Realization and maintenance of UTC

Elisa Felicitas Arias

Director

BIPM Time Department

ITU/BIPM Workshop on the future of the international time scale

Geneva, 19-20 September 2013
Responsibilities in the establishment and realization of the international reference time scale UTC

The concept of traceability in metrology

The various time scales; characteristics

Maintenance and dissemination of UTC

Opinion of the CCTF y CIPM on the future of the international time scale

Considerations for the future
Bureau international des poids et mesures
International Bureau of Weights and Measures (BIPM)

Organisation intergouvernementale
dont le siège est à Sèvres, France
Intergovernmental Organization
with headquarters located in Sèvres, France

États membres du BIPM
BIPM’s Member States

Conférence générale des poids et mesures
General Conference on Weights and Measures (CGPM)
Elle rassemble les délégués des États membres et se réunit tous les quatre ans.
Consists of delegates from Member States and meets every four years.

Comité international des poids et mesures
International committee for Weights and Measures (CIPM)
Il est constitué de dix-huit membres, élus à titre personnel par la Conférence générale. Il est chargé de superviser le BIPM et ses activités. Il se réunit tous les ans au siège du BIPM.
Consists of eighteen individuals elected by the CGPM. It is charged with the supervision of the BIPM and its activities. The CIPM meets annually at the BIPM’s headquarters.

Siège
Headquarters
Direction, laboratoires et membres du personnel permanent du BIPM.
Direction, laboratories and permanent staff members of the BIPM.

Consultative Committee for Time and Frequency (CCTF)

Members:
- National Metrology Institutes and others
- ITU-R
- IAU
- IUGG
- IGS
- URSI

CGPM
Diplomatic Treaty of the Metre Convention

55 Member States of BIPM
38 Associates

Convention du Mètre
Traité
Metre Convention
Treaty
1875
Responsibilities on time scales

General Conference on Weights and Measures (CGPM)
- Defined the second – 1967
- Adopted International Atomic Time (TAI) - 1971
- Endorsed Coordinated Universal Time (UTC) – 1975

International Telecommunication Union (ITU)
- Fixes de rules for t&f dissemination by signals
- Rec ITU-R TF.460-6 (describes the process for synchronizing UTC to UT1 better than 0.9 s)
Responsibilities on time scales (cont.)

International Bureau of Weights and Measures (BIPM)
- Calculates UTC based on data provided by ~ 70 institutes world-wide spread
- Coordinates activities for accomplishing this mandate

International Earth Rotation and Reference Systems Service (IERS)
- Monitors the rotation of the Earth and provides EOP
- Announces the dates of application of leap seconds

National institutes (72)
- Maintain local approximations to UTC (UTC(k))
- Broadcast UTC(k)
The concept of metrological traceability

A National Metrology Institute (...) can establish traceability to the SI via a primary realization or representation of the unit of measurement concerned ...

In the case of the SI second and the reference time scale UTC, the key comparison CCTF K-001.UTC gives traceability to the SI to the atomic time scales maintained in the participant laboratories.

The time scales maintained by this laboratories are considered the unique representations of UTC, and are designed as UTC(k).
UTC Participating laboratories
(April 2013)
Unit, time scale

- Unit of time: SI second
- Measuring time intervals:
  - Time scale
- Unitary interval of a time scale traceable to the SI
  - SI second
- Unique definition of a unit (i.e. the SI second)
- Unique reference time scale
  - CIPM (2012)
The various time scales

International Atomic Time (TAI)
- Continuous
- Interval unit is the SI second
- Calculated monthly at BIPM
- No clock representation, no broadcast
- 1-second discontinuities
- Interval unit is the SI second
- Calculated monthly at BIPM, derived from TAI

Coordinated Universal Time (UTC)
- Traceable to UTC via monthly BIPM Circular T
- Clock representation
- Broadcast
- Basis of legal times

Local representations UTC(\(k\))
- Coordinate times
- Related to TAI
- No clock representation
- No broadcast

Other time scales (scientific, space navigation, etc)
UTC

- Coordinated
  - Coordinated broadcast of time signals at laboratories (ITU-R)
- Universal
  - Time for the entire Earth, universality of the time scale
- Time
  - TAI differs from UTC in an integral number of seconds (35 until July 2014 at least)

