48th CGSIC Meeting - Timing Subcommittee

Savannah, Georgia, 16 September 2008

Chair: Włodzimierz Lewandowski, BIPM,
Co-Chair: Victor Zhang, NIST

14:00 Introduction – Włodzimierz Lewandowski, BIPM
14:20 Report from NIST – Victor Zhang, NIST
14:40 USNO Time Service – Demetrios Matsakis, USNO
15:00 Timing operations – Wendy Kelley, USNO
15:10 Progress on time transfer calibration – Ed Powers, USNO
15:20 Break
15:40 Update on the ITU-R WP7A work on the Future of UTC
    – Tom Bartholomew (invited talk)
16:00 Time and Navigation Exhibition at the Smithsonian: An Update
    – Andrew Johnston, National Museum of American History
16:20 Discussion
17:20 Session End
AREAS BEING SERVED

- International Atomic Time (TAI) and UTC
- International Timing Centers
- Global Navigation Satellite Systems
- Telecommunications Industries
- NASA/JPL Deep Space Network
- NIST Global Time Service
- Power Grids and other Industries
- As Research and Comparison Tool
- Other
Outline of presentation

- International time comparisons
  - Uncertainties
  - Upcoming techniques
  - Glonass and Galileo
- Time scales for satellite navigation systems
  - Leap second
  - ICG Recommendation
Methods now in use

<table>
<thead>
<tr>
<th>Method</th>
<th>$uA/\text{ns}$</th>
<th>$uB/\text{ns}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS C/A-code SCH</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>GPS C/A-code MCH</td>
<td>1.5</td>
<td>5.0</td>
</tr>
<tr>
<td>GPS P3 (geod. receiv.)</td>
<td>0.7</td>
<td>5.0</td>
</tr>
<tr>
<td>TWSTFT</td>
<td>0.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*IGS precise orbits and iono maps applied for GPS
48th CGSIC - Timing Subcommittee

Laboratory equipped with TWSTFT (not yet used)

- TWSTFT by Ku band with X band back-up
- TWSTFT link
- GPS single-channel link
- GPS single-channel back-up link
- GPS multi-channel link
- GPS multi-channel back-up link
- GPS dual frequency link
- GPS dual frequency back-up link

Organization of the Common-View International Time

August 2006
BIPM CALIBRATIONS OF
GPS/GLONASS C/A-code and P-code
TIME EQUIPMENT
BIPM differential calibrations of GPS/GLONASS

C/A-code and P-code time equipment

Uncertainty for GPS C/A-code 3 ns (1 $\sigma$)

- In 2004/2006 six campaigns were carried out
  - 2004: OP, PTB, NPL, VSL
  - 2005: OP, NTSC, HKO, TL, SG, AUS, KRIS, NMIJ, NICT
  - 2005: OP, TCC, ONBA, IGMA, CNMP
  - 2006: OP, CNM, NIST, USNO, NRC
  - 2006: BIPM, OP, PTB, AOS, USNO, NRL, CSIR (ongoing)
  - 2006: OP, AOS, GUM, LT, TP, BEV, OMH, NIMB, NMC, ZMDM
- In total 20 laboratories out of the 50 that contributes to TAI have been calibrated, and additional 10 will be this autumn.
### PTB

<table>
<thead>
<tr>
<th>Date</th>
<th>UTC(i)–UTC(j)</th>
<th>Differential correction</th>
<th>Estimated uncertainty</th>
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<tbody>
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<td>Oct 86</td>
<td>UTC(PTB) – UTC(OP)</td>
<td>+9</td>
<td>2</td>
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<td>Oct 94</td>
<td>UTC(PTB) – UTC(OP)</td>
<td>+4</td>
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<td>+2</td>
<td>3</td>
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<td>Nov 97</td>
<td>UTC(PTB) – UTC(OP)</td>
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<td>2</td>
</tr>
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<td>Mar 98</td>
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<td>2</td>
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<td>June 98</td>
<td>UTC(PTB) – UTC(OP)</td>
<td>+5</td>
<td>3</td>
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<tr>
<td>June 03</td>
<td>UTC(PTB) – UTC(OP)</td>
<td>–5</td>
<td>4</td>
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<td>August 03</td>
<td>UTC(PTB) – UTC(OP)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>July 04</td>
<td>UTC(PTB) – UTC(OP)</td>
<td>0</td>
<td>3</td>
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</table>
BIPM calibrations

- BIPM will continue its GPS/GLONASS C/A-code/P-code calibration campaigns; a new TTS-3 receiver is now dedicated for this purpose.

- Two new BIPM calibrations campaigns are now ongoing.

