

Space and Missile Systems Center



GPS Program Update to Stanford PNT Symposium

13 Nov 2013

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Global Positioning Systems Directorate

SPACE AND MISSILE SYSTEMS CENTER

Mission:

Acquire, deliver and sustain reliable GPS capabilities to America's warfighters, our allies, and civil users



Col Bill Cooley



Deliver and Sustain Global Navigation and Timing Service

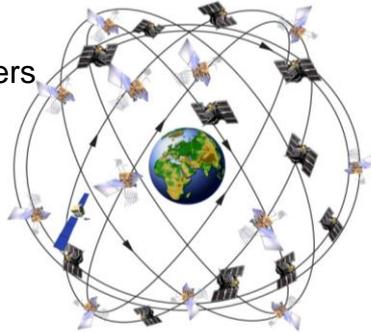
GPS Overview

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Civil Cooperation

- 1+ Billion civil & commercial users
- Search and Rescue
- Civil Signals
 - L2C (2nd Civil Signal)
 - L5 (Safety of Life)
 - L1C (International)



36 Satellites/ 31 Set Healthy
Baseline Constellation: 24 Satellites

Satellite	Quantity	Avg Life	Oldest
GPS IIA	8	19.3	22.8
GPS IIR	12	11.7	16.2
GPS IIR-M	7	6.2	8.0
GPS IIF	4	1.7	3.3
Constellation	31	11.1	22.8

AS OF: 6 NOV 13

Spectrum

- World Radio Conference
- International Telecommunication Union
- Bilateral Agreements
- Adjacent Band Interference



Department of Transportation

- Federal Aviation Administration

Department of Homeland Security

- U.S. Coast Guard

Department of Defense

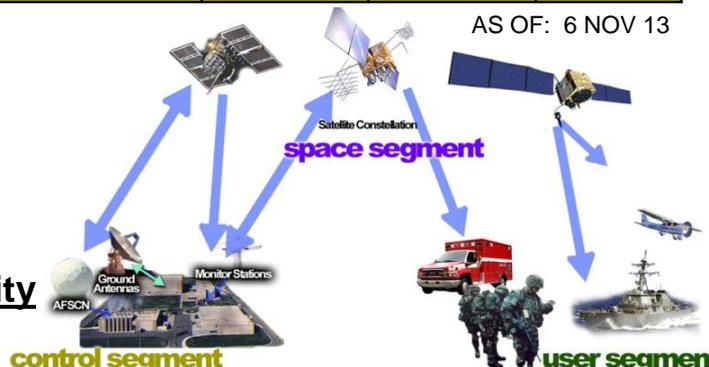
- Services (Army, Navy, AF, USMC)
- Agencies (NGA & DISA)
- US Naval Observatory
- PNT EXCOMS
- GPS Partnership Council

Maintenance/Security

- All Level I and Level II
 - Worldwide Infrastructure
 - NATO Repair Facility
- Develop & Publish ICDs Annually
 - ICWG: Worldwide Involvement
- Update www.GPS.gov Webpage
- Load Operational Software on over 1 million SAASM Receivers
- Distribute PRNs for the World
 - Including 90 for GNSS

International Cooperation

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





GPS Constellation

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- Very robust constellation
 - 31 space vehicles currently in operation
 - 8 GPS IIA
 - 12 GPS IIR
 - 7 GPS IIR-M
 - 4 GPS IIF
 - 4 additional satellites in residual status, 1 in test status
- Global GPS civil service performance commitment met continuously since Dec 1993
 - Best performance 47 cm URE 8 Jun 13; previous best 51.4 cm URE 21 Apr 13
 - Performance improving as new satellites replace older satellites