Leap second announcement is the responsibility of the IERS

- GMT (Greenwich Mean Time) was replaced by UT in 1948 (IAU)
- UT was replaced by UTC in 1972
Each month:

~70 participants

ftp server

~400 clocks,
one measurement / 5 days, t&f corr.
monthly

13 primary freq. standard data
monthly

~180 time transfer files
daily, weekly, (monthly)

Data submission deadline
4/mm/yy/

Datation is in « Modified Julian Date », a continuous count of days since an arbitrary origin
Elaboration of TAI and UTC - ALGOS

≈ 420 atomic clocks in ≈ 70 laboratories

13 primary frequency standards

Measurement of Earth’s rotation (IERS)

“average”

“steering”

“leap seconds”

Echelle Atomique Libre
Freq stability 0.4 x 10^{-15} @30-40 days

Temps Atomique International
Freq accuracy ~10^{-16}

UTC

BIPM Circular T

[UTC - UTC(k)]
## Traceability of UTC(k) to UTC

**BIPM Circular T**

### Table: UTC-UTC(k) values and uncertainties (ns)

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>MJD 56504</th>
<th>MJD 56509</th>
<th>MJD 56514</th>
<th>MJD 56519</th>
<th>MJD 56524</th>
<th>MJD 56529</th>
<th>MJD 56534</th>
<th>Uncertainty/ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOS (Borowiec)</td>
<td>-1.2</td>
<td>-3.1</td>
<td>-3.4</td>
<td>-4.1</td>
<td>-4.0</td>
<td>-3.9</td>
<td>-2.2</td>
<td>0.3</td>
</tr>
<tr>
<td>APL (Laurel)</td>
<td>2.2</td>
<td>2.3</td>
<td>3.4</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>2.6</td>
<td>0.3</td>
</tr>
<tr>
<td>AUS (Sydney)</td>
<td>282.7</td>
<td>267.8</td>
<td>260.6</td>
<td>257.6</td>
<td>256.9</td>
<td>251.4</td>
<td>249.7</td>
<td>0.3</td>
</tr>
<tr>
<td>BEV (Wien)</td>
<td>49.8</td>
<td>51.2</td>
<td>58.4</td>
<td>60.6</td>
<td>65.0</td>
<td>47.0</td>
<td>39.0</td>
<td>0.3</td>
</tr>
<tr>
<td>BIM (Sofiya)</td>
<td>367.3</td>
<td>386.8</td>
<td>378.6</td>
<td>395.2</td>
<td>401.6</td>
<td>405.1</td>
<td>405.8</td>
<td>1.5</td>
</tr>
<tr>
<td>BIRM (Beijing)</td>
<td>227.8</td>
<td>226.6</td>
<td>226.8</td>
<td>223.7</td>
<td>226.9</td>
<td>231.5</td>
<td>234.0</td>
<td>1.5</td>
</tr>
<tr>
<td>BY (Minsk)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CAO (Cagliari)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CH (Bern-Wabern)</td>
<td>10.1</td>
<td>11.5</td>
<td>12.5</td>
<td>10.4</td>
<td>13.8</td>
<td>16.5</td>
<td>18.7</td>
<td>0.3</td>
</tr>
<tr>
<td>CNM (Queretaro)</td>
<td>-6.4</td>
<td>-8.8</td>
<td>-10.1</td>
<td>-12.1</td>
<td>-16.1</td>
<td>-18.3</td>
<td>2.0</td>
<td>5.2</td>
</tr>
<tr>
<td>CNMP (Panama)</td>
<td>16.3</td>
<td>17.7</td>
<td>31.9</td>
<td>20.7</td>
<td>9.9</td>
<td>17.5</td>
<td>30.1</td>
<td>3.5</td>
</tr>
<tr>
<td>DLR (Oberpfaffenhofen)</td>
<td>-18.1</td>
<td>-20.8</td>
<td>-27.4</td>
<td>-32.2</td>
<td>-26.8</td>
