Headquarters U.S. Air Force

Integrity - Service - Excellence

GPS PROGRAM UPDATE

U.S. AIR FORCE

ICG Expert Meeting on GNSS
15 July 2008
Montreal, Canada

Lt Col Patrick Harrington
SAF/USAL

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Overview

- GPS Constellation Status and Modernization
- GPS Signals
- GPS Services (Performance Standards)
- Compatibility and Interoperability
- Summary

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GPS Constellation Status & Availability

as of 15 Jul 08

- 13 Block IIA satellites operational
- 12 Block IIR satellites operational
- 6 Block IIR-M satellites operational
  - 2 additional IIR-M satellites to launch
- Since Dec 93, U.S. Government met/exceeded civil GPS service performance commitments
  - SPS Performance Standard (PS)
- U.S. DoD committed to superior GPS service

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GPS Evolution – Continuous Improvement

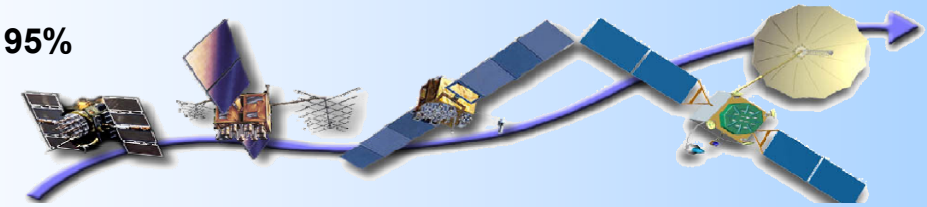
Space Segment

Legacy (Block IIA/IIR)
- Std Service (≤ 6 meters RMS SIS SPS URE)
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service (≤ 2.6 m 95% URE PPS at Zero AOD)
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Modernized (Block IIR-M)
- 2nd civil signal (L2C)
- M-Code signals (L1M, L2M)
- Anti-jam flex power

Modernized (Block IIF)
- 3rd civil signal (L5)

GPS III (Block III)
- Increased accuracy
- Increased A/J power
- Signal integrity
- Search and Rescue
- L1C civil signal common w/Galileo, QZSS, & possibly GLONASS