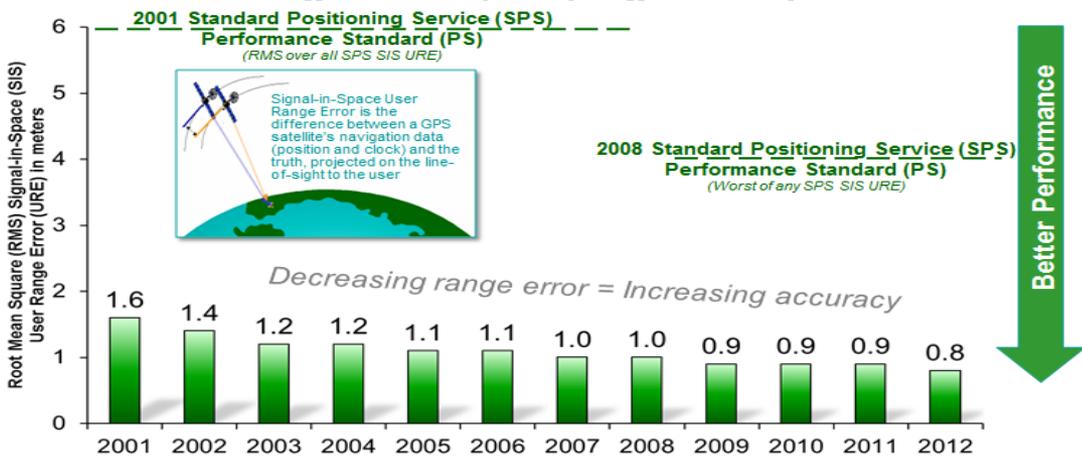




GPS Signal in Space Performance

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



Mining and Construction



Precision Agriculture

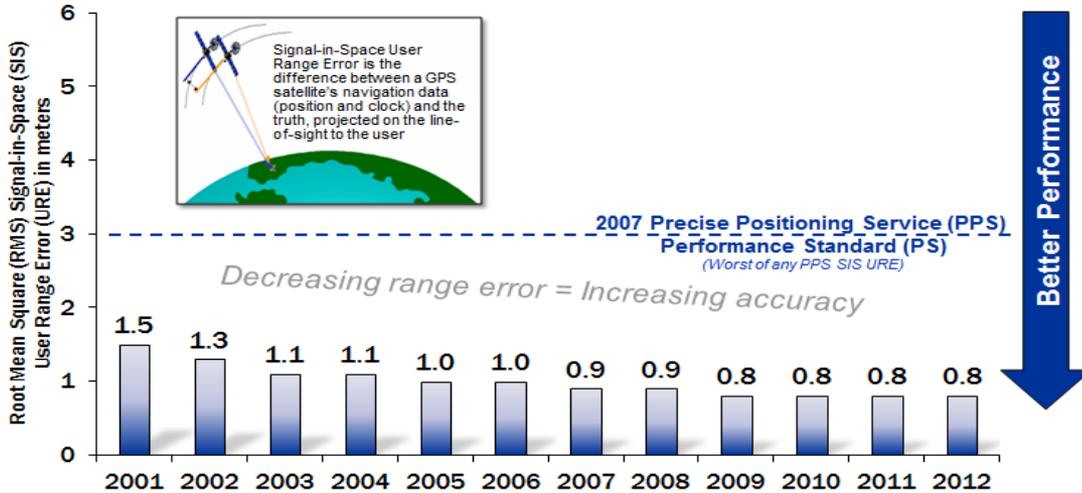


Wildlife Research



Aviation

