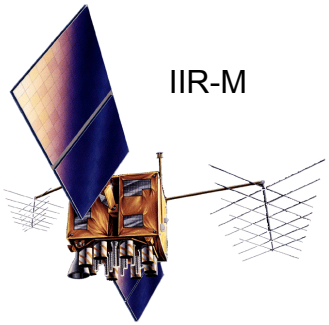


GPS Modernization Program
Current Status and Plans

National Space-Based PNT Coordination Office

Larry Hothem
Reston, VA USA

IGS Workshop 2006
Darmstadt, Germany
10 May 2006

OVERVIEW

- Background
- Positioning, Navigation, and Timing Policy
- Constellation Status
- Modernization Program
- Summary

GPS Background

- Active program for over 30 years
  - 1973: development underway from separate programs
  - 1978: begin launch developmental satellites
  - 1989: begin launch operational satellites
  - 1993: Initial Operational Capability (IOC)
  - 1995: Full Operational Capability (FOC)
- Developed as a dual-use system
  - Military applications for US and Allied use
  - Civilian applications for worldwide use
- Consistent U.S. National Policy from both Executive and Legislative branches
  - 1996, March: Presidential Decision Directive; captured by U.S. Public Law - December 1997
  - 2004, December: U.S. Space-Based Positioning, Navigation, and Timing (PNT) Policy [http://pnt.gov]

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

- **Released December 2004**
- **Recognized changes since 1996 policy**
- **Improved management for PNT issues**
- **Policy established:**
  - **National Space-based PNT Executive Committee**
  - **National PNT Coordination Office**
  - **Space-Based PNT Advisory Board, chartered as a Federal Advisory Committee (non Federal members)**
- **Publicly available information available at: http://pnt.gov**

GPS Constellation Status (1)

29 Operating Satellites
(to ensure 24)

- 16 II/IIA satellites operational
- 12 IIR satellites operational
  - Modernizing up to 8 Block IIR satellites
- 1st IIR-M, launched 25 September 2005
  - Set healthy on 16 December 2005
- 2nd IIR-M launch currently scheduled
  - Tentative: 14 September 2006
- 3rd IIR-M launch currently scheduled
  - Tentative: 14 December 2006

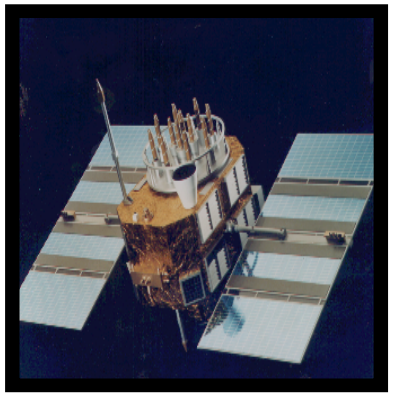


Illustration reprinted courtesy of the GPS Joint Program Office

GPS Constellation Status (2)

29 Operating Satellites
(to ensure 24)

- **Continuously assessing constellation health to determine launch need**
  - Constellation (operational) average life, as of 7 April 2006: 8.55 years
  - Sustainment issues
    - ✓ Aging satellites – past design life
    - ✓ 12 SVs launched in 1990-1994 time period
    - ✓ 12 SVs are more than 12 yrs old
      - ➢ 1 SV over 15 yrs old
    - ✓ 3 SVs about 10 years old
    - ✓ Power management requirements
- **Since December 1993 (IOC), GPS civil service performance commitment met continuously**

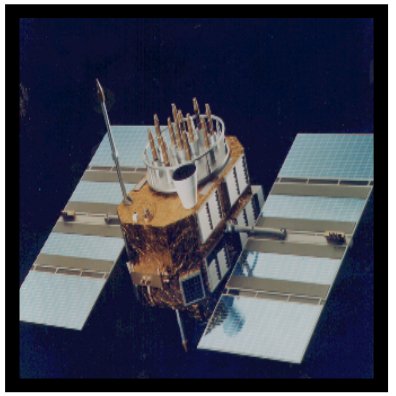


Illustration reprinted courtesy of the GPS Joint Program Office

Constellation Performance

January 1-December 31, 2004

Specification values from the Standard Positioning Service Performance Standard, October, 2001

PDOP (Geometry) Availability

- Specification - PDOP of 6 or Less, 98% of the time
- Actual - 99.98798%

Horizontal Service Availability

- Specification - 95% Threshold of 36 meters, 99% of the Time
- Actual – 2.74 meters