Ground Segment

Legacy
- TT&C
- L1 & L2 monitoring

Upgraded (AEP)
- IIR-M IIF TT&C
- WAGE, AII, LADO
- NMCS/AMCS

Modernized (OCX V1)
- New Architecture
- Signal Monitoring

GPS III (OCX V2)
- GPS III TT&C
- Real-Time C2

GPS III Block Based Capabilities

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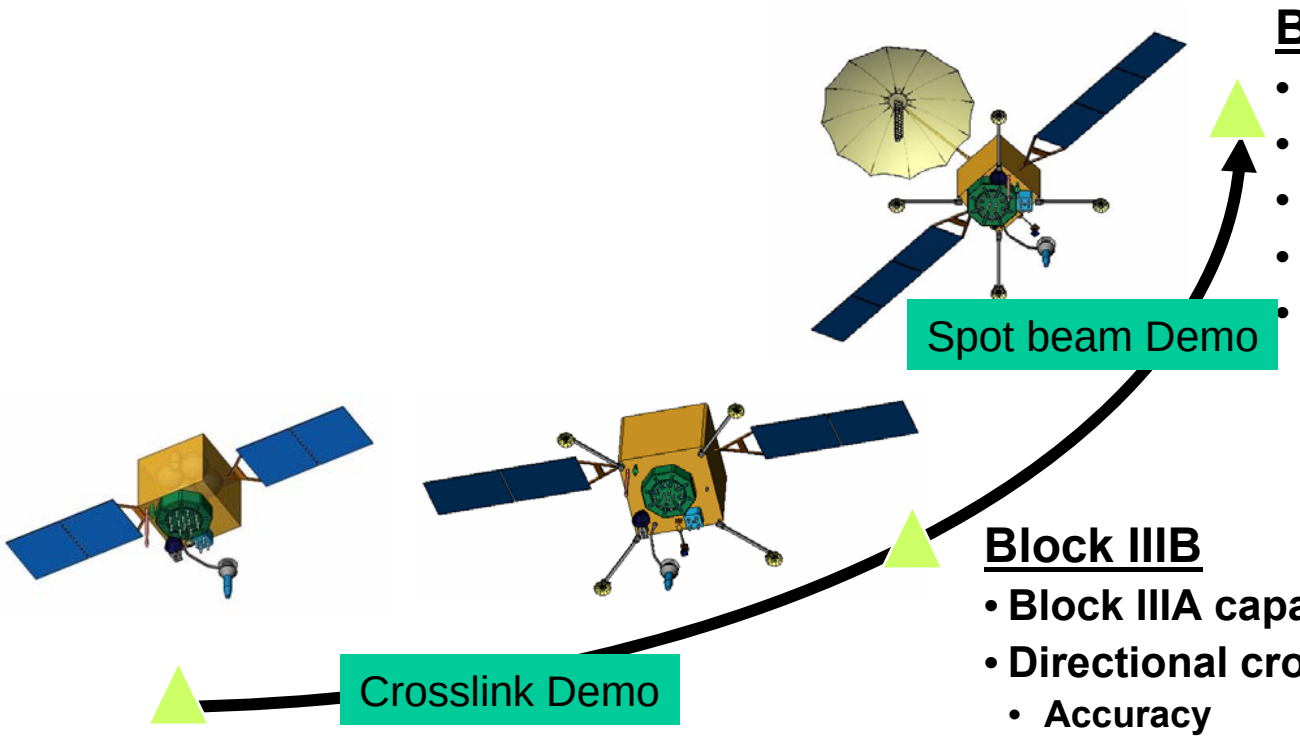

Block IIIC
- Block IIIB capabilities
- NAVWAR spot beam
- Flexible payload
- Integrity monitoring
- Potential SEDP

Block IIIB
- Block IIIA capabilities
- Directional crosslink antennas
  - Accuracy
  - Integrity
  - NAVWAR C2
- High-speed UL/DL antenna
- Potential DASS

Block IIIA

IIF capabilities plus:
- Enhanced Earth Coverage M-Code
- Commonality with Galileo (L1C)
- IIIA bus: foundation for IIIC

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GPS Operational Control Segment

Schriever AFB, CO

- **New Master Control Station (NMCS)**
  - Improved operator interfaces
  - Includes AFSCN Interface
- **Launch and Early Orbit, Anomaly Resolution and Disposal Operations (LADO) System**

Vandenberg AFB, CA

- **Alternate Master Control Station (AMCS)**

L-Band 

S-Band 

6 GPS Monitor Stations
11 NGA Monitor Stations

4 GPS Ground Antennas
8 AFSCN ARTS Antennas

Worldwide Network Allows Near Continuous Satellite Coverage

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GPS Modernization

- Block IIF
  - 12 satellites
  - First launch 2009
- Block III Satellites
  - Capabilities released in increments: A, B, & C
  - Contract awarded to Lockheed Martin May 2008
  - First launch planned for 2014
- Operational Control Segment
  - Capabilities tailored to match Block III satellites
  - Contracts awarded to Raytheon & Northrop Grumman Nov 2007

Area	Capability	IIR/M	IIF	IIIA
Bus	Modern bus w/ margin for growth	No	No	Yes
Navigation Signals	L1 C/A, L2C, P(Y), M-code	Yes	Yes	Yes
	L5: I, Q	No†	Yes	Yes
	L1C	No	No	Yes
Network comm	S-Band Up/Down links	Yes	Yes	Yes