Precise Positioning Service (PPS) Signal-in-Space Performance



Precision Navigation



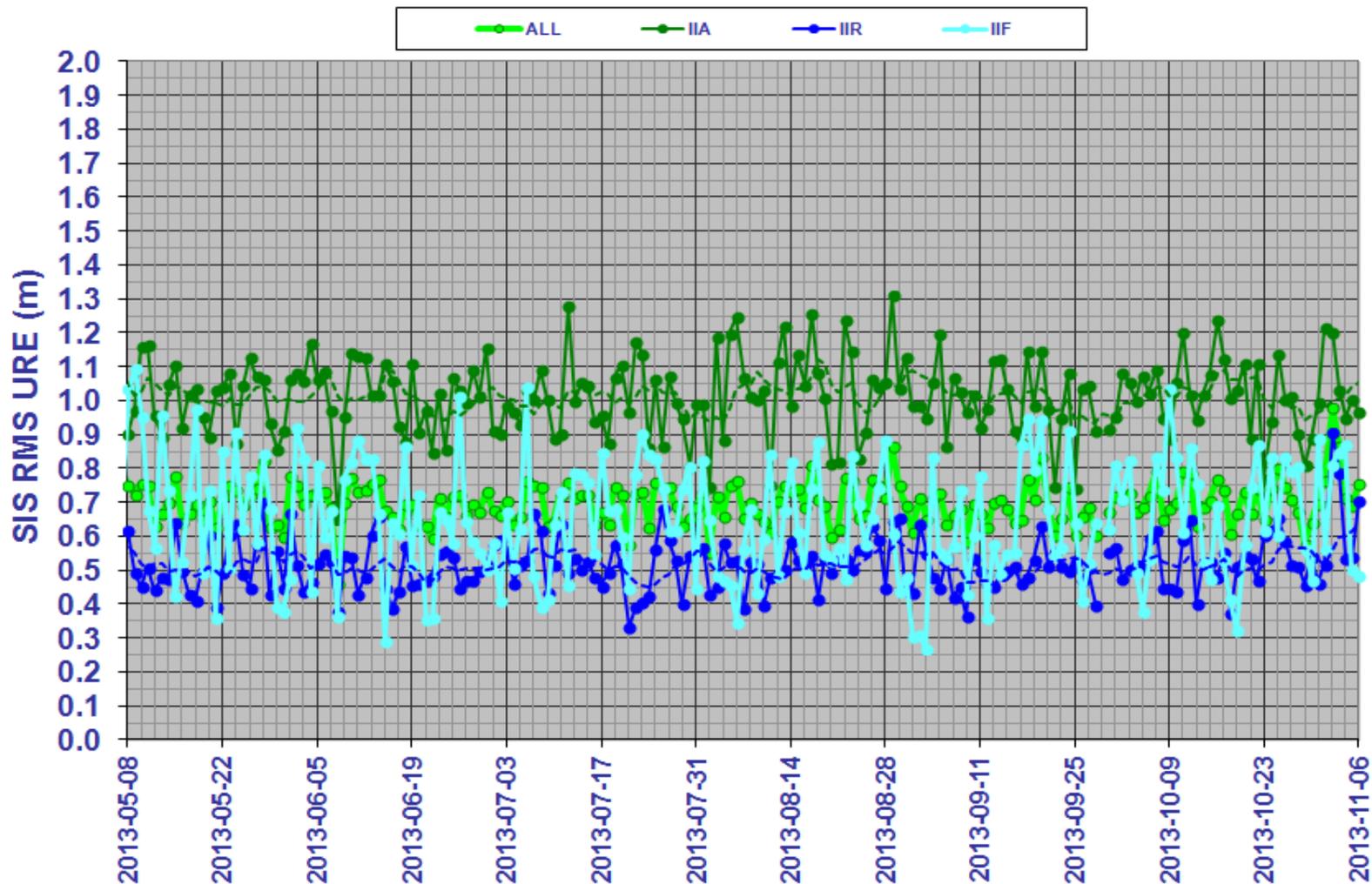
System accuracy exceeds published standard



GPS Performance – Past 6 Months

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As-Broadcast SIS vs JPL Real Time

