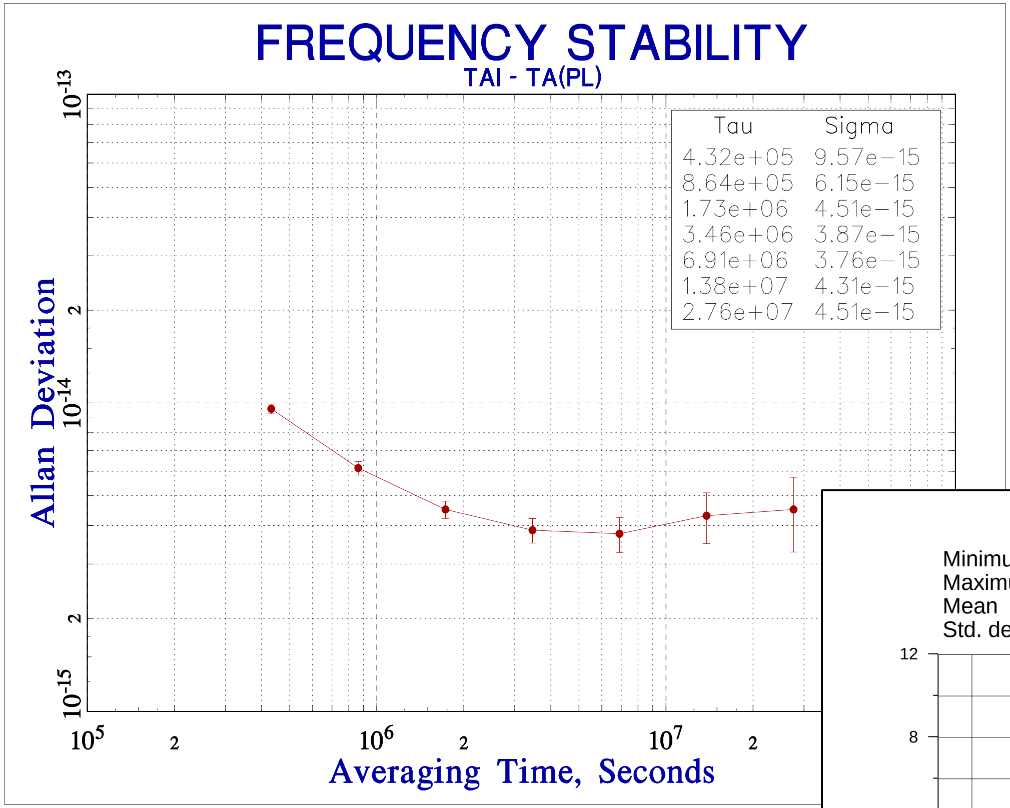


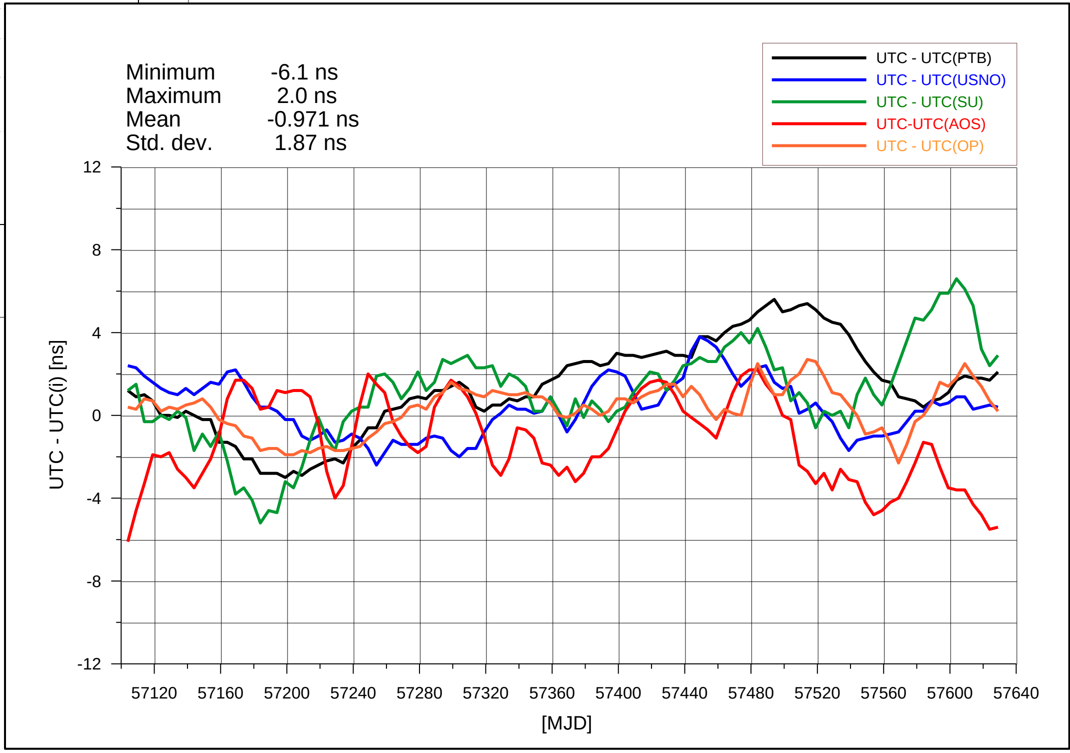
The real-time clock comparison between UTC(AOS) and UTC(PL) through a fibre link, www.optime.org.pl/node/47