† IIR-20(M) will have an L5 demonstration payload

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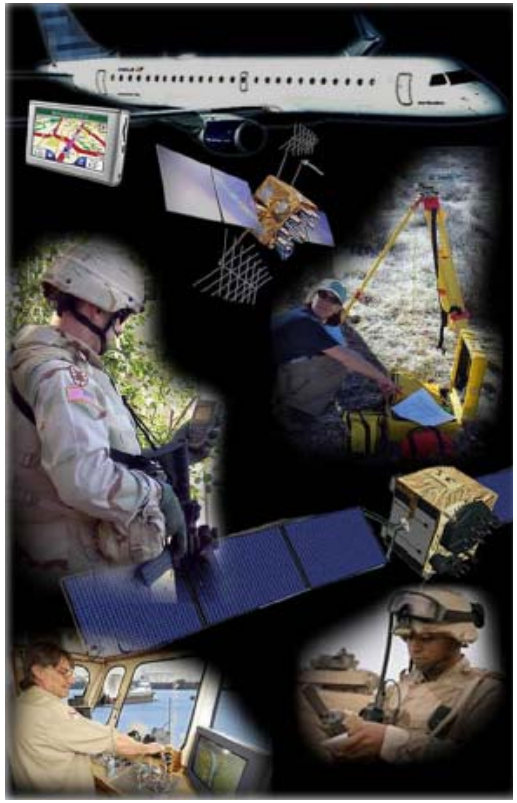
Civil Capability Improvements

- L2C
  - 24 operational satellites in FY16
- L5
  - Demonstration payload on IIR-20(M)
  - 24 operational satellites in FY18
- L1C
  - 24 operational satellites in FY21
- Integrity Monitoring
  - GPS III integrity enhanced by SV reliability and on-board clock monitoring



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GPS Signal Background

- Signal descriptions (ICDs, ISs) publicly available for civil GPS signals at

http://gps.losangeles.af.mil/engineering/icwg/

  - IS-GPS-200D for C/A code, P(Y) code, and L2C
  - IS-GPS-705 for L5
  - IS-GPS-800 for L1C
- Center frequencies
  - L1 = 1575.42 MHz = 154 × 10.23 MHz
  - L2 = 1227.60 MHz = 120 × 10.23 MHz
  - L5 = 1176.45 MHz = 115 × 10.23 MHz
- All signals are nominally right hand circularly polarized (RHCP)
- All signals use code division multiple access (CDMA)
- Received signal power measured using 3 dBi linearly polarized antenna, located near the ground, at worst normal orientation, at elevation angles greater than 5 degrees