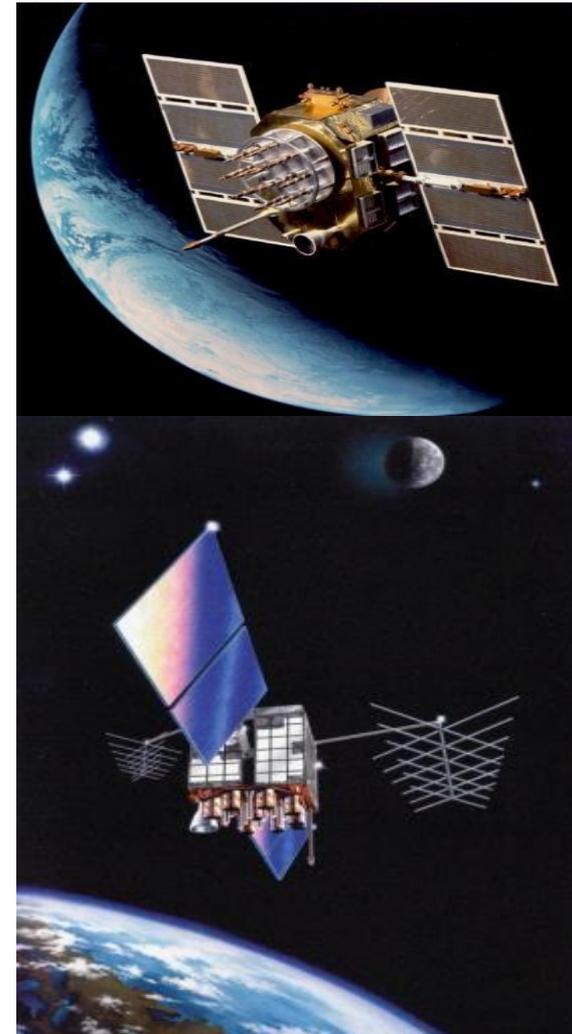




GPS IIA/IIR/IIR-M Status

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- 19 GPS IIR and IIR-M satellites are on orbit
 - Current backbone of the GPS constellation
 - SIS URE of 0.51 meters (1 yr performance Jun 2013)
- Excellent life expectancy
 - IIAs performing well past design life (2.5x on avg)
 - IIR/IIR-M solar array capacity far exceeds specified Mean Mission Duration
 - No IIR/IIR-M clock failures to date
 - IIR/IIR-M battery life extension underway





GPS IIF Status

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- Launched GPS IIF-4 on 15 May 13
 - Satellite Vehicle Number 66, PRN 27
 - Set healthy 21 Jun 13
 - Fourth operational L5 signal
 - Providing enhanced GPS clock performance
- 4 total GPS IIFs on orbit
 - Continued demonstration of Flex Power capability
- 8 more GPS IIFs in the pipeline
 - Next launch tentatively scheduled for Dec 2013
 - SVs 6-9 are in storage
 - SVs 10-12 are accepted pending testing
 - Improved Rubidium clocks on SVs 3 and 5-12





GPS III Status

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- Newest block of GPS satellites
 - First satellite to broadcast common L1C signal
 - Multiple civil and military signals; L1 C/A, L1 P(Y), L1M, L1C, L2C, L2 P(Y), L2M, L5
 - Three Rubidium clocks
- Achieved SV01 initial power turn-on 27 Feb 13
- GPS Satellite Simulator delivered to support OCX, 21 May 13
- GPS Non-Flight Satellite Testbed electrical and mechanical testing underway at Cape Canaveral

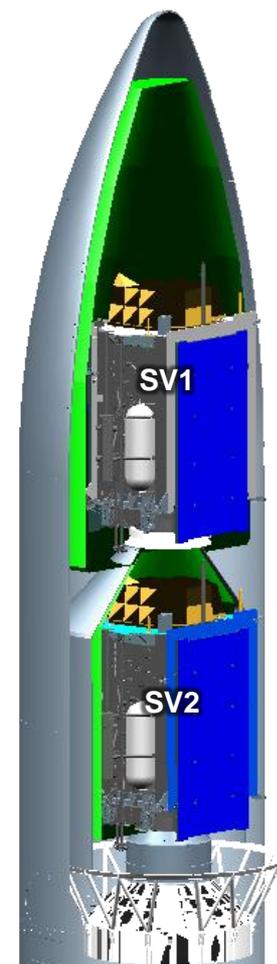




Enabling Affordability & Capability

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- Dual launch of GPS III satellites significantly reduces launch costs GPS and Launch Directorates are coordinating on final requirements for a GPS-specific dual payload adapter and mission profile requirements
 - Early studies indicate only minor changes needed to support this capability, with minimal changes in the production line of GPS III Space Vehicles
- Future Size, Weight, Power (SWAP) considerations
 - Improved Battery & Solar Array Efficiency
 - High Efficiency Amplifiers (GaN, TWTA)
 - Reprogrammable Digital Waveform Generator
- Added Capability
 - Search and Rescue/GPS
 - Laser Retroreflector Arrays
 - Unified S-Band TT&C
 - Multi-GNSS Receiver



