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GNSS Space Service Volume

NASA User Perspectives

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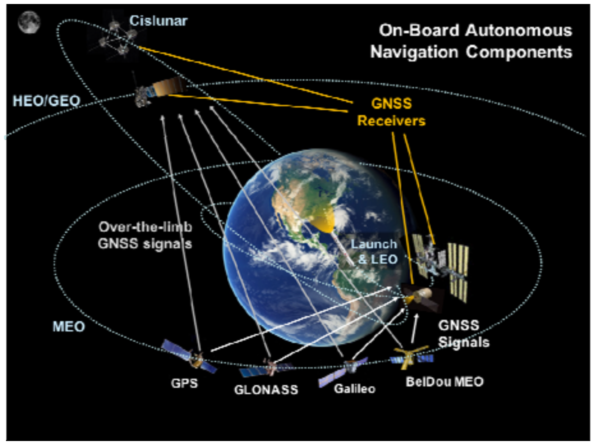
Contents

Space Uses of Global Navigation Satellite Systems (GNSS)

- **Real-time On-Board Navigation:** Enables new methods of spaceflight ops such as precision formation flying, rendezvous & docking, station-keeping, Geosynchronous Orbit (GEO) satellite servicing
- **Earth Sciences:** GPS used as a remote sensing tool supports atmospheric and ionospheric sciences, geodesy, and geodynamics -- from monitoring sea levels & ice melt to measuring the gravity field
- **Attitude Determination:** Use of GPS/GNSS enables some missions to meet their attitude determination requirements, such as the International Space Station (ISS)

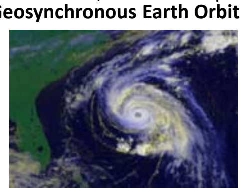


GPS capabilities to support space users will be further improved by pursuing compatibility and interoperability with GNSS

The Promise of GNSS for Real-Time Navigation in the SSV

Benefits of GNSS use in SSV:

- Significantly **improves real-time navigation performance** (from: kilometer-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 **High Earth Orbit (HEO) and Geosynchronous Earth Orbit (GEO) missions,** such as:

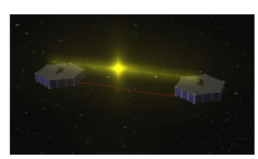

Earth Weather Prediction using Advanced Weather Satellites


Space Weather Observations


Precise Relative Positioning


Launch Vehicle Upper Stages and Beyond-GEO applications

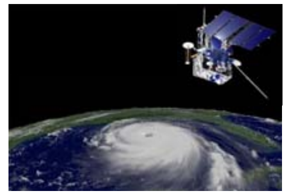

Formation Flying, Space Situational Awareness, Proximity Operations


Precise Position Knowledge and Control at GEO

Current U.S. Missions using GPS above the GPS Constellation

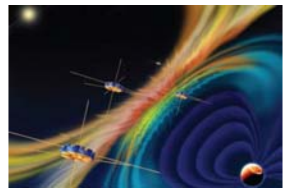
GOES-R Weather Satellite Series:

- Next-generation U.S. operational GEO weather satellite series
- Series is first to use GPS for primary navigation
- GPS provides quicker maneuver recovery, enabling continual science operations with <2 hour outage per year
- Introduction of GPS and new imaging instrument are game-changers to humanity, delivering data products to substantially improve public and property safety



Magnetospheric Multi-Scale (MMS) Mission:

- Four spacecraft form a tetrahedron near apogee for magnetospheric science measurements (space weather)
- Highest-ever use of GPS; Phase I: 12 Earth Radii (RE) apogee; Phase 2: 25 RE apogee
- GPS enables onboard (autonomous) navigation and potentially autonomous station-keeping



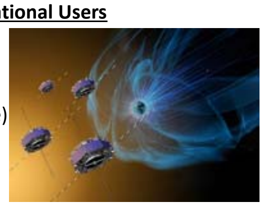
Exploration Mission 1 (EM-1):

- First cis-lunar flight of NASA Space Launch System (SLS) with an Orion crew vehicle equipped with a Honeywell high-altitude GPS receiver as an experiment

U.S. Initiatives & Contributions to Develop & Grow an Interoperable GNSS SSV Capability for Space Users

Operational Users

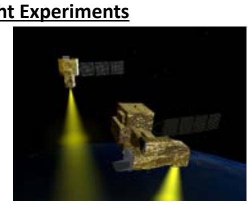
- MMS
- GOES-R, S, T, U
- EM-1 (Lunar en-route)
- Satellite Servicing



