CGSIC Timing Subcommittee

Introduction

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Polish Central Office of Measures
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 $[UTC_r - UTC(k)]$

– 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.
Every Wednesday before 18:00 UTC
on
ftp://tai.bipm.org/UTCr/Results/
• Long-term goal: Compare the optical clocks $\sim 10^{-18}$@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 $u_B \sim 200$ ps
  - Validate the new GNSS and TWSTFT techniques

• **New challenges**
  - the theoretical issues
  - the practical issues: data processing, format, programs …
Configuration of permanent T&F optical fibre links in Poland

- 421.4 km fiber-optic connection between Central Office of Measures (GUM) in Warsaw and the Astrogeodynamic Observatory (AOS), from 27th January 2012.

- 330 km optical line from the Astrogeodynamic Observatory (AOS) to the National Laboratory of Atomic, Molecular and Optical Physics in Torun, operational from December 2014.

- 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.

- 40 km line connected Central Office of Measures (GUM) with the Centre of Network Synchronization of Orange Polska, in Anin near Warsaw, 2015.
First Operational Optical Fibre Time Link
420 km between UTC Laboratories AOS-PL
Combined uncertainty 112 ps

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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)

FREQUENCY STABILITY

Tai - Ta(PL)

<table>
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<tr>
<th>Tau</th>
<th>Sigma</th>
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<tbody>
<tr>
<td>4.32e+05</td>
<td>9.57e-15</td>
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<tr>
<td>8.64e+05</td>
<td>6.15e-15</td>
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<tr>
<td>1.73e+06</td>
<td>4.51e-15</td>
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<tr>
<td>3.46e+06</td>
<td>3.87e-15</td>
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<td>6.91e+06</td>
<td>3.76e-15</td>
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<tr>
<td>1.38e+07</td>
<td>4.31e-15</td>
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<tr>
<td>2.76e+07</td>
<td>4.51e-15</td>
</tr>
</tbody>
</table>

Minimum         -6.1 ns
Maximum         2.0 ns
Mean              -0.971 ns
Std. dev.          1.87 ns

UTC - UTC(PTB)
UTC - UTC(USNO)
UTC - UTC(SU)
UTC - UTC(AOS)
UTC - UTC(OP)

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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

 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.)
Diagram of connections at AOS

- Active H-Maser CH1-75A
- AOG Micro-Stepper/Clock
- Freq. Distribution Amplifier
- Pulse Distribution Unit
- 6-ch. Phase Comparator
- AOS Opto-Electronic Optical Fiber Transceiver
- WAT T-4100U Universal Counter
- UTC(AOS)
- UTC(AOS) 1PPS
- UTC(AOS) 10MHz

Connections:
- Master clock
- To main AOS TTS-2, TTS-4 Time Transfer Receivers
- To AOS FAMO Optical Fiber Transceiver
- Re-transmitted ("Returned") 1PPS & 10MHz back to AOS
- Optical Fiber Connection from AOS to FAMO

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Stability of AOS – KLFAMO link, reflected at Torun 1 pps signal measured at the AOS
UTC(AOS) as realized in the past 3 years
Optical Fibre Connection  AOS - FAMO

Measurements at KL FAMO

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