**Notional
Dual Launch
Configuration**



Ground Segment Status

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- Current system Operational Control Segment (OCS)
 - Flying GPS IIA/IIR/IIR-M/IIF constellation with AEP 5.8.2 and LADO 2.11.2A currently deployed
- Next Generation Operational Control System (OCX) on track
 - Exercise 3 completed on schedule, demonstrated:
 - End to end capability from satellite separation to on orbit planning
 - Successful anomaly resolution
 - OCX Block I Ready to Transition to Operations planned for 2016
- OCX development successes:
 - Interim Authority to Test granted to Launch and Checkout System by Space Designated Accreditation Authority (Jun 2013)
 - Demonstrated reduction in navigation estimation error (JPL Data)
- OCX to GPS III Integration Status
 - Initiated Hardware in the Loop (HWIL) testing using OCX LCS
 - Communicated with Ground Non-flight Satellite Testbed at Cape Canaveral
 - Actively working System Integration demonstrations highlighting key system interactions



Monitor Station



Ground Antenna

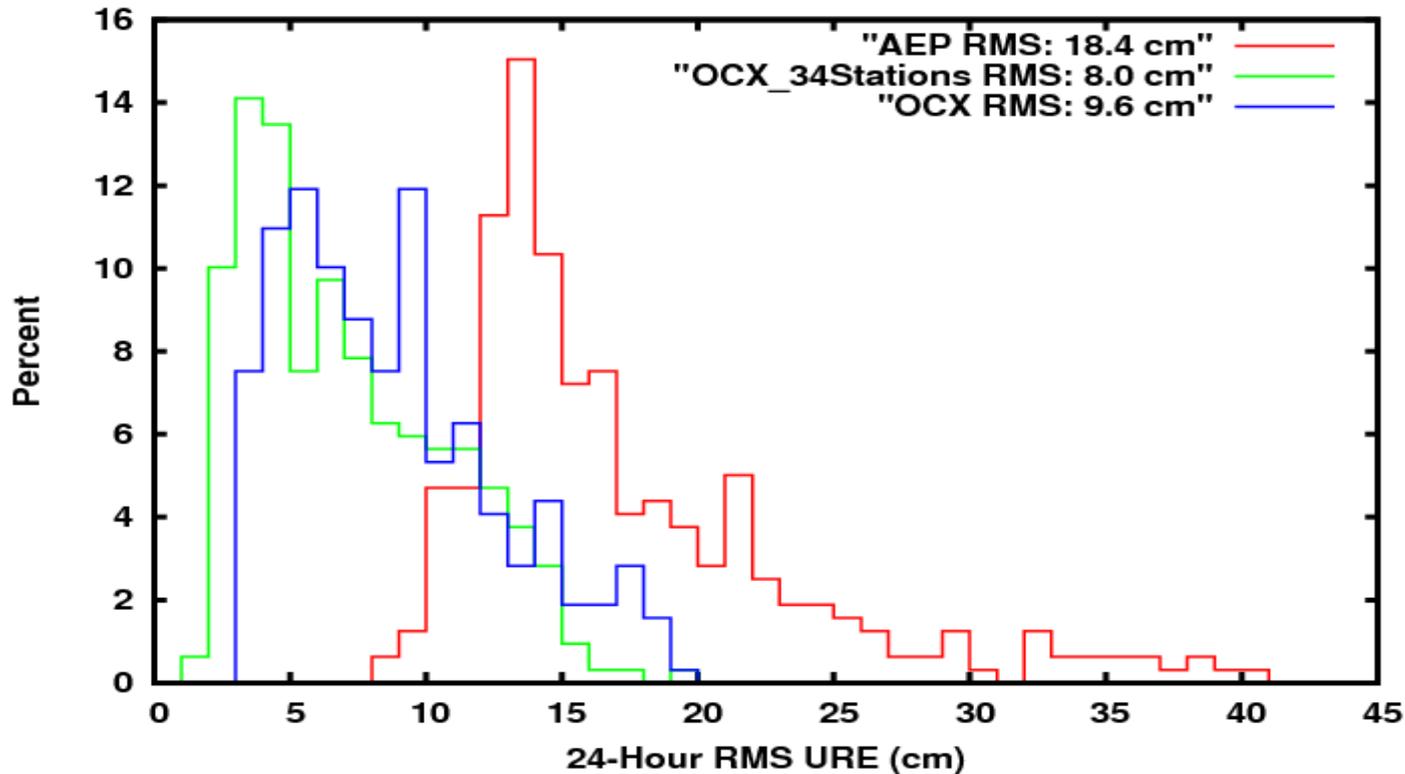


OCX Estimated Performance

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- JPL has employed OCX core Kalman filter for over 6 months
- User Range Error = Satellite Ephemeris Error + Satellite Clock Error

Aug. 5-15, 2012 Zero Age of Data RMS URE



* Zero Age of Data is a current estimation, not a prediction



GPS Modernization – New Civil Signals

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- Second civil signal “L2C”
 - Designed to meet commercial needs
 - Available since 2005 without data message
 - Phased roll-out of CNAV message
 - Currently 11 SVs broadcasting L2C



- Third civil signal “L5”
 - Designed to meet transportation safety-of-life requirements
 - Uses Aeronautical Radio Navigation Service band
 - Currently 4 SVs broadcasting L5

- Fourth civil signal “L1C”
 - Designed for GNSS interoperability
 - Specification developed in cooperation with industry
 - Launches with GPS III in 2015
 - Improved tracking performance



Urban Canyons

Improved performance in challenged environments

