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GNSS Space Service Volume Update
Providers’ Forum

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Human Exploration and Operations Mission Directorate (HEOMD), NASA

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Benefits of GNSS use in SSV:

- Significantly improves real-time navigation performance (from: km-class to: meter-class)
- Supports quick trajectory maneuver recovery (from: 5-10 hours to: minutes)
- GNSS timing reduces need for expensive on-board clocks (from: $100sK-$1M to: $15K–$50K)
- Supports increased satellite autonomy, lowering mission operations costs (savings up to $500-750K/year)
- Enables new/enhanced capabilities and better performance for HEO and GEO missions, such as:

- Earth Weather Prediction using Advanced Weather Satellites
- Space Weather Observations
- Precise Relative Positioning
- Launch Vehicle Upper Stages and Beyond-GEO applications
- Formation Flying, Space Situational Awareness, Proximity Operations
- Precise Position Knowledge and Control at GEO
U.S. Initiatives & Contributions to Ensure an Interoperable, Sustained, Quantified GNSS Capability for Space Users

- Performing additional flight experiments above the constellation (e.g. ACE)
- Developing new weak signal GPS/GNSS receivers for spacecraft in cis-Lunar space (e.g. NASA Goddard Navigator and its commercial variants)
- Working with the GPS Directorate and DoD community to formally document GPS requirements and antenna patterns for space users
- Encouraging international coordination with other GNSS constellations (e.g. Galileo, GLONASS, BeiDou) to specify interoperable SSV capabilities
- Developing missions and systems to utilize GNSS signals in the SSV (e.g. MMS, GOES)
GNSS SSV Observations

- WG-B is making significant progress in establishing an interoperable Global Navigation Satellite System (GNSS) Space Service Volume (SSV) through pre-work, analyses and periodic teleconferences.

- WG-B Analyses underway to solidify understanding of HEO/GEO user capabilities using all provider’s SSV capabilities (BeiDou, Galileo, GLONASS, GPS, IRNSS, QZSS).

- Despite this, SSV users should not be relying on capabilities that are not specified. Capabilities available now may not be available in the future if not specified.

Recommendations

- Encourage all providers to baseline SSV specifications as part of future constellation developments.

- Encourage all providers to participate in WG-B initiatives, including interoperable GNSS analyses.
Phase 1: Geometrical Access

Phase 2: Signal Strength Access

Phase 3: Specific User Missions
## 3 Phase Analysis Status

<table>
<thead>
<tr>
<th>Phase 1 Activities</th>
<th>Status</th>
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<tbody>
<tr>
<td>Orbit Propagation Technique</td>
<td>Complete</td>
</tr>
<tr>
<td>Geometrical-Based Access Calculation Technique</td>
<td>Complete</td>
</tr>
<tr>
<td>Figure of Merit Calculations</td>
<td>Complete</td>
</tr>
<tr>
<td>Documentation in ICG WG-B Booklet</td>
<td>In-Work</td>
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<table>
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<tr>
<th>Phase 2 Activities</th>
<th>Status</th>
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<tbody>
<tr>
<td>RF Link Budget Technique</td>
<td>Planning</td>
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<tr>
<td>Geometrical/RF-Based Access Calculation Technique</td>
<td>Not Yet Started</td>
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<td>Figure of Merit Calculations</td>
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<tr>
<td>Documentation in ICG WG-B Booklet</td>
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<table>
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<tr>
<th>Phase 3 Activities</th>
<th>Status</th>
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<tr>
<td>Derive User-Specific Missions</td>
<td>Planning</td>
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<tr>
<td>RF-Based Access Calculation Technique</td>
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GPS SSV Status and Lessons Learned: Executive Summary

• Current SSV specifications, developed with limited on-orbit knowledge, only capture performance provided by signals transmitted within 23.5° (L1) or 26° (L2/L5) off-nadir angle.

• On-orbit data & lessons learned since spec development show significant PNT performance improvements when the full aggregate signal is used.

• Numerous Military & Civil operational missions in High & Geosynchronous Earth Orbit (HEO/GEO) utilize the full signal to enhance vehicle PNT performance
  – Multiple military & civil stakeholders require this enhanced PNT performance to meet mission requirements.