<td>-14.2</td>
<td>-7.2</td>
<td>0.7</td>
</tr>
<tr>
<td>DDOM (Belgrade)</td>
<td>20.8</td>
<td>15.3</td>
<td>16.3</td>
<td>23.1</td>
<td>30.6</td>
<td>18.4</td>
<td>8.1</td>
<td>0.3</td>
</tr>
<tr>
<td>DTAG (Frankfurt/M)</td>
<td>337.1</td>
<td>337.6</td>
<td>336.9</td>
<td>333.7</td>
<td>330.8</td>
<td>325.8</td>
<td>329.2</td>
<td>0.3</td>
</tr>
<tr>
<td>EIM (Thessaloniki)</td>
<td>7.3</td>
<td>16.3</td>
<td>10.9</td>
<td>6.1</td>
<td>6.5</td>
<td>-3.9</td>
<td>0.0</td>
<td>4.5</td>
</tr>
<tr>
<td>ESTC (Noordwijk)</td>
<td>-5.2</td>
<td>-5.5</td>
<td>4.8</td>
<td>-1.3</td>
<td>0.0</td>
<td>0.9</td>
<td>2.3</td>
<td>0.3</td>
</tr>
<tr>
<td>HKO (Hong Kong)</td>
<td>1649.3</td>
<td>445.6</td>
<td>443.8</td>
<td>436.3</td>
<td>432.6</td>
<td>426.7</td>
<td>430.8</td>
<td>1.0</td>
</tr>
<tr>
<td>IFAG (Wetzell)</td>
<td>-695.6</td>
<td>-704.0</td>
<td>-713.6</td>
<td>-714.8</td>
<td>-720.8</td>
<td>-737.5</td>
<td>-747.9</td>
<td>0.3</td>
</tr>
<tr>
<td>IGNA (Buenos Aires)</td>
<td>2868.5</td>
<td>2962.6</td>
<td>3064.0</td>
<td>3162.3</td>
<td>3259.1</td>
<td>3365.1</td>
<td>3464.0</td>
<td>2.0</td>
</tr>
<tr>
<td>INPL (Jerusalem)</td>
<td>43.4</td>
<td>37.2</td>
<td>35.1</td>
<td>34.0</td>
<td>40.7</td>
<td>34.2</td>
<td>0.7</td>
<td>19.9</td>
</tr>
<tr>
<td>INTI (Buenos Aires)</td>
<td>28.4</td>
<td>63.6</td>
<td>82.8</td>
<td>47.7</td>
<td>38.2</td>
<td>17.0</td>
<td>11.7</td>
<td>2.5</td>
</tr>
<tr>
<td>INXE (Rio de Janeiro)</td>
<td>4.4</td>
<td>0.4</td>
<td>-0.9</td>
<td>-0.5</td>
<td>0.3</td>
<td>-4.7</td>
<td>3.4</td>
<td>0.3</td>
</tr>
<tr>
<td>IPQ (Caparica)</td>
<td>6.8</td>
<td>7.3</td>
<td>-7.6</td>
<td>-9.7</td>
<td>-11.0</td>
<td>-12.5</td>
<td>-12.8</td>
<td>0.3</td>
</tr>
<tr>
<td>IT (Torino)</td>
<td>11.5</td>
<td>15.9</td>
<td>15.7</td>
<td>12.2</td>
<td>5.1</td>
<td>3.4</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>JATC (Lintong)</td>
<td>488.6</td>
<td>477.0</td>
<td>471.1</td>
<td>497.3</td>
<td>488.4</td>
<td>465.2</td>
<td>489.8</td>
<td>5.0</td>
</tr>
<tr>
<td>JN (Kjeller)</td>
<td>1.4</td>
<td>4.5</td>
<td>-7.5</td>
<td>-10.0</td>
<td>-10.7</td>
<td>-11.0</td>
<td>-8.8</td>
<td>0.3</td>
</tr>
<tr>
<td>KBS (Nairobi)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>KIM (Serpung-Tangerang)</td>
<td>634.7</td>
<td>643.2</td>
<td>679.8</td>
<td>710.5</td>
<td>741.6</td>
<td>754.6</td>
<td>754.6</td>
<td>2.0</td>
</tr>
<tr>
<td>KRIS (Daejeon)</td>
<td>-1.4</td>
<td>-4.5</td>
<td>-7.5</td>
<td>-10.0</td>
<td>-10.7</td>
<td>-11.0</td>
<td>-8.8</td>
<td>0.3</td>
</tr>
<tr>
<td>KZ ( Astana)</td>
<td>2347.8</td>
<td>2301.1</td>
<td>2249.8</td>
<td>2188.4</td>
<td>2141.3</td>
<td>2078.2</td>
<td>2025.9</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**ISSN 1143-1393**

