Complete Relativistic Modelling of the GIOVE-B clock parameters and its impact on POD, track-track ambiguity resolution and precise timing

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Introduction

• Complete Relativistic Modelling of GIOVE-B Clock

• Track-to-Track Phase Clock Ambiguity Resolution
Periodic relativistic IGS correction (eccentricity of the orbit):

\[ \Delta t_{\text{per}} = -\frac{2}{c^2} \sqrt{a \cdot GM} \cdot e \cdot \sin E \]

\[ \Delta t_{\text{per}} = -\frac{2\vec{r} \cdot \vec{v}}{c^2} \]
Relativistic clock time transformation:

\[
\frac{dT_{sv}}{dt} = 1 - \left[ V(x, y, z) - W_0 + \Delta V(x, y, z) + \frac{v^2}{2} \right] / c^2
\]

Satellite \rightarrow \text{Central gravity term} \rightarrow J_2

Ground (Equator, TT)

In addition:
Motion of the satellite and station in baricentric frame (TCB terms)
Lunisolar potential (Sun and Moon)

\[
TCB - TCG = c^{-2} \left[ \int_{t_0}^{t} \left( \frac{v_E^2}{2} + w_{0ext}(x_E) \right) dt + v_E^i r_E^i \right] \\
- c^{-4} \left[ \int_{t_0}^{t} \left( -\frac{1}{8} v_E^4 - \frac{3}{2} v_E^2 w_{0ext}(x_E) + 4 v_E^i w_{ext}(x_E) + \frac{1}{2} w_{0ext}(x_E) \right) dt \\
- (3 w_{0ext}(x_E) + \frac{v_E^2}{2}) v_E^i r_E^i \right],
\]
GIOVE-B Passive H-Maser - Performance

GIOVE-B Clock Estimation

Estimated GIOVE-B clock shows peak-to-peak error of 30-40 cm (1 ns) over orbit period.

GIOVE-B clock parameter estimated every 5-min using standard IGS relativity model (23 stations GESS+CONGO)

Agreement is fantastic!
GIOVE-B Passive H-Maser - Performance

SLR Validation

SLR Residuals and Estimated Clock Parameters (30 s)

GIOVE-B Clock After Removing Clock Drift

- Estimated Clock
- New Model
- SLR residuals, RMS=5.43 cm

Agreement with SLR is fantastic!
GIOVE-B Clock vs. SLR

SLR Residuals and Estimated GIOVE-B Clock Parameters (30 s)

Agreement GIOVE-B clock and SLR is fantastic (a few cm)!!!
GPS Radial Orbit Error and Clock Simulation

Estimated clock nicely measures simulated radial orbit error

Simulated radial orbit error

Estimated GPS clock
Clock stability is fantastic!

Overlapping ADEV – sampling 30 s

GIOVE-B PHM Allan Deviation

- Complete Relativity
- Standard Relativity
- PHM specs

Dominant orbit error
GIOVE-B clock drift still needs to be corrected by one order of magnitude of the entire effect!

Test of General Relativity: **161 ppm**
Comparable to GP-A (slightly better)!

Total effect: Special + General Relativity: **51 ppm**
Direct Phase Clock Ambiguity Resolution
EFTF 2006 and EGU 2007

Clock comparison using Phase Clocks

WSRT-USNO Clock difference, day 196/2003

WSRT-USNO Clock difference after removing bias/drift, STD=0.032 ns

Impact of the ambiguity resolution on Coordinates

Only phase clocks estimated. Troposphere (TZD), station coord., EOPs, etc., fixed to IGS

Poor performance in fixing (≈20%) due to low number of fixed MW ambiguities

Solution:
1) CNES: estimate additional wide-lane biases (per day)
2) ESOC: network solution (GFZ, JPL)
3) ESOC: form Track-to-Track ambiguities
Differential Code Biases

P1-P2

DCB Datum (=TEC datum): Zero-mean over SV/Rec. DCBs
- impossible to fix un-differenced wide-lane ambiguities

Jump \( \approx 7 \text{ cm} \)
MW Ambiguities
Un-differenced

Only SMALL PERCENTAGE of wide-lane ambiguities can be fixed! DCB-definition (mean over all satellites/stations) prevents AR!
Track-to-Track MW Ambiguities

Un-differenced

\[ \lambda_W N^i_W := \lambda_W N^1_W + \lambda_W \sum_{k=2}^{i} \Delta N^{i-1}_W \]

Track-to-Track MW Ambiguities - ALGO station (one day from an IGS run)

All track-to-track wide-lane ambiguities can be fixed!
Narrow-Lane Track-to-track Ambiguities
Un-differenced

Steps:
1. Solution: DD solution with Ambiguity resolution (orbit)
2. Estimation of phase clocks (orbit fixed)
3. Track-to-track ambiguity resolution
4. Carrier-phase Range

Phase clocks to bridge the gap between tracks!!!!

Track-to-Track NL Ambiguities - ALGO station (one day from an IGS run)
IGS Clocks vs. H-Maser Performance

Comparison

Clock stability is always better compared to the clock accuracy in this table!

\[ \sigma\left(\delta_{\text{clock}}(\tau)\right) = \text{ADEV}(\tau) \cdot \tau \cdot \sigma \]
\[ \text{ADEV}(\tau) = \text{ADEV}(1\ s) / \sqrt{\tau} \]

<table>
<thead>
<tr>
<th></th>
<th>ADEV(τ = 1 s)</th>
<th>σ(τ = 0.5 h)</th>
<th>σ(τ = 1 h)</th>
<th>σ(τ = 6 h)</th>
<th>σ(τ = 12 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1×10^{-12} (GALILEO FHM)</td>
<td>13 mm</td>
<td>18 mm</td>
<td>44 mm</td>
<td>62 mm</td>
<td></td>
</tr>
<tr>
<td>1×10^{-13} (ground H-maser)</td>
<td>1.3 mm</td>
<td>1.8 mm</td>
<td>4.4 mm</td>
<td>6.2 mm</td>
<td></td>
</tr>
<tr>
<td>1×10^{-15} (optical clock)</td>
<td>0.013 mm</td>
<td>0.018 mm</td>
<td>0.044 mm</td>
<td>0.062 mm</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• Excellent GIOVE-B Clock Stability!

• For the first time GNSS clock used to map the radial orbit error!

• GIOVE-B clock drift agrees with the GP-A test of general relativity (slightly better)

• Track-to-track MW ambiguities can be fixed!

• Track-to-track NL ambiguities can be fixed!!! Clock stability or good a priori estimated phase clocks or IGS clocks to guarantee correct fixes.

• Track-to-Track Phase Clock Ambiguity Resolution demonstrated!
Different clock for L1 and L2 phase
STD up to 15 mm