Operational Use Demonstrates Future Need

Space Flight Experiments

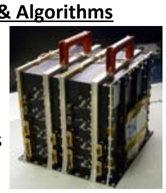
- Falcon Gold
- EO-1
- AO-40
- GPS ACE
- EM-1 (Lunar vicinity)



Breakthroughs in Understanding; Supports Policy Changes; Enables Operational Missions

SSV Receivers, Software & Algorithms

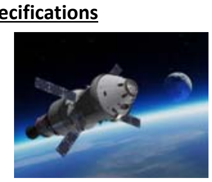
- GEONS (SW)
- GSFC Navigator
- General Dynamics
- Navigator commercial variants (Moog, Honeywell)



Develop & Nurture Robust GNSS Pipeline

SSV Policy & Specifications

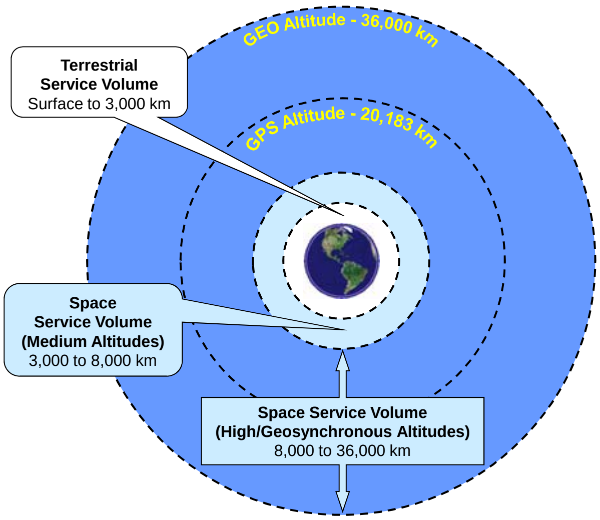
- SSV definition (GPS IIF)
- SSV specification (GPS III)
- ICG Multi-GNSS SSV common definitions & analyses



Operational Guarantees Through Definition & Specification

From 1990's to Today, U.S. Provides Leadership & Guidance Enabling Breakthrough, Game-changing Missions through use of GNSS in the SSV

Current GPS SSV Definition



The GPS SSV is defined by three interrelated performance metrics for the SSV Medium Altitudes and the SSV High/Geosynchronous altitudes:

- Availability
- Minimum received power
- Pseudorange accuracy

SSV Template Data for GPS

Definitions	Notes
Lower Space Service Volume (also known as 'MEO altitudes'): 3,000 to 8,000 km altitude	Four GPS signals available simultaneously a majority of the time but GPS signals over the limb of the Earth become increasingly important. One-meter orbit accuracies are feasible (post processed).
Upper Space Service Volume (also known as 'HEO/GEO altitudes'): 8,000 to 36,000 km altitude	Nearly all GPS signals received over the limb of the Earth. Users will experience periods when no GPS satellites are available. Accuracies ranging from 10 to 100 meters are feasible (post-processed) depending on receiver sensitivity and local oscillator stability.

Parameters	Value	
User Range Error	0.8 meters	
Signal Center Frequency		
L1 C/A	1575.42 MHz	
L1C	1575.42 MHz	
L2 (L2C or C/A)	1227.60 MHz	
L5 (I5 or Q5)	1176.45 MHz	
Minimum Received Civilian Signal Power	0 dBi RCP antenna at GEO	Reference Off-Boresight Angle
L1 C/A	-184.0 dBW	23.5 deg
L1C	-182.5 dBW	23.5 deg
L2 (L2C or C/A)	-183.0 dBW	26 deg
L5 (I5 or Q5)	-182.0 dBW	26 deg
Signal Availability[1]		
Lower Space Service Volume (MEO)	At least 1 signal	4 or more signals
L1	100%	> 97%
L2, L5	100%	100%
Upper Space Service Volume (HEO/GEO)	At least 1 signal	4 or more signals
L1	≥ 80%[2]	≥ 1%
L2, L5	≥ 92%[3]	≥ 6.5 %
Note 1: Assumes a nominal, optimized 27-satellite constellation and no GPS spacecraft failures. Signal availability at 95% of the areas at a specific altitude within the specified space service volume		
Note 2: Assumes less than 108 minutes of continuous outage time		
Note 3: Assumes less than 84 minutes of continuous outage time		

GPS SSV Specification

- The GPS SSV Template data is backed by formal specification.

