SPACE-BASED POSITIONING NAVIGATION & TIMING

NATIONAL COORDINATION OFFICE

U.S. Space-Based Positioning, Navigation and Timing (PNT)

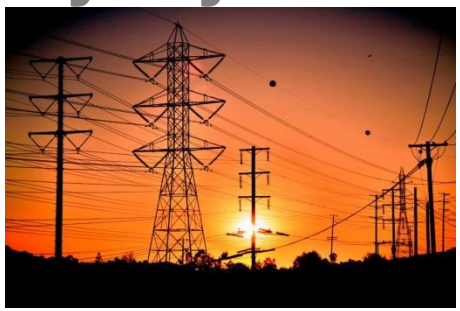
11th Meeting of the International Committee on Global Navigation Satellite Systems (ICG-11)
Sochi, Russia

7 November 2016

Ken Alexander, Senior Advisor
on behalf of
Harold W. Martin III, Director
National Coordination Office

GPS Enables and Enhances Life Everyday





Applications include:

- Aviation
- Agriculture
- Search & rescue
- Surveying & mapping
- Trucking & shipping
- Fishing & boating
- Scientific
- Timing
- Tracking
- Exploration
- Offshore drilling
- Military



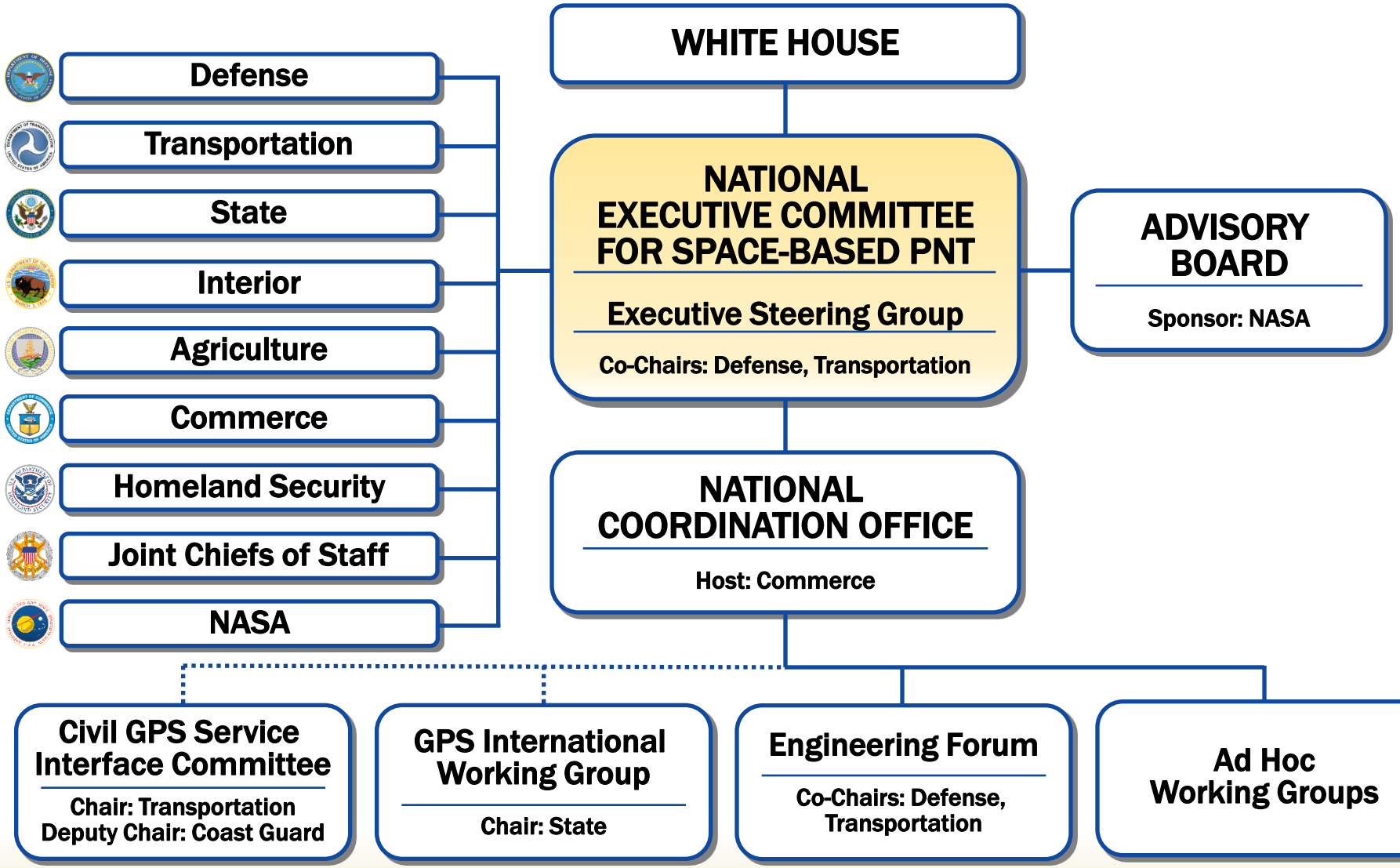

GPS provides Worldwide Utility

U.S. Policy Promotes Civilian GPS Use

- Continuous, worldwide, free of direct user fees
- Encourage compatibility and interoperability with foreign GNSS services and promote transparency in civil service provisioning
- Operate and maintain GPS constellation to satisfy civil and national security needs
  - Foreign PNT services may be used to augment and strengthen the resiliency of GPS
- Invest in domestic capabilities and support international activities to: detect, mitigate and increase resiliency to harmful interference

Space-Based PNT Policy Guidance: Maintain leadership in the service, provision, and use of GNSS

National Space-Based PNT Organization



PNT Executive Committee (EXCOM) Strategic Focus Areas

EXCOM Strategic Focus Areas Include:

- GPS Sustainment and Modernization
