GNSS Timing monitoring with calibrated receivers at ESA
Content

- Background and Objectives
- Multi-GNSS calibration
- Multi-GNSS timing monitoring
- Conclusions, Outlook
Background and Objectives

(multi-)GNSS calibration is required for

• System level: Generation of System Time Offsets (GGTOs), UTC-GNSST parameters …etc…
• User level: GNSS-Time transfer and dissemination at the few ns level, traceability…

Multi-GNSS Timing Monitoring is required for

• Consistency check/assessment of system timing performance (GGTO, UTC, DCB…)
• Estimation of inter-system biases for e.g. interoperability

Objectives:
To have independent capabilities (equipment, tools, processes, know-how…) for the continuous monitoring of multi-GNSS timing performance at the ~ns level
Multi-GNSS Calibration

Based on consistent measurement/processing of absolute delay measurement:

- Antenna: Group-Delay measurement in anechoic chamber
- Antenna Cable: Vector Network Analyser
- Receiver: GNSS Simulator
Multi-GNSS Calibration

Receiver absolute Calibration:

Receiver Delay for signal component $i$:

$$X_{Ri} = (PR_i - D_{sim})/c - (X_{RF} - X_{pps})_i + X_0$$

- $PR_i$: measured pseudorange
- $D_{sim}$: Simulated pseudorange
- $X_{RF}$, $X_{pps}$: cable delays

**Constellation/Signals covered:**
- GPS: L1C/A, L1P, L2P, L5
- GAL: E1, E6, E5a, E5b, E5
- GLO: L1C, L2C, L1P, L2P
- BDS2: B2i, B3I, B1i
- BDS3: B2a, B2b, B3I, B1C
- NavIC: L5 $\rightarrow$ New
Multi-GNSS Calibration

Uncertainty Budget, Test and Validation:

- Detailed uncertainty budget
- Several test campaign conducted
- Several Receiver types/brands tested
- Validation campaign with CNES absolute calibration*
- Validation campaign against relative calibration
- Overall agreement/consistency at the 1~2ns level

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Type</th>
<th>Description</th>
<th>Value (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim_noise</td>
<td>A</td>
<td>Measurement Noise (std over 16 runs/PRNs)</td>
<td>50 to 350</td>
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<tr>
<td>Sim_resol</td>
<td>B</td>
<td>Oscilloscope Resolution (10GSps)</td>
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<tr>
<td>Sim_trigger</td>
<td>B</td>
<td>Oscilloscope Trigger error (specs)</td>
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<td>Sim_config</td>
<td>B</td>
<td>Simulator output power effects (tests)</td>
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<tr>
<td>Sim_filter</td>
<td>B</td>
<td>Correlator low-pass filter effects (test)</td>
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<td>PR_noise</td>
<td>A</td>
<td>Pseudorange Noise (std of the PR differences)</td>
<td>10 to 155</td>
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<td>PR_icb</td>
<td>B</td>
<td>Receiver inter-channel biases (test)</td>
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<tr>
<td>PR_agc</td>
<td>B</td>
<td>Receiver AGC-dependant biases (test)</td>
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<td>PR_temp*</td>
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<td>Thermal effects on receiver (test)</td>
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<tr>
<td>LD</td>
<td>A</td>
<td>LD measurement noise (conservative assumption)</td>
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<tr>
<td>LD</td>
<td>B</td>
<td>Receiver autocalibration (test)</td>
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TOTAL: 418 to 564

* IEEE IFCS-EFTF 2019, “Cross-calibrations of multi-GNSS Receiver Chains”, ESA, CNES
## Multi-GNSS Calibration

### Results (example: BP27, calibrated for the BIPM):

<table>
<thead>
<tr>
<th></th>
<th>Signal</th>
<th>FW 3.2.0</th>
<th>uncert.</th>
<th>FW 5.4.0</th>
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<tbody>
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<tr>
<td>L1C</td>
<td>C1C</td>
<td>11.16</td>
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<td>11.45</td>
<td>0.48</td>
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<tr>
<td>L1P</td>
<td>C1W</td>
<td>10.83</td>
<td>0.45</td>
<td>11.11</td>
<td>0.45</td>
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<tr>
<td>L2P</td>
<td>C2W</td>
<td>10.19</td>
<td>0.47</td>
<td>10.49</td>
<td>0.47</td>
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<tr>
<td>L5Q</td>
<td>C5Q</td>
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<td>0.42</td>
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<td>E1C</td>
<td>C1C</td>
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<tr>
<td>E5Q</td>
<td>C5Q</td>
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<td>E7Q</td>
<td>C7Q</td>
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<td>E8Q</td>
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<td>E6C</td>
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<td>B1I</td>
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<td>C1P</td>
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<td>B2A</td>
<td>C5P</td>
<td>11.29</td>
<td>0.52</td>
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</table>
Multi-GNSS Timing Monitoring

Principle:

Receiver Chain:
- Fixed multi-GNSS receiver
- Absolute multi-GNSS calibration

Processing:
- Based on Rinex, Calibration and CirT files
- Same and consistent process for all GNSS

Diagram:

- Rx
- Rinex
- Cal data
- CGGTTS processing
- GNSST-UTC(k) mod. 1s
- GNSST2UTC processing
- UTC - BrdcUTC
- CirT

UTC(k)
Multi-GNSS Timing Monitoring

GNSSTime – UTC (modulo 1sec), Aug-2021 to Aug-2022

GPS

GAL

GLO

BDS
Multi-GNSS Timing Monitoring

UTC – BrdcUTC, Aug-2021 to Aug-2022

- GPS
- GAL
- GLO
- BDS
Conclusions, Outlook

Multi GNSS calibration
- Equipment, tools and processes available for multi-GNSS receiver chain calibration
- Covers all operational GNSSes
- Validation campaign demonstrated agreement/consistency at the 1~2ns level

Multi-GNSS Timing Monitoring
- Consistent tools and processes available for multi-GNSS timing monitoring
- Covers all operational GNSSes (NAViC to come soon)
- Observed GLO and BDS inconsistencies need further investigations

Outlook
- Implement NAViC in routine processes
- Investigate observed inconsistencies
- Further validate tools and processes, in particular with non-EU entities