Polish time scales

TA(PL) and UTC(AOS)

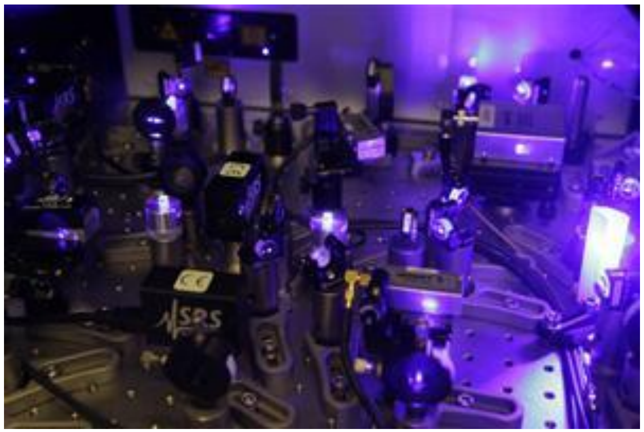
TA(PL) AND UTC(AOS)





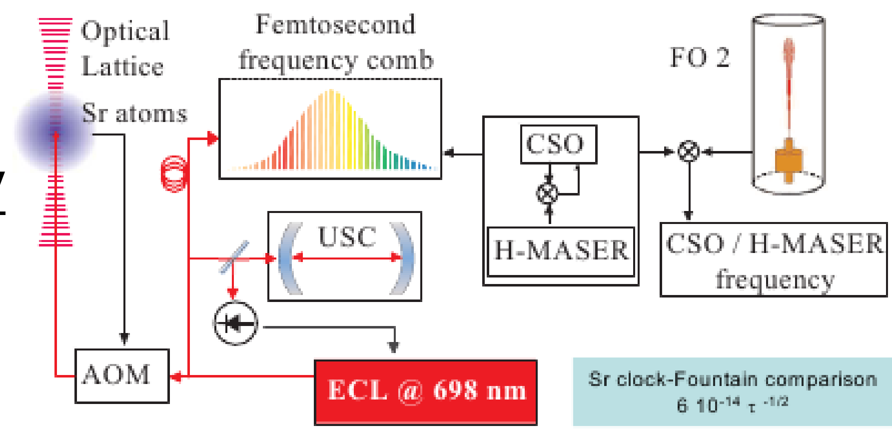
Polish Optical Clock - FAMO

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
$\sim 10^{-18}$



Two Caesium Frequency Standards

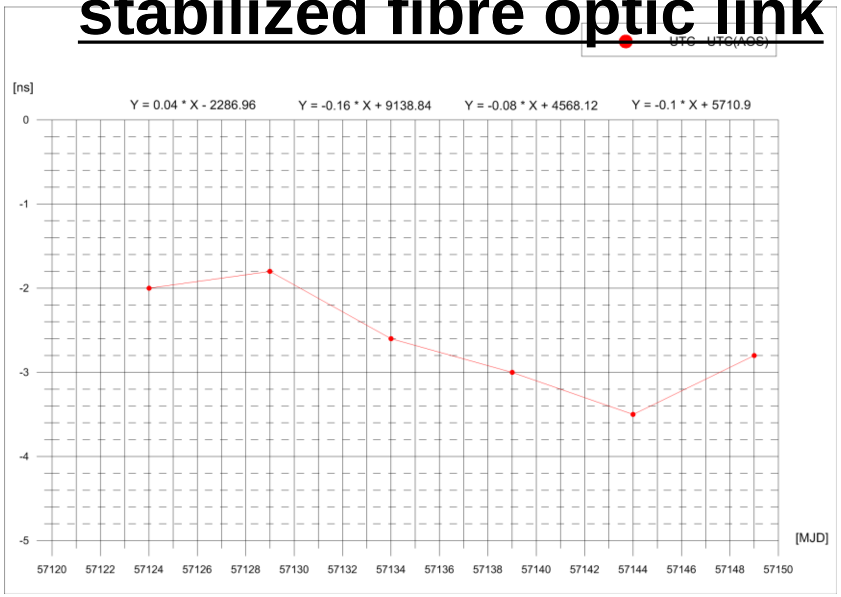
Under construction
in cooperation with
British NPL

CsF-1, December 2016

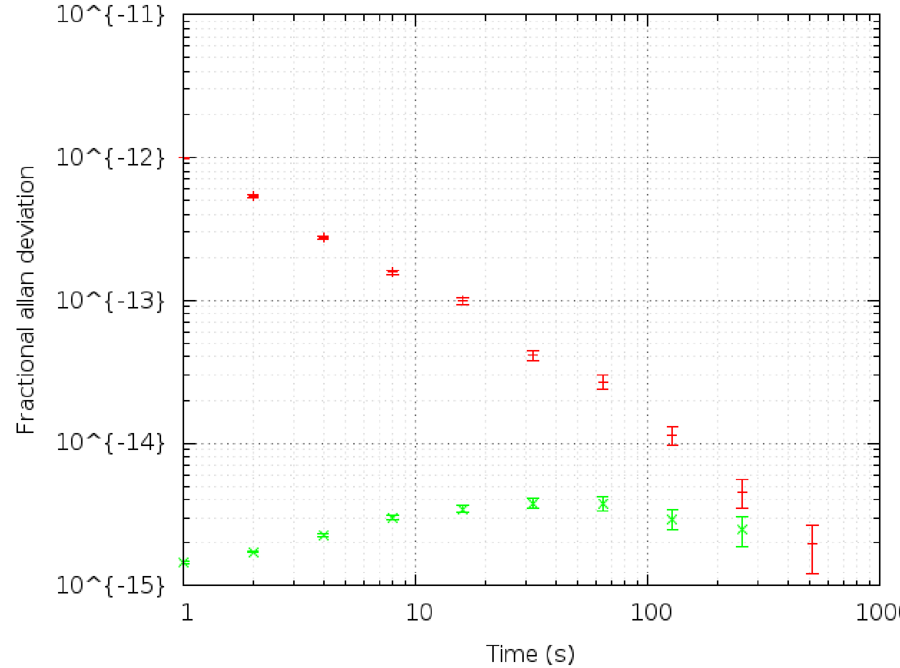
CsF-2, July 2017

Thank you
for your attention!

Absolute measurement of the 1S0 – 3P0 clock transition in neutral 88Sr over the 330 km-long stabilized fibre optic link