- International Cooperation
- Spectrum Management
- Critical Infrastructure
- PNT Resilience
- Complementary PNT
- Outreach and Education

GPS Overview

Civil Cooperation

- 1+ Billion civil & commercial users worldwide
- Search and Rescue
- Civil Signals
  - L1 C/A (Original Signal)
  - L2C (2nd Civil Signal)
  - L5 (Aviation Safety of Life)
  - L1C (International)

Department of Defense

- Services (Army, Navy, AF, USMC)
- Agencies (NGA & DISA)
- US Naval Observatory
- PNT EXCOMS
- GPS Partnership Council

Maintenance/Security

- All Level I and Level II
  - Worldwide Infrastructure
  - NATO Repair Facility
- Develop & Publish ICDs Semi-Annually
  - ICWG: Worldwide Involvement
- Update GPS.gov Webpage
- Load Operational Software on over 970,000 SAASM Receivers
- Distribute PRNs for the World
  - 120 for US and 90 for GNSS

Spectrum

- World Radio Conference
- International Telecommunication Union
- Bilateral Agreements
- Adjacent Band **Compatibility**

37 Satellites / 31 Set Healthy
Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age	Oldest
GPS IIR	12	14.7	19.1
GPS IIR-M	7	9.1	10.9
GPS IIF	12	2.6	6.3
Constellation	31	8.7	19.1

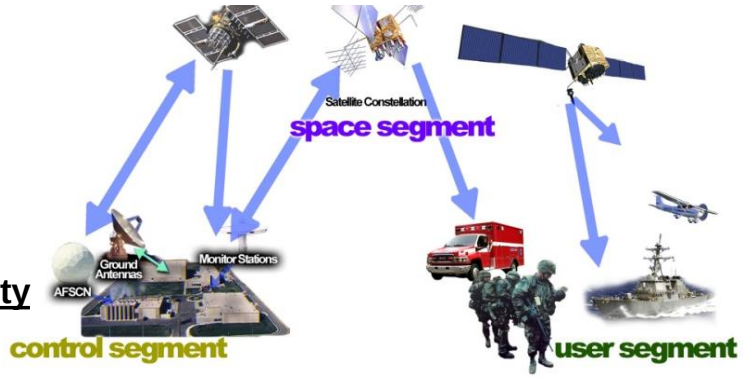
AS OF 29 AUG 16

Department of Transportation

- Federal Aviation Administration

Department of Homeland Security

- U.S. Coast Guard



International Cooperation

- GNSS
  - Europe - Galileo
  - China - Beidou
  - Russia - GLONASS
  - Japan - QZSS
  - India - IRNSS
- 57 Authorized Allied Users
  - 25+ Years of Cooperation