Minimum Availability Requirement

- Assuming a nominal, optimized GPS constellation and no GPS spacecraft failures, signal availability at 95% of the areas at a specific altitude within the specified SSV are planned as:

	MEO SSV		HEO/GEO SSV	
	at least 1 signal	4 or more signals	at least 1 signal	4 or more signals
L1	100%	≥ 97%	≥ 80% [1]	≥ 1%
L2, L5	100%	100%	≥ 92% [2]	≥ 6.5%

1. With less than 108 minutes of continuous outage time.
2. With less than 84 minutes of continuous outage time.

Pseudorange Accuracy

- The space service volume pseudorange accuracy shall be less than or equal to 0.8 meters (rms)

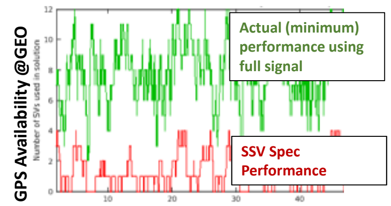
GPS SSV Specification: Minimum Received Signal Power (dBW)

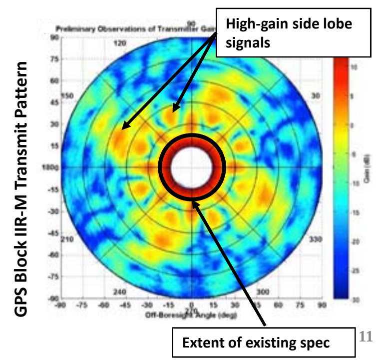
Signal	Terrestrial Minimum Power (dBW)	SSV Minimum Power (dBW)	Reference Half-beamwidth
L1 C/A	-158.5	-184.0	23.5
L1C	-157.0	-182.5	23.5
L2 C/A or L2C	-158.5	-183.0	26
L5	-157.0	-182.0	26

- The SSV minimum received power levels are specified based on the worst-case (minimum) gain across the Block IIA, IIR, IIR-M, and IIF satellite builds
- Some signals have several dB margin with respect to these requirements at reference half-beamwidth point

SSV Lessons Learned

- Current SSV specifications, developed with limited on-orbit knowledge, only capture performance provided by signals transmitted within 23.5 degrees (L1) or 26 degrees (L2/L5) off-nadir angle
- On-orbit data & lessons learned since spec development **show significant PNT performance improvements** when the full aggregate (main and side lobe) signal is used
- **Numerous** operational missions in High & Geosynchronous Earth Orbit (HEO/GEO) utilize the full signal to enhance vehicle PNT performance
  - **Multiple** stakeholders **require** this enhanced PNT performance to meet mission requirements
- **NASA has proposed** an updated GPS SSV specification to capture the needs of existing and future critical users in the HEO/GEO SSV.





GNSS SSV Observations & Forward Priorities

<u>Observations:</u>

- The International Committee on GNSS (ICG) WG-B is establishing an interoperable GNSS SSV through pre-work, analyses and meetings
- Analyses are underway to solidify our understanding of an SSV that combines the capabilities of all GNSS and regional navigation systems
- Despite this, SSV users should not rely on **unspecified capabilities** from any particular GNSS
  - SSV capabilities that are currently available <u>may not</u> be available in the future unless they are documented in specifications for that GNSS

<u>Forward Priorities:</u>

GNSS service providers, supported by space agencies & research institutions encouraged to:

- Support SSV in future generation of satellites, preferably through the baseline of SSV specifications
- Measure and publish GNSS antenna gain patterns to support SSV understanding & use of the GNSS aggregate signal
- Share SSV user experiences and lessons learned to improve SSV responsiveness to emerging needs

Conclusions

- The Space Service Volume, first defined for GPS Block IIF in 2000, **continues to evolve** to meet high-altitude user needs. **GPS has led the way** with a formal specification for GPS Block III, requiring that GPS provides a core capability to space users
- Current and future space missions in the SSV are **becoming increasing reliant** on near-continuous GNSS availability to improve their mission performance
- Today, we **continue to work** to ensure that the SSV keeps pace with user demands:
  - For GPS, with its well-characterized performance, we are working towards **updating the SSV specification** to capture the needs of emerging GPS-only users like the Geostationary Operational Environmental Satellite - R Series (GOES-R), the first of which (GOES-16) was launched on Nov. 19, 2016
  - In partnership with foreign GNSS providers, we are working to characterize, analyze, document, and publish the capabilities of an **interoperable multi-GNSS SSV** with ultimate goal of provider specification
- **Both approaches** are equally critical: (1) a robust GPS capability will enable and enhance new missions in applications that only rely on GPS signals; while (2) an interoperable GNSS SSV will ensure that a wider capabilities are available as needed
- NASA and the U.S. Government are **proud to work** with the GNSS providers to contribute making GNSS services more accessible, interoperable, robust, and precise for all users, for the **benefit of humanity**. We encourage all providers to continue to support this essential capability.

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