Report of the IGS Clock Products Working Group

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IGS Combined Clock Products

- IGS Analysis Centers contributing clocks since Nov. 2000:
  - CODE Center for Orbit Determination in Europe, AIUB, Switzerland
  - ESOC European Space Operations Center, ESA, Germany
  - GFZ GeoForschungsZentrum, Germany
  - JPL Jet Propulsion Laboratory, USA
  - NRCan Natural Resources Canada, Canada
  - USNO‡ U.S. Naval Observatory, USA
  - MIT† Mass. Institute of Technology, USA

- 5-minute intervals for all satellites & ~175 stations
- Supports global autonomous PPP
  - cm-level positioning/dissemination of IG(R)ST
  - dissemination of UTC < 50 ns
- Final, Rapid, & Ultra-Rapid products w/ latencies of 13 d to 3 h
- IGS Reanalysis underway 2006/2007
  - will reanalyze data back to 1994
  - clock densification a high priority
  - PPP using IGS products still an option for obtaining geodetic estimates for non-combination or non-IGS stations

‡Rapids & Ultra-rapids only †Finals only
## IGS High Performance Clocks

### Time Labs

<table>
<thead>
<tr>
<th>IGS Site</th>
<th>Time Lab</th>
<th>Freq. Std.</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td>AMC2</td>
<td>AMC</td>
<td>H-Maser</td>
<td>Colorado Springs, CO USA</td>
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<td>BOR1</td>
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<td>Rubidium</td>
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</table>

- masers (54)  ⭐️ time lab stations (25)
- cesiums (32)
- rubidiums (27)

+ GPS space clocks …
IGS Timescales (cont.)

• Kalman continuous filter implementation
  – formulated as a frequency ensemble
  – deterministic models for rates & drifts
  – process noise capabilities: WHFM, RWFM, RRFM,
  – inputs from ~54 H-maser, 32 Cs, & 27 Rb clocks
  – ~25 stations at timing labs
• Can support IGS move to real-time operations
• Instability \( \sim 1 \times 10^{-15} \) at 1 d
• Suffers in longer term by steering to GPS Time
• Implemented for Final (IGST) & Rapid (IGRT) clocks
• Has run autonomously since 2001, officially adopted in 2003 as reference for IGS Rapid & Final Combined Clock Products

• New Kalman filter implementation (adaptive parameter estimation)
  – filters clock difference measurements, separating phase, freq., and drift shocks as well as fixed-phase sinusoid (WHPM, WHFM, RWFM, & RRFM capable)
  – Utilizes separate set of weights for each filter state
    • set of phase weights optimized for masers
    • set of frequency weights optimized for cesiums
  – LQG multiple-input steering filter utilizing (calibrated) IGS stations colocated at time labs (UTC(k) realizations)
  – Development complete, testing underway
“in situ” Calibration Technique

\[ B_i = \text{CLK}_i - \text{UTC}_i \]

\[ \begin{align*}
\text{CLK}_i & = \text{GPS geodetic clock estimates at lab } i \\
\text{UTC}_i & = \text{local realization of UTC for lab } i 
\end{align*} \]

STATION CALIBRATION BIAS: includes internal GPS receiver/antenna calibration bias & intra-lab offset to UTC

From IGS clock products & BIPM Circular T, can compute:

\[ B'_i = (\text{CLK}_i - \text{GPST})_{\text{IGS}} - (\text{UTC} - \text{GPST})_{\text{T}} + (\text{UTC} - \text{UTC}_i)_{\text{T}} \]
\[ = (\text{CLK}_i - \text{UTC}_i) + (\text{GPST}_{\text{T}} - \text{GPST}_{\text{IGS}}) \]
\[ = B_i + \Delta\text{GPST} \]

Method good to \( \sim 2 \) ns

Small corrections due to different methods of observing GPS time

Senior K., Ray J., Petit G., EFTF 2004
• IGS timescales also useful as valuable station performance feedback to station operators via new time transfer performance measure

*updated weekly at*
https://goby.nrl.navy.mil/IGStime/daybdy/
Clock RINEX Format

a. "RINEX VERSION / TYPE" header changed to 3.00 and to add satellite system
designator.
b. "PGM / RUN BY / DATE" header date format elaborated.
c. "SYS / # / OBS TYPES" header added.
d. Added Galileo and Space-Based Augmentation System (SBAS) satellite designators
   in Section 5.
e. "TIME SYSTEM ID" header added.
f. The satellite antenna phase center offset information has been moved from a
   mandatory comment to the "SAT ANT PCO / PCV" header and now includes the
   associated phase center variation information also. It is expected that an external
   file will be referenced.
g. "SYS / DCBS APPLIED" header added. [NOTE: The format -- taken from RINEX 3.00
   is not adequate to give DCBs for each satellite. Further changes are under
   discussion.]
h. Capability of handling inter-system timing biases (possibly as a new type of CR data
   record) are under consideration.

To view the pending revised version, please see:
ftp://www.ngs.noaa.gov/dist/jimr/rinex_clock.30aug06 Send any comments to me
and Werner Gurtner (werner.gurtner@aiub.unibe.ch).
CANVAS Software

Clock ANalysis Visualization & Archiving Software

- NRL contribution through IGS Clock Products working group
- Built on Matlab®, though binaries available not requiring Matlab
- Source code available
- Standard Clock time & frequency domain measures
- Clock simulation
- Interactive Visualization (zooming)
- Opportunity to contribute/help with further development
- Download at https://goby.nrl.navy.mil/canvas/

Matlab is a registered trademark of the Mathworks Inc. This does not constitute an endorsement by the U.S. Navy of Mathworks products