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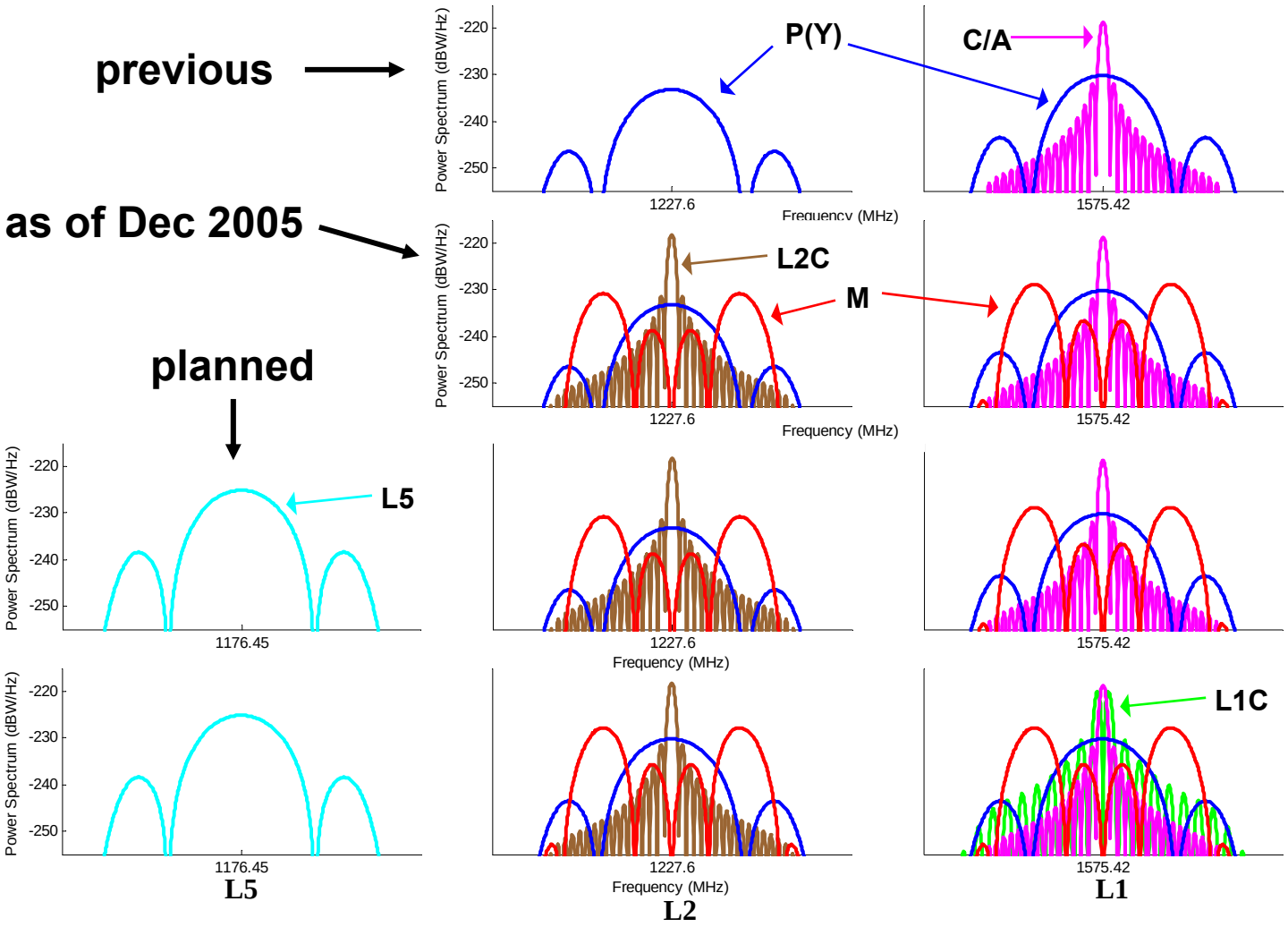
GPS Modernization – Spectrum

previous

as of Dec 2005

planned

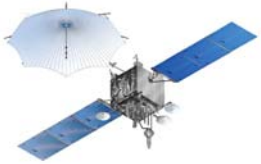


Block IIA, 1990

Block IIR-M, 2005

Block IIF, 2009

Block III, 2014



(artist's concept)

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GPS C/A Code Signal Characteristics

- Carrier frequency: L1 (quadrature phase)
- Received Power:
  - Minimum of –158.5 dBW, maximum near –153 dBW
- Spreading modulation: BPSK-R(1)
- Spreading codes: 1023-bit Gold codes
- Data modulation: 50 sps biphase modulation of all spreading code bits
- Overlay codes: none
- Data message structure: NAV message, 50 bps
- Data message channel encoding: no FEC, no interleaving
- Multiplexing
  - Block IIA and IIR satellites: phase quadrature with L1 P(Y)
  - Block IIR-M and IIF satellites: Y, M, C/A Interplex, C/A still in phase quadrature with P(Y)
  - Block III satellites: not yet defined

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GPS P(Y) Code Signal Characteristics

- Carrier frequencies: L1 and L2 (in phase)
- Received Power: L1 and L2: minimum of –161.5 dBW, maximum near –150 dBW (IIR-M and IIF)
- Spreading modulation: BPSK-R(10)
- Spreading codes: P codes or encrypted (Y) codes
- Data modulation: 50 sps biphase modulation of all spreading code bits
- Overlay codes: none
- Data message structure: NAV message; optional no message on L2
- Data message channel encoding: no FEC, no interleaving
- Multiplexing
  - Block IIA and IIR satellites: L1—phase quadrature with C/A, L2—P(Y) or C/A
  - Block IIR-M and IIF satellites: L1—Y, M, C/A Interplex, P(Y) in phase quadrature with P(Y); L2—Y, M, L2C Interplex
  - Block III satellites: not yet defined