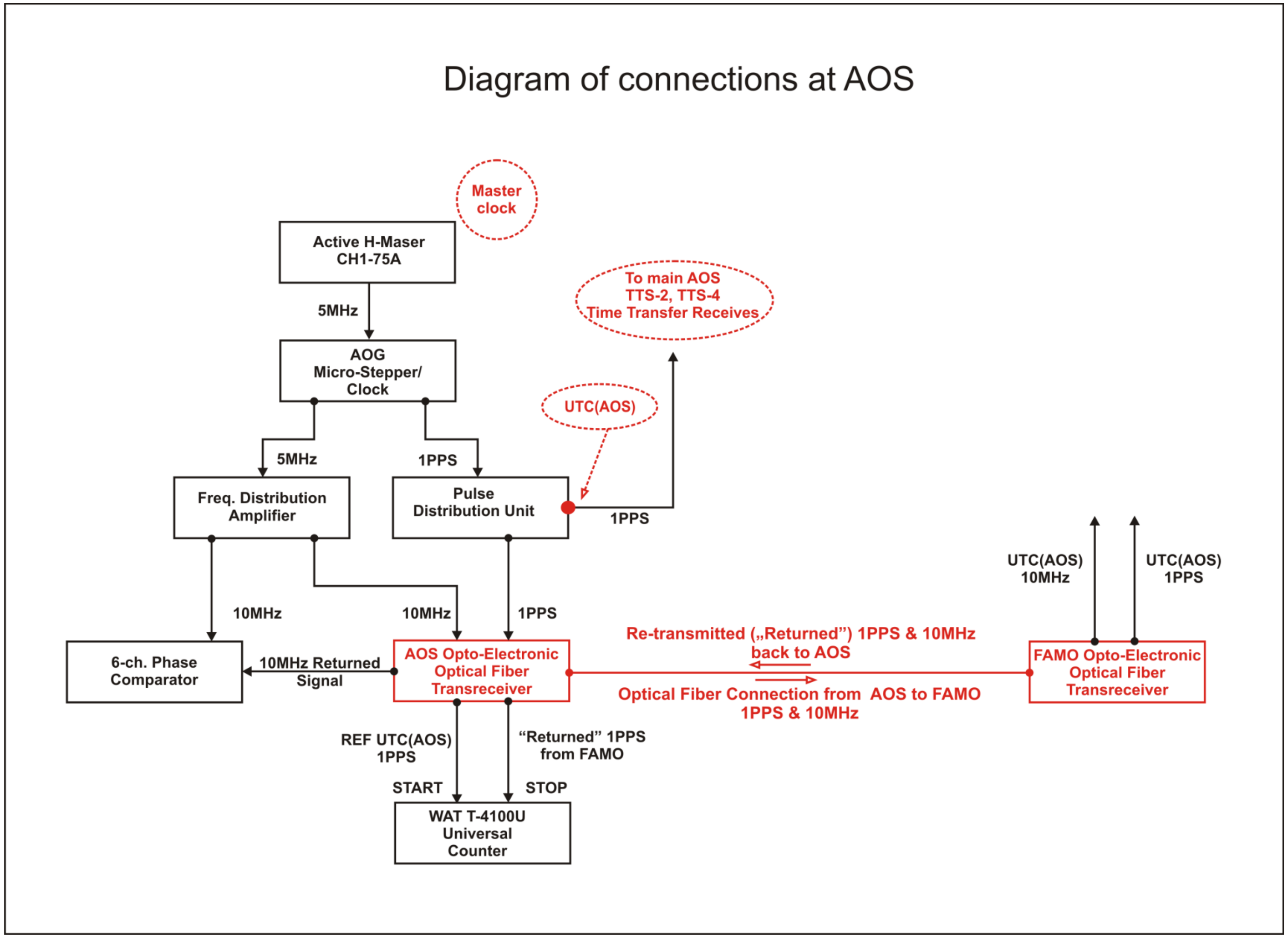
Frequency uncertainty UTC(AOS) ~1xe^{-15}



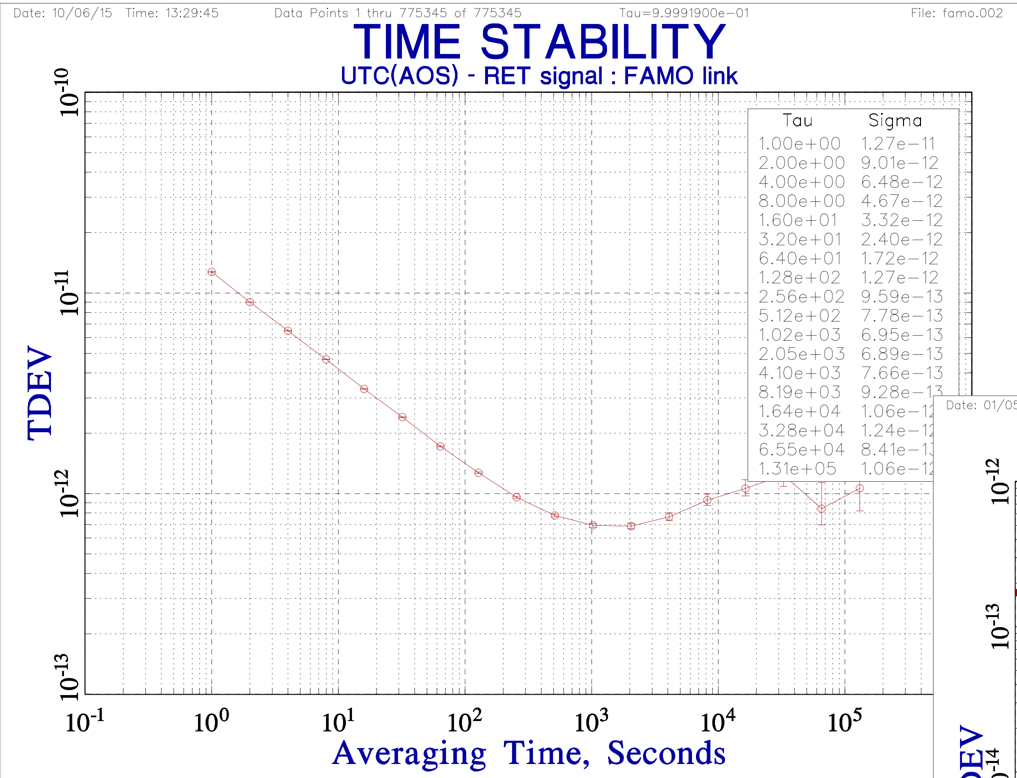
start	[MJD]	57138,030	57131,7030	57137,801	57140,290	57140,510	57140,812	57141,221	57141,605	57141,700	57141,794	57142,440
stop	[MJD]	57138,900	57131,8450	57137,950	57140,445	57140,770	57140,910	57141,320	57141,695	57141,794	57142,280	57142,568