Bureau International des Poids et Mesures
Relations between UTC and time scales and system times broadcast by GNSS

Predictions of: UTC(USNO) ; UTC(SU) – differ from UTC by a few ns and hundreds of ns, respectively

GPStime – offset from UTC by 16 s + few ns, offset changing (leap second insertion)

GLONASSStime – 0 ns offset from UTC + hundreds of ns

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>UTC</th>
<th>MJD</th>
<th>C0/ns</th>
<th>N0</th>
<th>C0'/ns</th>
<th>N0'</th>
<th>C1/ns</th>
<th>N1</th>
<th>C1'/ns</th>
<th>N1'</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>JUL</td>
<td>0.3</td>
<td>88</td>
<td>1.4</td>
<td>88</td>
<td>-172.9</td>
<td>89</td>
<td>-361.8</td>
<td>89</td>
<td>-361.8</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>-0.1</td>
<td>86</td>
<td>-2.3</td>
<td>86</td>
<td>171.8</td>
<td>89</td>
<td>361.0</td>
<td>89</td>
<td>361.0</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>0.2</td>
<td>89</td>
<td>-0.2</td>
<td>89</td>
<td>173.1</td>
<td>88</td>
<td>363.0</td>
<td>89</td>
<td>363.0</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>0.2</td>
<td>89</td>
<td>-0.2</td>
<td>89</td>
<td>172.1</td>
<td>89</td>
<td>362.9</td>
<td>89</td>
<td>362.9</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>0.0</td>
<td>90</td>
<td>-2.0</td>
<td>90</td>
<td>169.3</td>
<td>89</td>
<td>361.2</td>
<td>89</td>
<td>361.2</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>0.4</td>
<td>89</td>
<td>1.4</td>
<td>89</td>
<td>170.2</td>
<td>84</td>
<td>363.2</td>
<td>87</td>
<td>363.2</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>0.1</td>
<td>89</td>
<td>0.6</td>
<td>89</td>
<td>169.7</td>
<td>87</td>
<td>362.2</td>
<td>87</td>
<td>362.2</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>1.2</td>
<td>89</td>
<td>2.2</td>
<td>89</td>
<td>168.1</td>
<td>89</td>
<td>360.7</td>
<td>89</td>
<td>360.7</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>AUG</td>
<td>2.4</td>
<td>89</td>
<td>2.5</td>
<td>89</td>
<td>168.4</td>
<td>90</td>
<td>360.2</td>
<td>90</td>
<td>360.2</td>
<td>90</td>
</tr>
</tbody>
</table>
The CCTF has discussed at its meeting on 13-14 September 2012 the feasibility of achieving a continuous reference time scale and made a recommendation to the International Committee on Weights and Measures (CIPM) which met on 18-19 October 2012. The CIPM considered the matter and concluded that

1. a continuous time scale is indeed achievable, and it has been realized and maintained by the BIPM (TAI);
2. a continuous reference time scale corresponds to UTC without leap second discontinuities;
3. the concepts of continuity and uniformity should be applied strictly in a reference time scale;
4. the unit for any quantity in metrology is unique, and as such, a single time scale shall also be unique;
5. in the event of a redefinition of any quantity in metrology, the unit should be invariant, and particularly for the second of the International System of Units (SI) the respective scale shall be continuous and uniform;

6. the name “Coordinated Universal Time (UTC)” should be retained for a new continuous time scale based on a redefinition of UTC without leap second adjustments;

7. the International Earth Rotation and Reference Systems Service (IERS) provides a means of accessing UT1 in real-time by means of routinely available predictions of UT1 - UTC with high precision

8. a wider dissemination of UT1 - UTC should be encouraged;
Consequences of stopping the insertion of leap seconds in UTC

✓ UTC will have no more discontinuities;

✓ UTC and TAI will differ in a constant offset,
  ✓ CCTF, then CIPM and finally CGPM could decide on suppressing TAI;

✓ Continuous system times and time scales created for avoiding the discontinuities of the present UTC will have constant offsets wrt UTC;

✓ Broader dissemination of the values of UT1-UTC, enhancing the role of the IERS.
Thanks for your attention!