GPS L2C Signal Characteristics

- Carrier frequency: L2 (quadrature phase—usually)
- Received Power:
  - Minimum of –160.0 dBW, maximum near –155 dBW
- Spreading modulation: BPSK-R(1)
- Spreading codes: 10230 bit L2CM codes and 767250 bit L2CL codes, alternating bits time division multiplexed
- Data modulation: 50 sps biphase modulation of L2CM bits (time division data multiplexing)
- Overlay codes: none
- Data message structure: NAV or L2 CNAV message, 25 bps
- Data message channel encoding: ½ rate convolutional code with constraint length 7, no interleaving
- Multiplexing
  - Block IIR-M and IIF satellites: Y, M, L2C Interplex
  - Block III satellites: not yet defined

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GPS M-Code Signal Characteristics

- Carrier frequencies: L1 and L2
- Spreading modulation: BOC(10,5)
- Spreading codes: Authorized user only
- Data modulation: 3 rates available—200 sps, 50 sps, no data (time division data multiplexing on every other spreading code bit)
- Overlay codes: none
- Data message structure: MNAV (100 bps, 25 bps, 0 bps)
- Data message channel encoding: ½ rate convolutional code with constraint length 7, interleaving
- Multiplexing
  - Block IIR-M and IIF satellites: L1-Y, M, C/A Interplex, L2-Y, M, L2C Interplex
  - Block III satellites: not yet defined

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GPS L5 Signal Characteristics

- Carrier frequency: L5 (in-phase and quadrature-phase)
- Received Power:
  - Minimum of –154.9 dBW, maximum near –150.0 dBW (each L5 signal channel)
- Spreading modulation: BPSK-R(10)
- Spreading codes: distinct 10230 bit I5 codes and 10230 Q5 codes, for pilot and data, in phase quadrature, defined in IS-GPS-705
- Data modulation: 100 sps biphase modulation of in-phase spreading code bits (phase division data modulation)
- Overlay codes: 10 bit, 1 kbps Neuman-Hofman code “synchronization sequence” on I5, 20 bit, 1 kbps Neuman-Hofman code “synchronization sequence” on Q5, defined in IS-GPS-705
- Data message structure: L5 CNAV message, 50 bps
- Data message channel encoding: ½ rate convolutional code with constraint length 7, no interleaving
- Multiplexing: no other GPS signals on L5

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GPS L1C Signal Characteristics

- Carrier frequency: L1
- Received Power: Minimum of –157 dBW, maximum near –154 dBW (–150 dBW for receiver design purposes)
- Spreading modulation
  - Baseline: BOC(1,1) for both pilot and data components
  - Option: Multiplexed BOC, MBOC(6,1,1/11); TMBOC(6,1,4/33) on pilot component, BOC(1,1) on data component
- Spreading codes: distinct 10230-bit Weil-based codes for pilot and data
- Data modulation: 100 sps biphase modulation of data component
- Overlay code on pilot: 1800 bits long at 100 bps
- Data message structure: CNAV2 message, 50 bps
- Data message channel encoding: half-rate Low Density Parity Check (LDPC) FEC, block interleaving
- Multiplexing on Block III satellites: not yet defined