• Failure to protect aggregate signal performance in future GPS designs creates the risk of significant loss of capability, and inability to further utilize performance for civil and military space users in HEO/GEO

• Protecting GPS aggregate signal performance ensures GNSS parity in the SSV
Key Civil Stakeholder: GOES-R

- GOES-R, -S, -T, -U: 4th generation NOAA operational weather satellites
- Launch: 2016, 15-year service life
  - Series operational through 2030s
- Driving requirements:
  - Orbit position knowledge requirement (right)
  - All performance requirements applicable through maneuvers, <120 min/year allowed exceedances
  - Stringent navigation stability requirements
  - Requirements unchanged for GOES-S, -T, -U

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement (m, 1-sigma)</th>
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<tbody>
<tr>
<td>Radial</td>
<td>33</td>
</tr>
<tr>
<td>In-track</td>
<td>25</td>
</tr>
<tr>
<td>Cross-track</td>
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- GOES-R cannot meet stated mission requirements with SSV coverage as currently documented
- NASA-led interagency requirement formulated as minimum-impact solution to meet GOES-R performance needs
Current requirement is a “triad” of three interrelated components:
- Signal availability (% of time that 1 or 4 GPS signals are available; max outage time)
- Minimum received signal power at GEO
- Maximum pseudorange accuracy (equivalent to user range error)

Proposed requirement adds second tier of capability specifically for HEO/GEO users
- Increased signal availability to nearly continuous for at least 1 signal
- Relaxed pseudorange accuracy from 0.8m RMS to 4m RMS
- No change to minimum received signal power
- Applies to all signals (L1/L2/L5), all codes

### Current minimum performance

<table>
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<tr>
<th>PR acc. (rms)</th>
<th>0.8 m</th>
<th>4m</th>
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<tbody>
<tr>
<td>1+ signal</td>
<td>≥ 80%</td>
<td>≥ 99%</td>
</tr>
<tr>
<td>4+ signals</td>
<td>≥ 1%</td>
<td>≥ 33%</td>
</tr>
<tr>
<td>Max outage</td>
<td>108 min</td>
<td>10 min</td>
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SSV L1 HEO/GEO availability
Status on Requirement Formulation Using USA Interagency Forum for Operational Requirements (IFOR) Process

  - Monthly IFOR WG meetings w/ NASA, AFSPC, SMC (Aerospace as “honest broker”)
  - Major deliverables provided by NASA:
    1. Requirement Language
    2. Statement of Need
    3. Analysis of Alternatives
  - NASA coordinating with interagency stakeholders for letters of support/commitment

- 9 Feb 2016: Final IFOR WG Meeting
  - NASA delivers final products
  - SMC delivers ROM cost estimate for impact to GPS system

- 26 Feb 2016: Formal SMC/SY (Space Superiority) endorsement of NASA requirement

- 22 Mar 2016: IFOR Co-Chair preliminary recommendation meeting
  - SMC requests for clarification on AoA and forward plan leads to IFOR-requested HPT

- 12–13 Apr 2016: NASA/AFSPC/SMC HPT
  - Drafting of USAF/NASA MoA
  - Clarification of AoA items
  - Agreement on forward engagement in SV11+ procurement process

- 19 Apr 2016: Formal NOAA endorsement of NASA requirement

- June 2016: Final IFOR Co-Chair recommendation meeting

Requirement Not Finalized--Work in Progress
Closing Remarks

- Space users rely on GNSS as a critical space navigation utility over an expanding range of orbital regimes.

- Missions using GNSS in HEO/GEO orbits are vulnerable to constellation design changes because availability provided by aggregate signals (main & side lobes) are critically important and should be specified.

- NASA has developed a proposed aggregate signal requirement based on documented mission needs that will benefit entire Space Enterprise.

- NASA is working through formal IFOR process for potential specification for the GPS III SV11+ vehicle build.

- If successful, GPS requirements update for HEO/GEO SSV users will:
  - Maintain critical capabilities employed by users in HEO/GEO.
  - Provide a green-light for civil and military space missions considering future operational use of GPS beyond LEO.

**Protection of GNSS Aggregate Signals (main & side lobes) through Specification is Critically Important for Current and Future Users in the SSV**