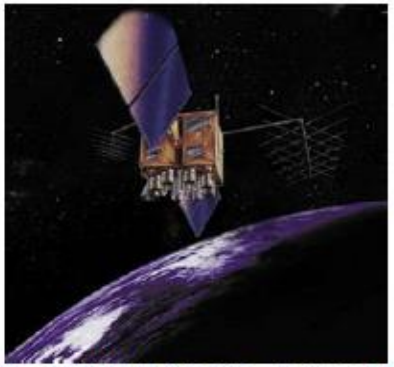
Constellation Snapshot

Four Generations of Operational Satellites

- Block IIA - 5 Residual
  - 7.5 year design life
  - Launched 1990 to 1997
- Block IIR - 12 Operational
  - 7.5 year design life (oldest operational satellite is 19 years old)
  - Launched 1997 to 2004
- Block IIR-M - 7 Operational, 1 Residual
  - 7.5 year design life
  - Launched 2005 to 2009
  - Added 2nd civil navigation signal (L2C)
- Block IIF - 12 Operational
  - 12 year design life
  - Launched 2010 to 2016
  - Added 3rd civil navigation signal (L5)

*** Current as of 28 Oct 16**

Block IIA Satellite – Designed & Built by Rockwell International

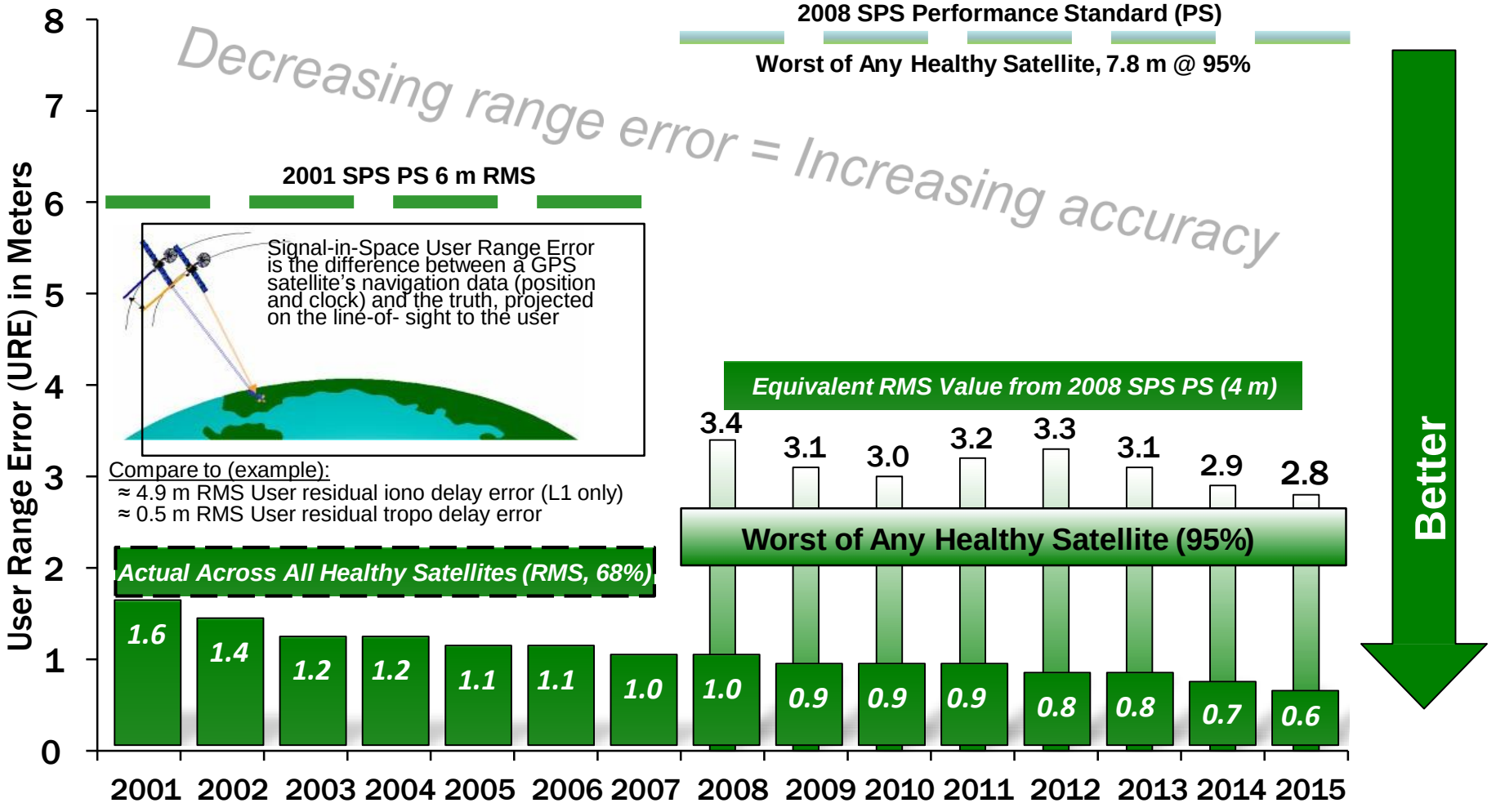


Block IIR/IIR-M Satellite – Designed & Built by Lockheed Martin

Block IIF Satellite – Designed & Built by Boeing

Accuracy: Civil Commitments

Standard Positioning Service (SPS) Signal-in-Space Performance



System accuracy substantially exceeds published standard

GPS Signal in Space Performance Scoreboard

GPS SIGNAL IN SPACE (SIS) PERFORMANCE (CM)*

	BEST WEEK		BEST DAY		WORST DAY	
	ENDING	SIS	DATE	SIS	DATE	SIS
ROLLING YEAR	14 APR 16	45.3	11 MAY 16	36.5	19 DEC 15	70.3
BEST WEEK EVER			14 APR 16		45.3	

* RMS across all healthy satellites

GPS Performance Report Card

- 2013 report now available on gps.gov
  http://www.gps.gov/systems/gps/performance/
- This report measures GPS performance against GPS SPS Performance Standard