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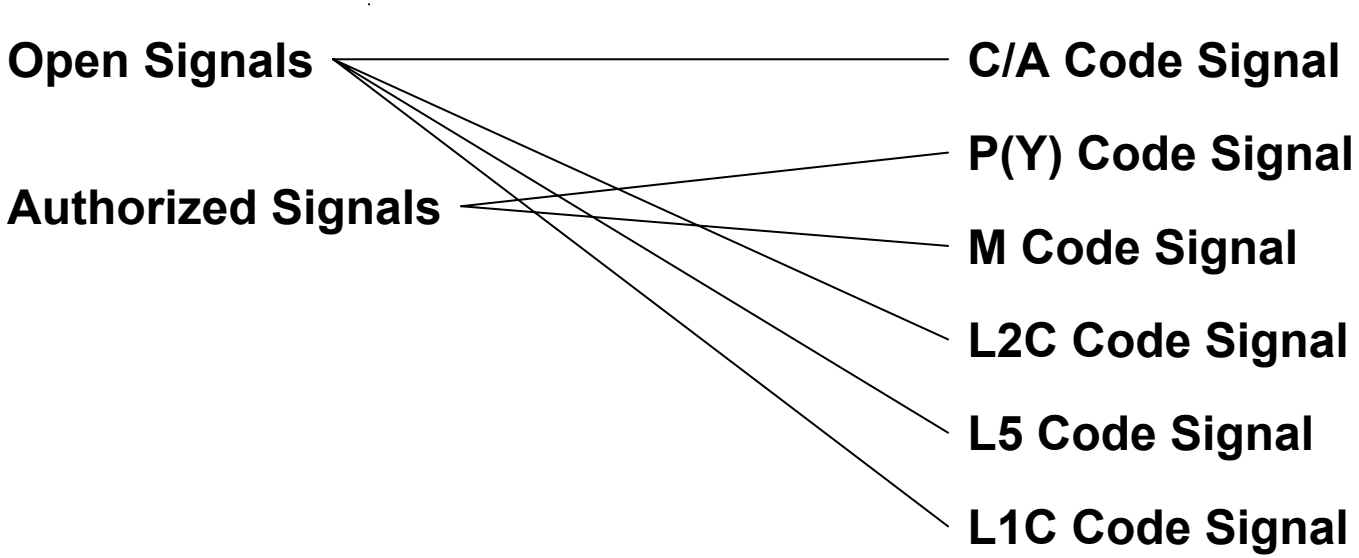
Allocation of GPS Signals



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GPS Performance Standards

- Purpose: GPS Performance Standards (PS) define the levels of performance the U.S. Government commits to provide
- The standards define: Reference orbit parameters; Orbital slot configurations; Coverage ; Accuracy; Integrity; Continuity; and Availability for the GPS Space and Control Segments
- Standard Positioning Service (SPS) PS
  - Intended for civil users
  - Single frequency (L1: C/A-Code)
  - Published in 2001
  - Draft update in work (expect publication soon)
- Precise Positioning Service (PPS) PS intended for
  - Intended for authorized users
  - Dual frequency (L1: P(Y)-Code and C/A-Code, L2: P(Y)-Code)
  - First published in February 2007