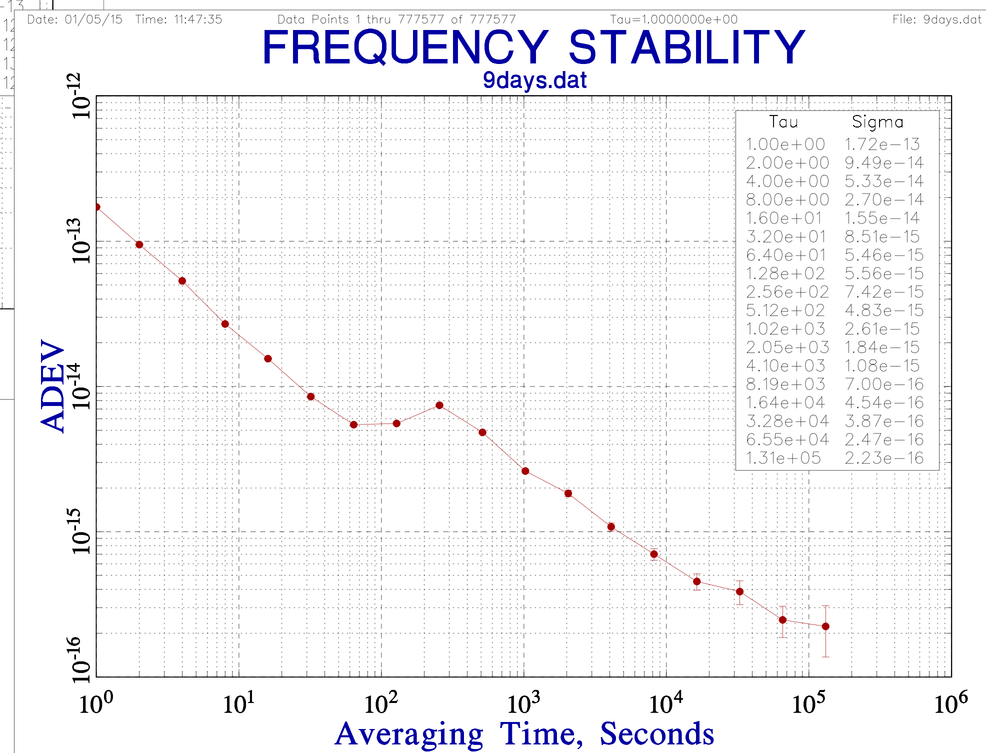
Obtained result :
Sr1: 429 228 066 418 008.3 Hz, uA = 0.9 Hz, uB = 1.9 Hz
Sr2: 429 228 066 418 007.3 Hz, uA = 0.9 Hz, uB = 2.8 Hz
Is about 10x better than previous one (2008, Katori et all.)