Early CNAV test conducted in Jun 2013



Jun 2013 Civil Navigation (CNAV) Testing

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- GPS CNAV testing publicized in advance through various PNT conferences and online at GPS.gov
- First CNAV live-sky test broadcast with civil input
 - Demonstrated CNAV messaging on GPS IIR-M & IIF SVs (L2C, L5)
 - Focused on basic PNT functionality
- Broadcast populated messages for two weeks
 - Contents included: CNAV ephemeris, clock, almanac, and non-navigation message types
- Perfect opportunity to identify or explore any CNAV message issues in order to implement fixes before operations
- CNAV returned to default message type 0 at test conclusion
- CNAV User Range Error results within GPS Standard Positioning Service Performance Standard (< 4m RMS)
- Further CNAV tests will be conducted to continue to troubleshoot before CNAV message is set healthy



US Gov't Committed to Civil Signals

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- The modernized civil signal deployment is in progress
 - 11 L2C and 4 L5 capable SVs on orbit
 - OCX will implement full command & control of L2C & L5
 - Expect the 1st L1C SV launch in 2015
- Intend to maintain semi-codeless phase relationships until 31 Dec 20
 - Documented in Federal Radionavigation Plan 2012
- Semi-codeless users should start transitioning to L2C
 - Most high-precision manufacturers already offer L2C capable receivers
 - Significant benefits available now
- Complete civil signal constellation implementation limited by:
 - Constellation health – currently enjoy a robust combination of legacy signals
 - Launch opportunities – acceleration possible with dual launch of GPS III

The PNT EXCOM drives civil signal implementation



Modernized Civil GPS Capability Features

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2nd Civil Signal (L2C)

Provide dual-frequency civil navigation and extend GPS availability in challenged environments



3rd Civil Signal (L5)

Provide dual-frequency and/or triple-frequency civil navigation and safety-of-life signals



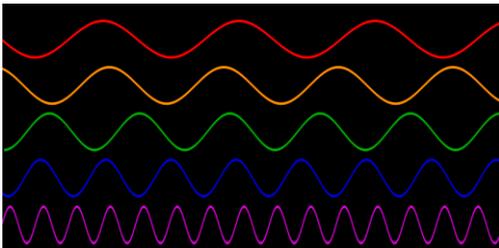
4th Civil Signal (L1C)