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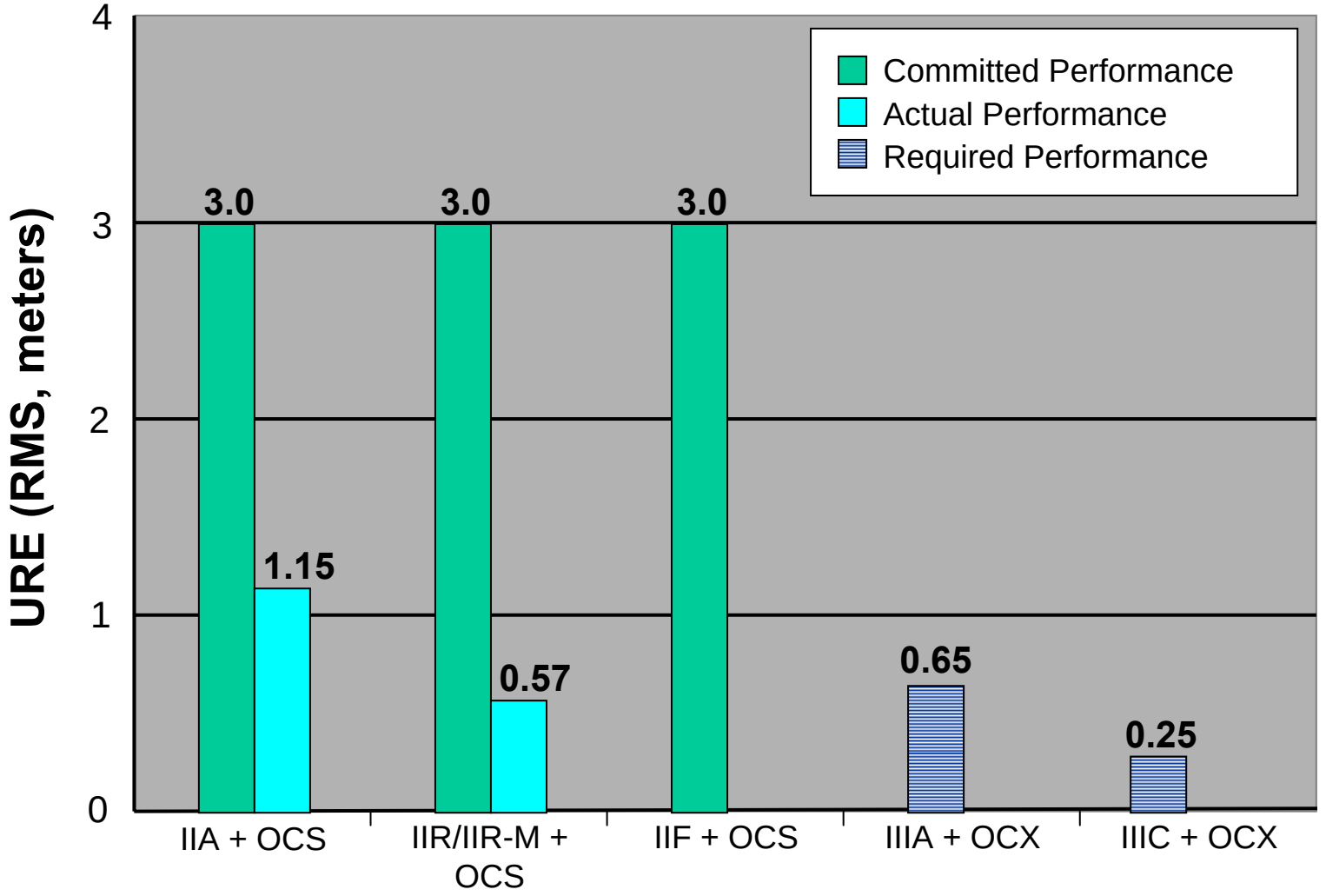
GPS Performance Standards- Highlights

Parameter	SPS PS (Oct 2001)	PPS PS (Feb 2007)	Draft SPS PS (soon)
Orbital Slots	24 Baseline slots	24 + 3 Expandable Slots	TBA
Accuracy	≤ 6m [single freq] (RMS) URE, Global Avg, 24hr Avg	≤ 5.9m [dual freq] (95%) URE, Global Avg, All AODs	TBA
Integrity	Not addressed	≤ $1x10^{-5}$ /hr w/out timely alert	TBA

GPS Performance Standards available on the Internet
http://gps.afspc.af.mil/gpsoc/gps_documentation.aspx

Accuracy Depends on User Range Error (URE)



"User Range Error" will continue to dramatically improve

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GPS Compatibility and Interoperability

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Definition of Compatibility

- "Compatible" refers to the ability of U.S. and foreign space-based positioning, navigation, and timing services to be used separately or together without interfering with use of each individual service or signal, and without adversely affecting navigation warfare