AOS – KL FAMO LINK

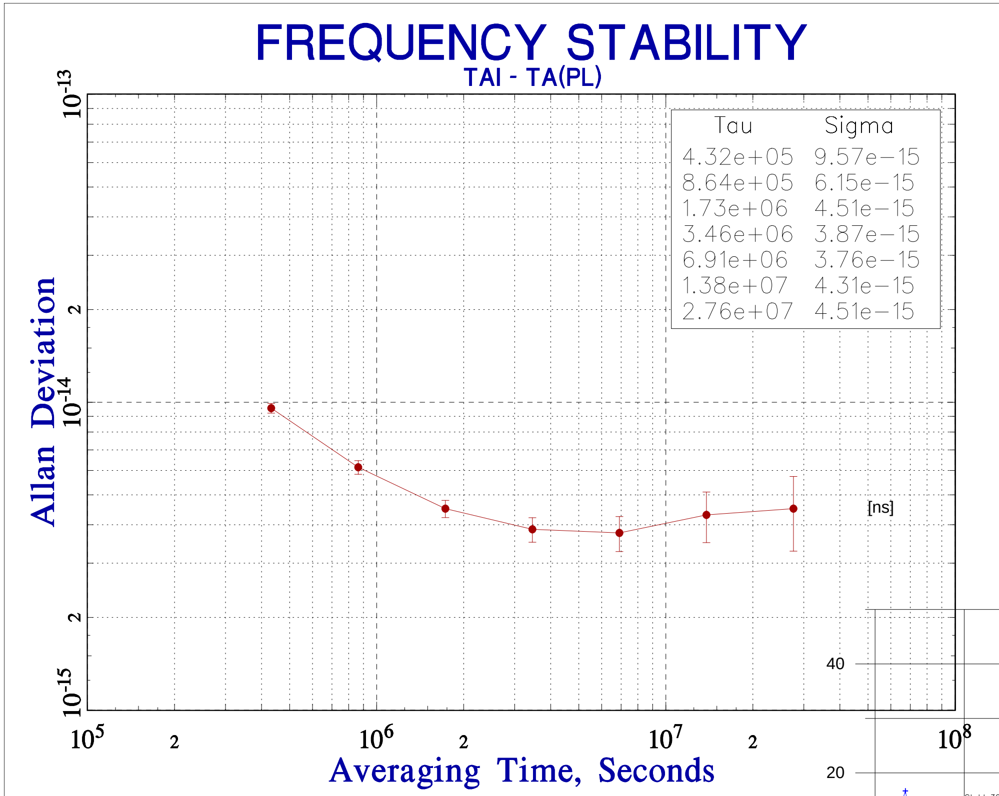


Stability of AOS – KLFAMO link, reflected at Torun 1pps signal measured at the AOS