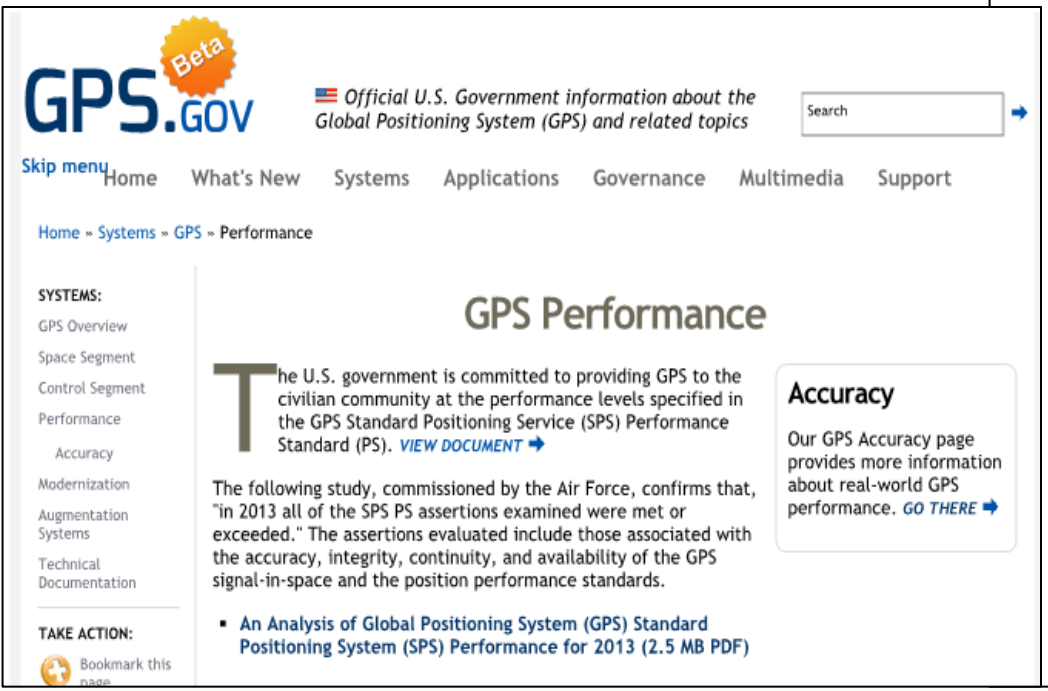


Table 2.1: Summary of SPS PS Metrics Examined for 2013

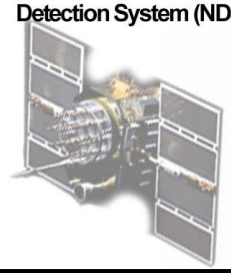
SPSPS08 Section	SPS PS Metric	2013 Status
3.4.1 SIS URE Accuracy	$\leq$ 7.8 m 95% Global average URE during normal operations over all AODs	✔+
	$\leq$ 6.0 m 95% Global average URE during normal operations at zero AOD	✔+
	$\leq$ 12.8 m 95% Global average URE during normal operations at any AOD	✔+
	$\leq$ 30 m 99.94% Global average URE during normal operations	✔+
	$\leq$ 30 m 99.79% Worst case single point average URE during normal operations	✔+
3.5.1 SIS Instantaneous URE Integrity	$\leq 1.X10^{-5}$ Probability over any hour of exceeding the NTE tolerance without a timely alert	✔+
3.6.1 SIS Continuity - Unscheduled Failure Interruptions	$\geq$ 0.9998 Probability over any hour of not losing the SPS SIS availability from the slot due to unscheduled interruption	✔+
3.7.1 SIS Per-Slot Availability	$\geq$ 0.957 Probability that (a.) a slot in the baseline 24-slot will be occupied by a satellite broadcasting a healthy SPS SIS, or (b.) a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SIS	✔+
3.7.2 SIS Constellation Availability	$\geq$ 0.98 Probability that at least 21 slots out of the 24 slots will be occupied by a satellite (or pair of satellites for expanded slots) broadcasting a healthy SIS	✔+
	$\geq$ 0.99999 Probability that at least 20 slots out of the 24 slots will be occupied by a satellite (or pair of satellites for expanded slots) broadcasting a healthy SIS	✔+