Compatible = Do No Harm

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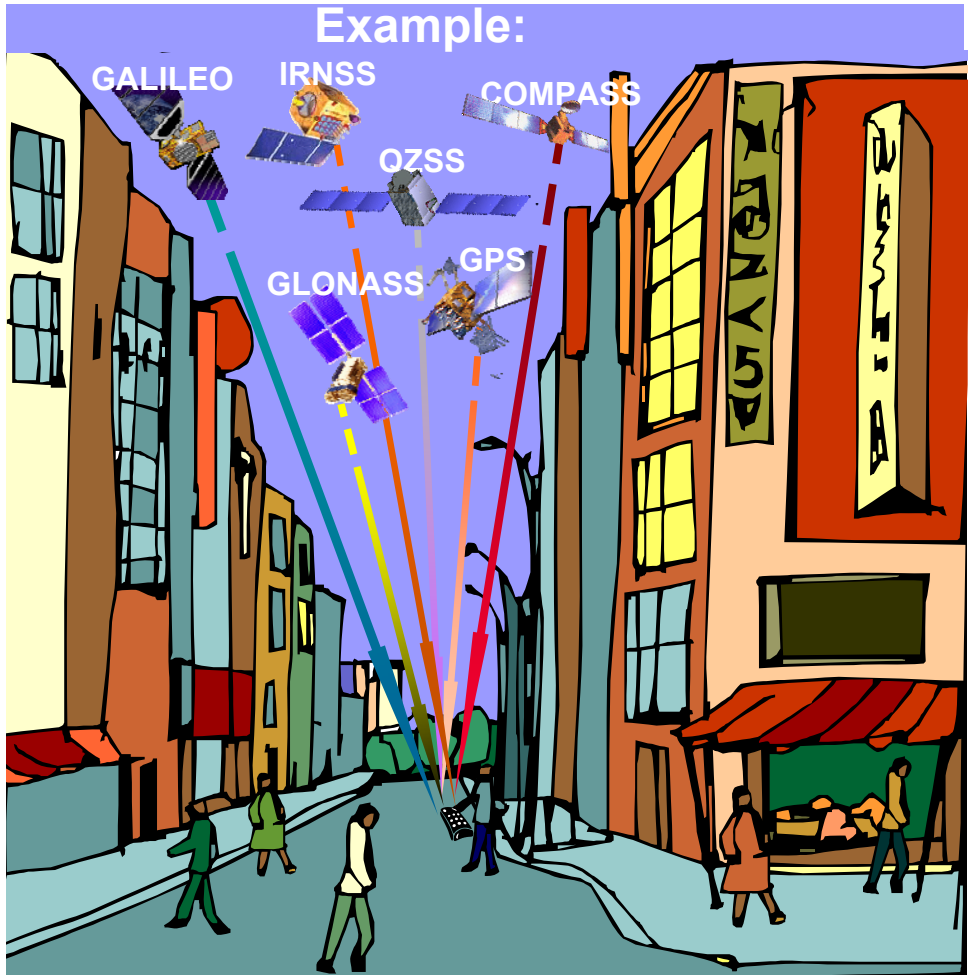
Goal of Civil Interoperability



- Interoperability provides users a better PNT solution using signals from multiple GNSSs rather than from one GNSS
- Ideally, interoperability involves no additional receiver cost or complexity

Interoperable = Better Together Than Separate

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U.S. Priorities

1. **Compatibility: Newly introduced signals should be compatible with GPS signals…and vice-versa**
   - **Radio frequency compatibility: signals do not unacceptably interfere with use of other signals**
   - **Spectral separation between M code and other signals**

2. **Interoperability: Encourage newly introduced civil signals to be highly interoperable with GPS civil signals**
   - **Primary focus on L1C and L5 signals**

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Mutual Benefits

- U.S. suggests that compatibility and interoperability are beneficial to both GPS and other systems
- Compatibility protects full utility of each system
  - For example, spectral separation from M code not only protects utility of M code, but also protects other systems signals
  - Avoids interference to other systems from higher power M code and large GPS constellation
- Interoperability benefits users and receiver manufacturers
  - Lower cost and better performance for receivers that use GPS and other systems signals together
  - More users benefit from both systems' signals
  - More rapid and extensive adoption of highly interoperable signals
- Interoperable and compatible signals simplify international acceptance of other systems in ITU and other forums

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Summary

- Working to make the constellation even more resilient
  - Developing the next generation spacecraft with new signals and increased integrity
  - Developing a control segment with flexibility and supports diverse military and civil requirements
- GPS interface documents and performance standards available on the internet
  - GPS interface control working group is an open forum
- GPS performance will continue to improve as more modernized satellites are introduced into the constellation
- U.S. encourages compatibility and interoperability between other systems and GPS