- BIPM will continue to help the regional metrology organizations to organize GPS/GLONASS calibration campaigns.
## CIRCULAR T 223
2006 AUGUST 10, 14h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES

<table>
<thead>
<tr>
<th>Date 2006 0h UTC</th>
<th>MJD</th>
<th>Laboratory k</th>
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<td></td>
<td>JUN 28</td>
<td>JUL 3</td>
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<tr>
<td></td>
<td>53914</td>
<td>53919</td>
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### Uncertainty/ns

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>UTC-UTC(k)/ns</th>
<th>uA</th>
<th>uB</th>
<th>u</th>
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<tr>
<td>AOS (Borowiec)</td>
<td>5.2</td>
<td>9.3</td>
<td>3.3</td>
<td>6.2</td>
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<td>-0.7</td>
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<td>-490.1</td>
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<td>-1898.2</td>
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<td>CH (Bern)</td>
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<td>31.3</td>
<td>36.1</td>
<td>32.2</td>
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<td>-4.6</td>
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<td>KRIJ (Daejeon)</td>
<td>-14.6</td>
<td>-5.4</td>
<td>-4.0</td>
<td>-8.2</td>
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<tr>
<td>LT (Vilnius)</td>
<td>147.0</td>
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<td>145.7</td>
<td>138.2</td>
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<td>-3.9</td>
<td>-2.7</td>
<td>-6.4</td>
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<tr>
<td>NIST (Boulder)</td>
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<td>8.3</td>
<td>9.2</td>
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<td>NMIIJ (Tsukuba)</td>
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<td>-8.1</td>
<td>-8.3</td>
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<td>NPL (Teddington)</td>
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<td>4.9</td>
<td>5.2</td>
<td>3.4</td>
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<td>154.2</td>
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<td>7.1</td>
<td>5.1</td>
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<td>7568.6</td>
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<td>2.0</td>
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<td>-3.9</td>
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<td>PL (Warszawa)</td>
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<td>9.0</td>
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<td>17.2</td>
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<td>63.4</td>
<td>67.0</td>
<td>61.3</td>
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<td>SP (Boras)</td>
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<td>20.1</td>
<td>24.1</td>
<td>25.5</td>
</tr>
<tr>
<td>SU (Moskva)</td>
<td>48.1</td>
<td>45.3</td>
<td>45.7</td>
<td>43.6</td>
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<tr>
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<td>-3.1</td>
<td>-3.8</td>
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<td>USNO (Washington DC)</td>
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<td>-0.3</td>
<td>2.9</td>
<td>3.9</td>
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<tr>
<td>VSL (Delft)</td>
<td>5.6</td>
<td>10.8</td>
<td>5.1</td>
<td>4.3</td>
</tr>
</tbody>
</table>
CCTF-K001.UTC  Calculation of UTC

Degrees of equivalence: [UTC - UTC(k)] and its expanded uncertainty (U_k = 2u_k)

Computed values for 30 November 2007 at 0h UTC, MJD = 54434

Red diamonds: direct values [UTC - UTC(k)]
Black squares: [UTC - UTC(k)] values taken modulo 100 ns
Open symbols represent values for laboratories in Associate States and Economies of the CIPM
UTC – UTC(i)
New Developments

- Melting pot / all-in-view with IGS time
- Use of Glonass P-code
- Use of SBAS (WAAS, EGNOS, …)
- New generations of TWSTFT
- Improvements in use of geodetic receivers
- GPS carrier-phase
- Use of geodetic techniques (PPP)
- Real-time (challenge for Galileo and in future for BIPM)
TIME SCALES
FOR SATELLITE NAVIGATION SYSTEMS

- Change in the definition of international time scales
  - UTC
  - TAI
  - Leap second

- Relation between satellite time scales
  - GPS time
  - Glonass time
  - Galileo system time
[TAI - Time scale(i)]
[TAI - Time scale (i)]

![Graph showing the comparison of TAI, UTC, GLONASS time, GPS time, and GALILEO time over the years.](image-url)
ICG Draft Recommendation

International Committee on Global Navigation Satellite Systems (ICG)

considering
- the international value of having many GNSS operational with a composite contribution of several tens of satellites,
- the desirability of using all systems interchangeably,
- the use by GPS of references very close to UTC and ITRF,
- the GLONASS efforts to approach UTC and ITRF,
- the Galileo design referring to UTC and ITRF,
- that other important satellite navigation systems are now being designed and developed*),

recommends
- that the reference times (modulo 1 s) of satellite navigation systems be synchronized as closely as possible to UTC,
- that the reference frames for these systems be in conformity with the ITRF,
- that these systems broadcast, in addition to their own System Time (ST):
  1. the time difference between ST and a real-time realization of UTC,
  2. a prediction of the time differences between ST and UTC.

*) Compass, IRNSS, QZSS, various SBAS, …

48th CGSIC - Timing Subcommittee
ITU meeting on redefinition of UTC
Geneva, 6 -10 October 2008
To avoid proliferation of time scales ITU plans to stop application of leap seconds to UTC

- October 2008: ITU Working Party 7A will submit to ITU Study Group 7 project recommendation on stopping leap second
- During 2009 Study Group 7 will conduct a vote through mail among member states
- 2011: if 70% member states agree World Radio Conference will approve recommendation
- 2013: application of leap second will stop and UTC will become a continuous time scale
Louis Essen:

“…… In 1960s there was a suggestion that astronomical time should be used for sea navigation and domestic purposes, and atomic time for air navigation and scientific work. My experiences with time signals and standard frequency transmissions convinced me that this would cause endless confusion as well as involving duplication of equipment and I argued strongly that a method of combining all the information in one set of transmission must be found…..”
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