3.7.3 Operational Satellite Counts	$\geq$ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	✔+
3.8.1 PDOP Availability	$\geq$ 98% Global PDOP of 6 or less	✔+
	$\geq$ 88% Worst site PDOP of 6 or less	✔+
3.8.2 Position Service Availability	$\geq$ 99% Horizontal, average location	✔+
	$\geq$ 99% Vertical, average location	
	$\geq$ 90% Horizontal, worst-case location	
	$\geq$ 90% Vertical, worst-case location	
3.8.3 Position Accuracy	$\leq$ 9 m 95% Horizontal, global average	✔+
	$\leq$ 15 m 95% Vertical, global average	
	$\leq$ 17 m 95% Horizontal, worst site	
	$\leq$ 37 m 95% Vertical, worst site	

✔+ - Met or Exceeded

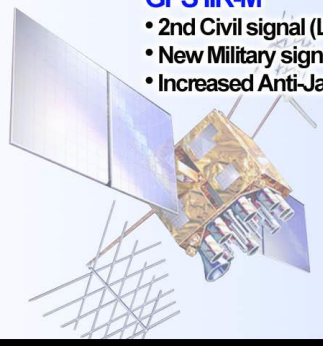
GPS Modernization

Space System (Satellites)

Legacy (GPS IIA/IIR)
- Basic GPS
- NUDET (Nuclear Detonation) Detection System (NDS)

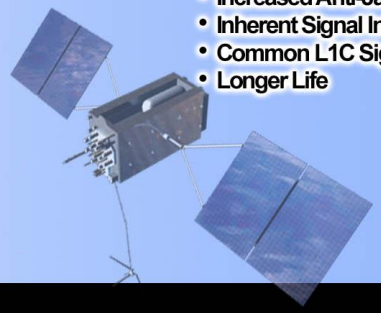


GPS IIR-M
- 2nd Civil signal (L2C)
- New Military signal
- Increased Anti-Jam power



GPS IIF
- 3rd Civil Signal (L5)
- Longer Life
- Better Clocks

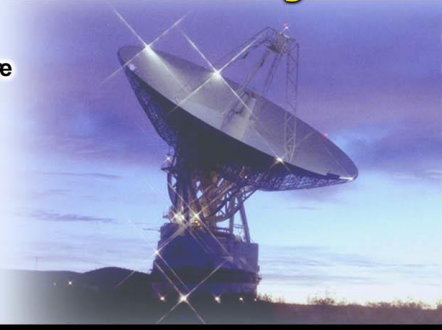
GPS III
- Accuracy & Power
- Increased Anti-Jam power
- Inherent Signal Integrity
- Common L1C Signal
- Longer Life



Ground System

Legacy (OCS)
- Mainframe System
- Command & Control
- Signal Monitoring

AEP
- Distributed Architecture
- Increased Signal Monitoring Coverage
- Security
- Accuracy
- Launch And Disposal Operations