Provide internationally harmonized civil navigation signals



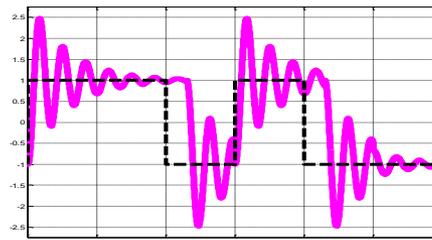
Precision Carrier Phase Tracking

Dataless pilot channels for precision carrier phase lock loop track



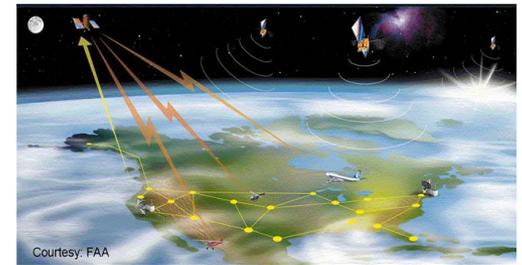
Monitored Integrity

On-board monitoring for clock anomalies, ground monitoring for signal malformation anomalies



External Augmentations

Extend GPS accuracy and integrity for safety-of-life applications

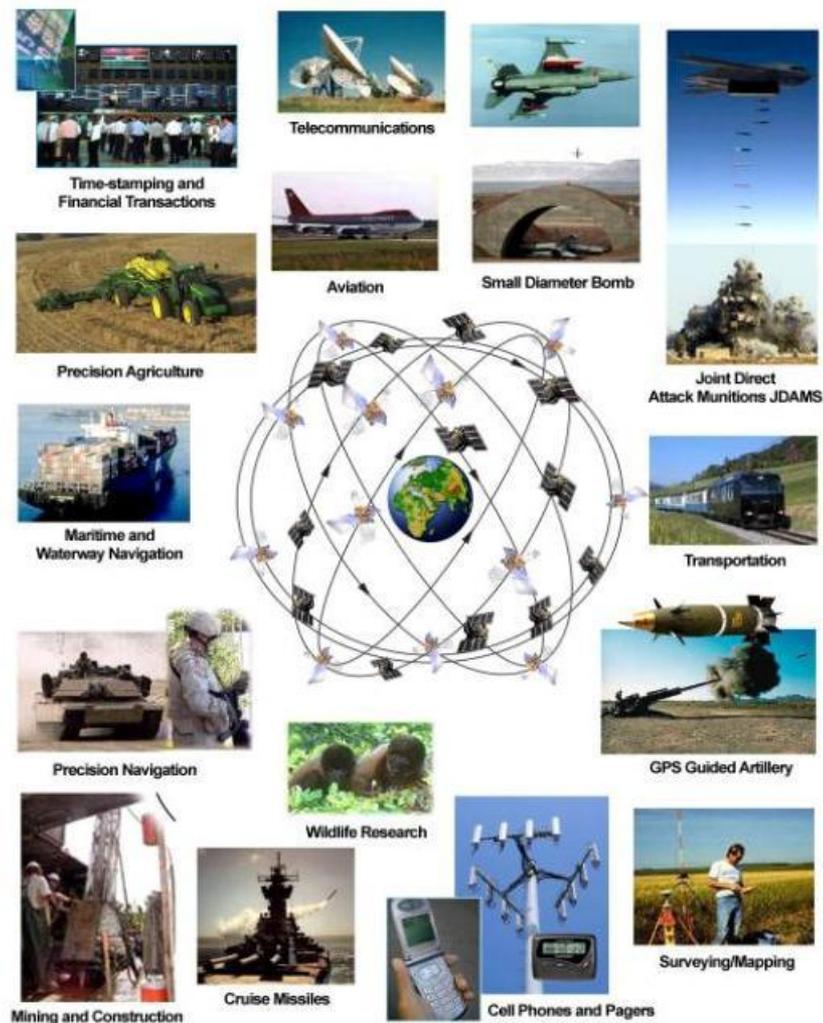




Summary

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- GPS has continuously met its commitments to all users
- GPS had multiple operational and acquisition successes in the past year
- Modernization of all GPS Segments is on track
- Striving to continually improve navigation and timing services while maintaining backward compatibility with legacy equipment



Maintaining and improving GPS services for all users is Job #1