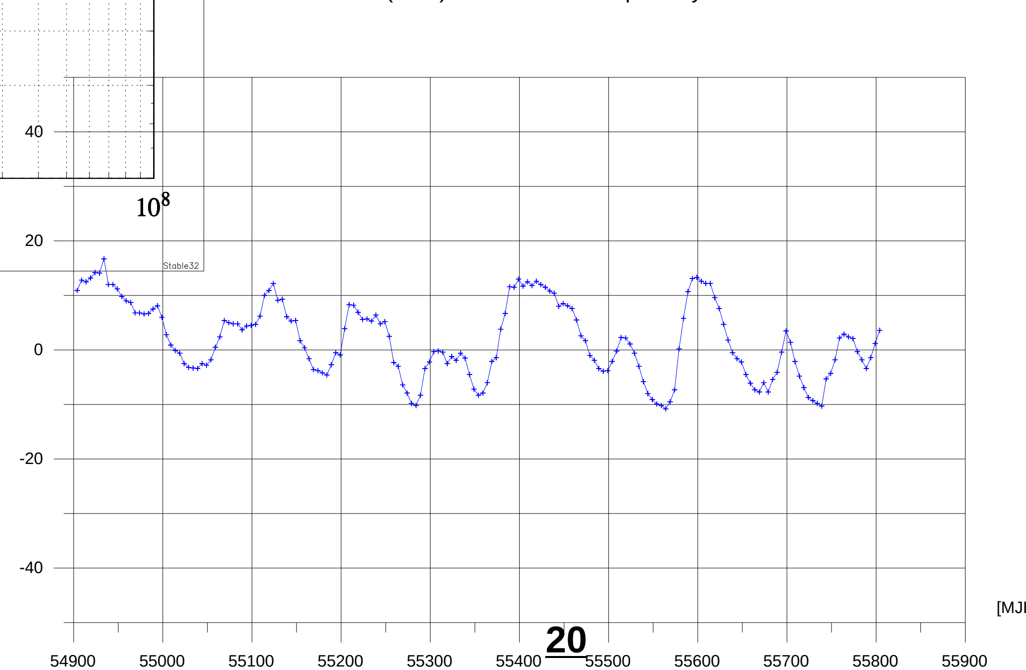




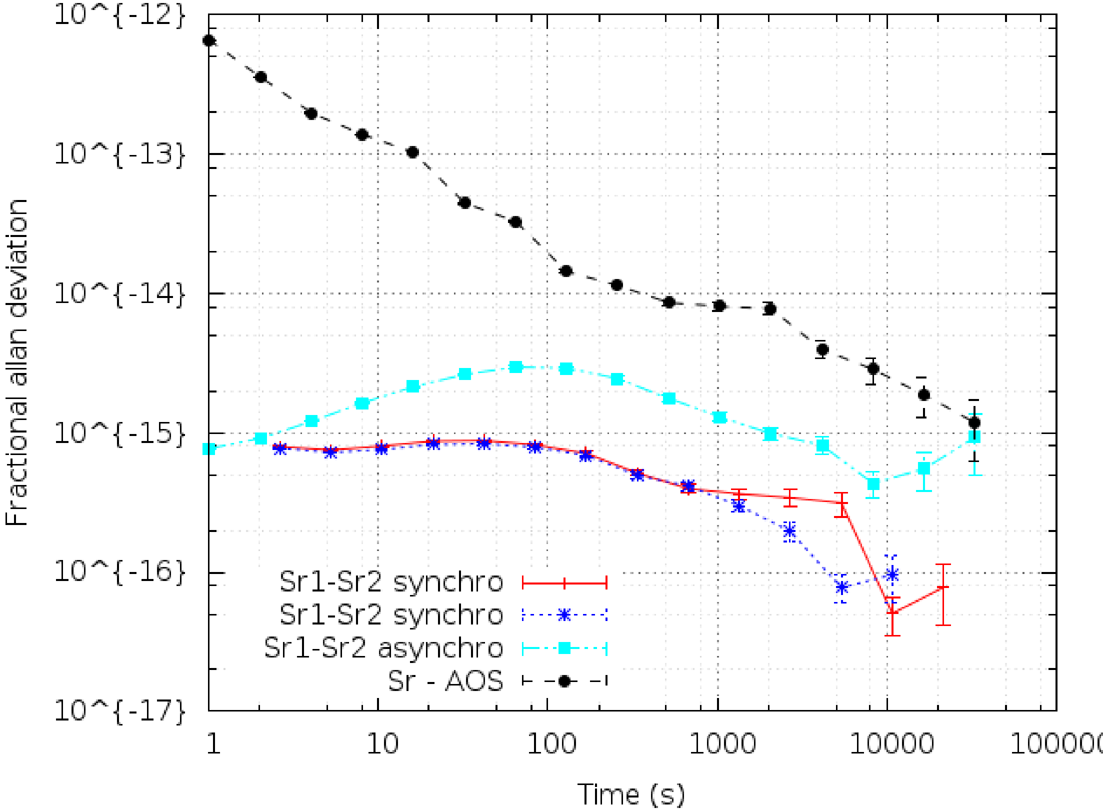
TA(PL) AND UTC(AOS)



UTC(AOS) as realized in the past 3 years



Optical Fibre Connection AOS - FAMO



Measurements at KL FAMO

ing e	2HP 5071A opt 001*	CH 1-75A opt 01**	$\sigma(\tau)$ MHM 2010**
1 s	$2e^{-12}$	$2.1e^{-13}$	$2.0e^{-13}$
10 s	$5e^{-12}$	$3.1e^{-14}$	$5.0e^{-14}$
100 s	$8.5e^{-13}$	$7.1e^{-15}$	$1.3e^{-14}$
1000 s	$2.7e^{-13}$	$2.5e^{-15}$	$3.2e^{-15}$
1 day	$2.7e^{-14}$	$7.1e^{-16}$	$3.0e^{-15}$
Long term	$5.0\ e^{-15}$	<3.0E-16	$2.0e^{-16}$
Jitter	<1.0 ns	< 0.1 ns	< 0.01 ns