OCX Block 1
- Fly Constellation & GPS III
- Begin New Signal Control
- Upgraded Information Assurance

OCX Block 0
- GPS III Launch & Checkout

GPS III Contingency Ops (COps)
- GPS III Mission

OCX Block 2+
- Control all signals
- Capability On-Ramps
- GPS III Evolution

User Equipment System (Receivers)

Legacy (PLGR/GAS-1/MAGR)
- First Generation System

User Equipment
- Improved Anti-Jam & Systems
- Reduced Size, Weight & Power

Upgraded Antennas
- Improved Anti-Jam Antennas

Modernized
- M-Code Receivers
- Common GPS Modules
- Increased Access/ Power with M-Code
- Increased Accuracy
- Increased Availability
- Increased Anti-Tamper/ Anti- Spoof
- Increased Acquisition in Jamming

GPS IIF

20 Feb 14: IIF-5

16 May 14: IIF-6

1 Aug 14: IIF-7

29 Oct 14: IIF-8

25 Mar 15: IIF-9

15 Jul 15: IIF-10

31 Oct 15: IIF-11

5 Feb 16: IIF-12

8 Launches in 24 Months – Most aggressive GPS launch schedule since 1993

GPS III

- GPS III is the newest block of GPS satellites
  - 4 civil signals: L1 C/A, L1C, L2C, L5
    - First satellites to broadcast common L1C signal
  - 4 military signals: L1/L2 P(Y), L1/L2M
  - 3 improved Rubidium atomic clocks
- SV01-SV10 on contract
  - Resolved technical challenges with payload
  - SV9-10 same requirements baseline as SV01-08
- Current Status
  - SV01 In Testing Flow
    - Baseline thermal vacuum testing completed 23 Dec 15
    - Electromagnetic Interference (EMI) test completed 14 May 16
  - SV02/03 In Assembly and Integration
  - SV04 thru 08 in box level assembly

GPS III SV01 Available For Launch Dec 2016

Ground Segment Status

- Current system Operational Control Segment (OCS)
  - Flying GPS constellation using Architecture Evolution Plan (AEP) and Launch and Early Orbit, Anomaly, and Disposal Operations (LADO) software capabilities
  - Increasing Cyber security enhancements
- Next Generation Operational Control System (OCX)
  - Modernized command and control system
  - Modern civil signal monitoring and improved PNT performance
  - Robust cyber security infrastructure
  - OCX currently in integration and test
  - Block 0 supports launch and checkout for GPS III
  - Block 1 supports transition from current control segment
  - Block 2 enables new capabilities including civil signal performance monitoring capability

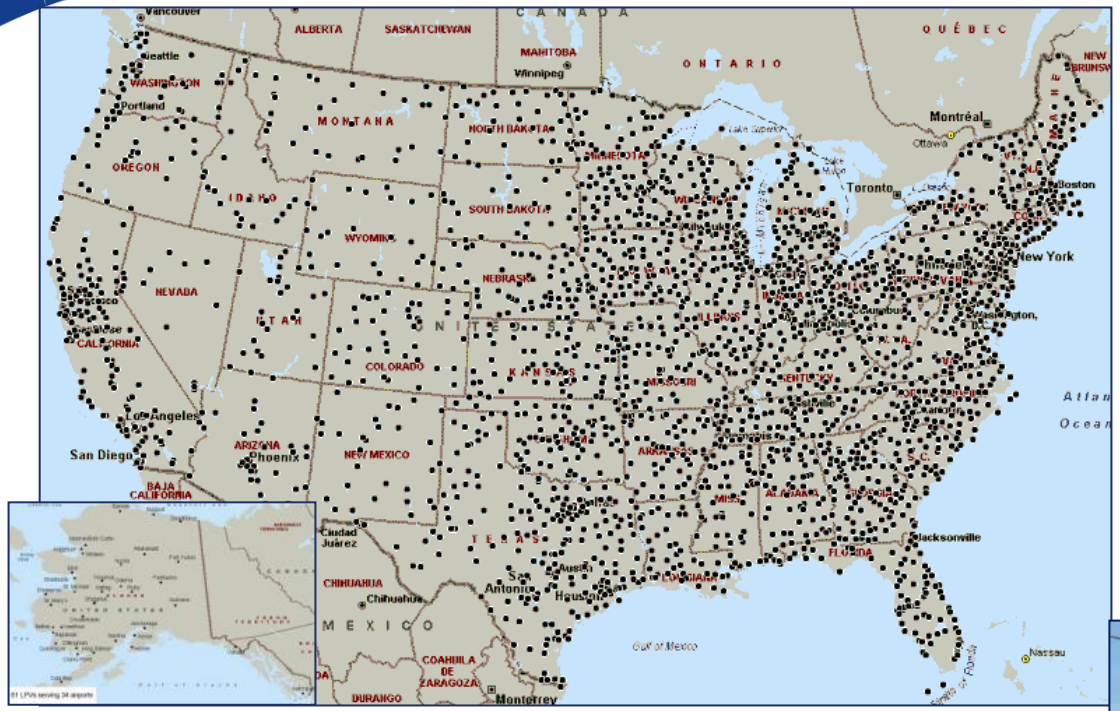
Monitor Station

Ground Antenna

Coordinated Universal Time Offset (UTCO) Anomaly

- GPS Mission Control Segment uploaded incorrect UTCO parameters to a portion of the GPS constellation
  - Occurred 25 - 26 Jan for ~14 hour window; 15 SVs affected
  - Once identified and confirmed, fix was uploaded to all affected satellites within 1.5 hours
- GPS Program Office and Ops Squadron implemented software update to resolve core upload issue
- GPS Program Office also exploring:
  - Potential addition of "resilience considerations for handling GPS data" to SPS PS
  - Increased UTCO parameter monitoring and additional options
  - Follow-on software update to provide additional protections against UTCO issues
- ION paper on UCTO Anomaly impacts to receivers posted at gps.gov http://www.gps.gov/systems/gps/performance/

Procedures and Users Depending on WAAS



Approach Procedures

- 4,343 WAAS Procedures published (as of Oct 2016)
  - 3,722 Localizer Precision Vertical (LPV) procedures
  - 621 LP procedures

Users

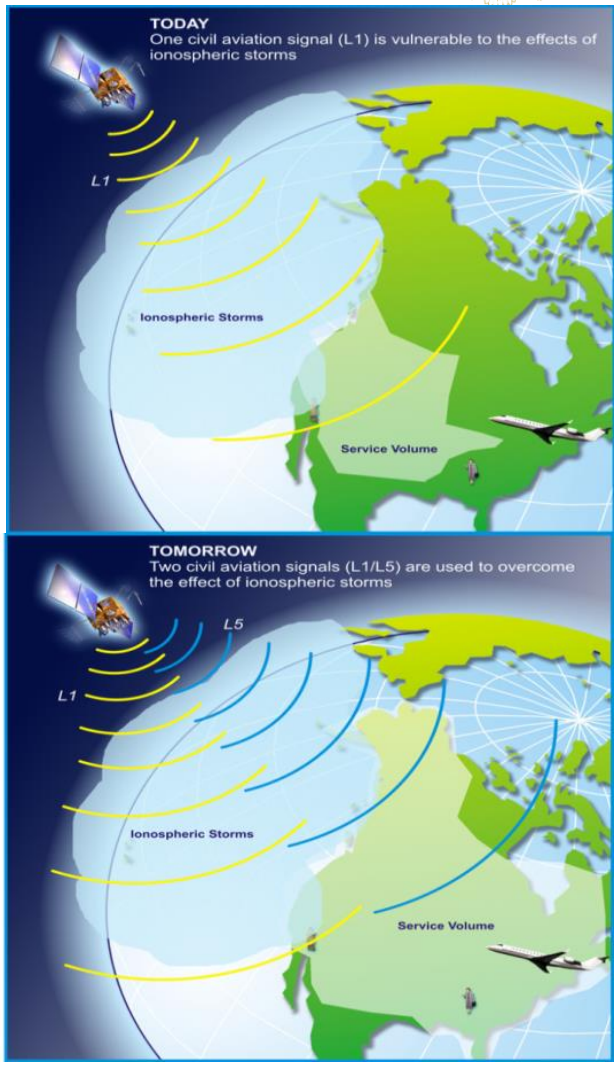
- Over 91,000 WAAS/SBAS equipped aircraft
- All aircraft classes served in all phases of flight
- WAAS/SBAS is enabling technology for FAA NextGen
  - Automatic Dependent Surveillance Broadcast (ADS-B)
  - Performance Based Navigation (PBN)

WAAS Phase IV Dual Frequency Operations

Objective: Obtain Dual-Frequency Multi-Constellation (DFMC) Service

Phase IV Segment 1: Infrastructure improvements and technical refresh to support current system and enable future DF operations

- Five Releases
  - Release 1: Processor Upgrades by 2nd quarter 2017
  - Release 2: Cutover to GEO 5 by 2nd quarter 2018
  - Release 3: GIII Multicast Structure (including monitoring): cutover to complete by 2nd quarter 2018
  - Release 4: Corrections & Verification Safety Computer: validation and deployment cutover by end of 2018
  - Release 5: GEO Uplink System (GUS) Safety Computer upgrade kits for GEO 5 summer 2017; GEO 6 cutover Sept 2019
- Dual-Frequency Multi-constellation Capability (DFMC)
  - Avionics and Infrastructure development underway
  - Assisting with SBAS provider perspective on DFMC capabilities
- Advanced RAIM (ARAIM): developing avionics centric approach for use of multi-constellation GNSS
  - Focus on requirements for horizontal navigation (H-ARAIM)
- Phase IV Segments 2 & 3 Tasks & Activities in definition phase



2016 National Differential GPS Changes

- Transitioned from 83 to 46 sites on Aug 4, 2016
  - Eliminated inland coverage
  - Maintained majority of maritime coverage and shifted to single maritime coverage in most areas
- Public comments were adjudicated via Federal Register Notices
- Continuing to evaluate future DGPS need as other GPS augmentation systems mature
- Assessing potential CPNT use of DGPS infrastructure
- Evaluating future reductions and alternatives

Complementary PNT

- EXCOM reaffirmed need for PNT complement(s) to GPS
- Recent Activities:
  - Assessment update considered many factors – policy to technology
  - U.S. coverage in event of GPS/GNSS outage (natural or man-made events)
  - Identified and assessed alternatives including a broad mix of terrestrial RF and autonomous PNT technologies
  - Federal Cooperative Research and Development Agreement with Industry
- Public stakeholder input obtained by Federal Register Notice
- Pending Federal Register Notice to identify Timing requirements
- Decision timeline supports FY18 investment decisions
- Pending Congressional action

Thank You

GPS B·U·L·E·T·I·N

Information for Policymakers from the National Coordination Office for Space-Based Positioning, Navigation, and Timing (PNT)

May 3, 2016

Space Bill Addresses PNT

On April 14, Rep. Jim Bridenstine (R-OK) introduced the American Space Renaissance Act.

Section 103 of the bill is titled "Positioning, Navigation, and Timing." According to the Congressman, the provision "Expresses a sense of Congress on the importance of positioning, navigation, and timing (PNT) for national security and economic prosperity. Requires the Secretary of Defense to provide a strategy to ensure DOD PNT leverages the best available signals from alternative PNT systems. The strategy will address issues associated with monitoring and verifying accuracy, integrity, availability, security, and reliability of foreign PNT signals."

Section 104 cites the National Executive Committee for Space-Based PNT as a model for establishing a new National Executive Committee on Weather.

Learn more at GPS.gov

DHS Demonstrates Precision Timing Technology at NYSE

On April 20, DHS announced the successful demonstration of Enhanced LORAN (eLoran), a precision timing technology, for financial transactions at the New York Stock Exchange (NYSE). Recognizing the challenges of space-based signals and the importance of having multiple timing sources, eLoran is one technology being considered to provide a complementary timing solution to existing GPS technology.

Precise and synchronized timing of financial transactions is critical to markets worldwide and is mandated by regulation in the European Union and is increasingly required in the United States. Today, precision timing capabilities are provided primarily by GPS. However, GPS's space-based signals are low-power and susceptible to possible disruptions. GPS signals are also difficult to receive indoors and in urban canyons.

The live demonstration at the NYSE was hosted by Juniper Networks, Harris Corporation, and UrsaNav, under a cooperative agreement with DHS. Over 60 industry and government representatives attended, including senior officials from DHS, DOT, DOD, Treasury, and DOE. The ensuing discussion highlighted the over-reliance upon GPS for precise timing, the threat of a loss of civil GPS services, possible impacts to the U.S. critical infrastructure and the economy, and a common interest in developing resilient timing solutions for our nation's critical infrastructure.

View press release at DHS.gov

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Contact Information:

National Coordination Office for Space-Based PNT

1401 Constitution Ave, NW – Room 2518

Washington, DC 20230

Phone: (202) 482-5809

www.gps.gov

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