Vertical Service Availability

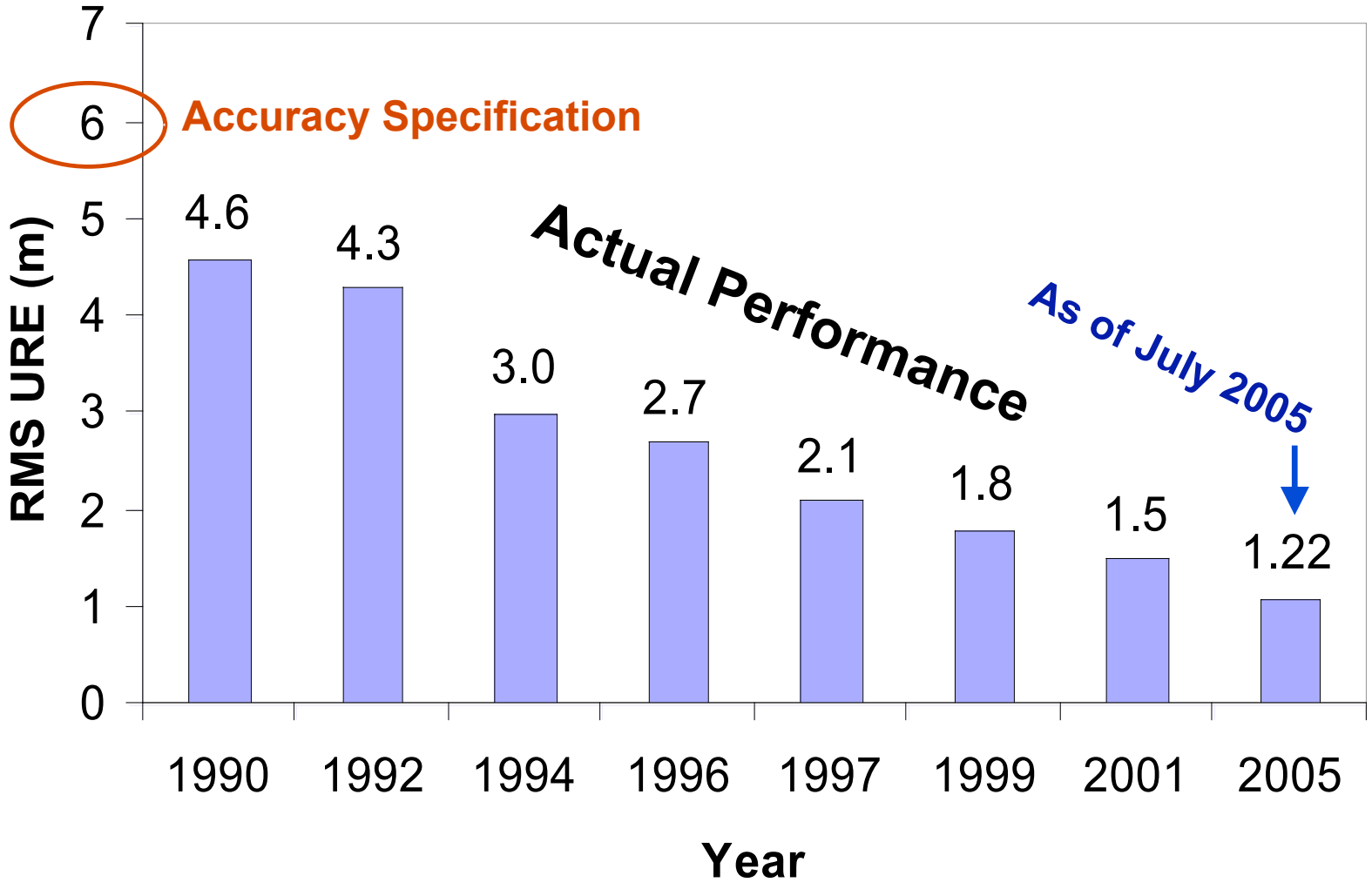
- Specification - 95% Threshold of 77 meters, 99% of the Time or Better
- Actual – 3.89 meters

User Range Error

- Specification - 6 meters or Less, Constellation Average
- Actual – see next chart

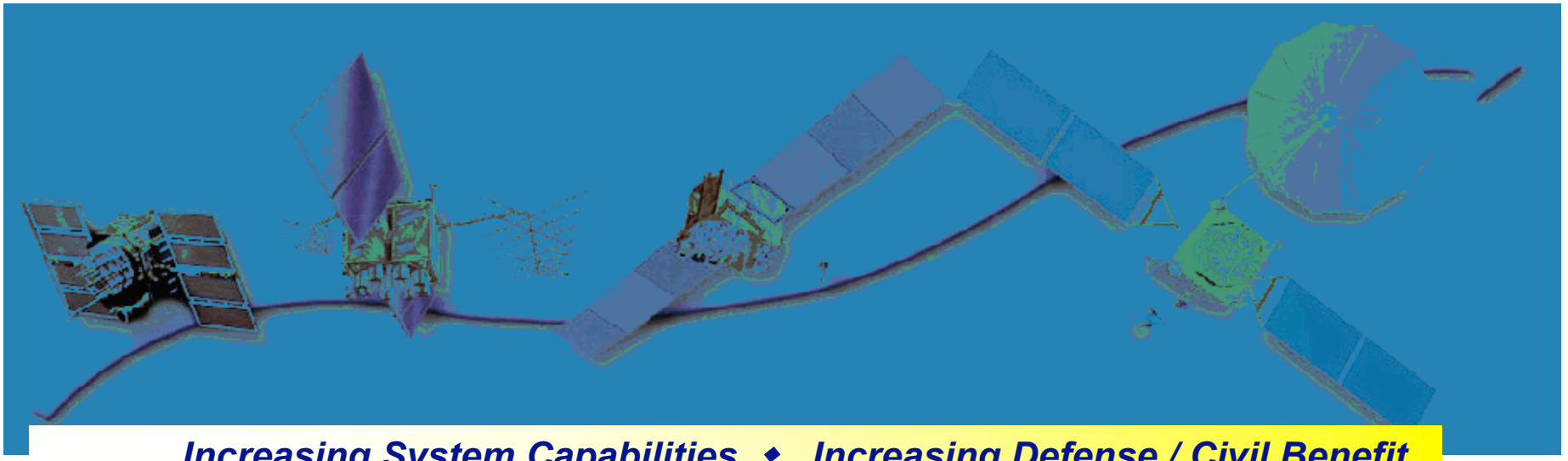
System accuracy and availability far exceed current specifications

GPS User Range Error (URE) History



System capability exceeds current specification

The GPS Modernization Path



Increasing System Capabilities ◆ Increasing Defense / Civil Benefit

Block IIA/IIR

Basic GPS

- Std Service (16-24m SEP)
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service (16m SEP)
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Block IIR-M, IIF

IIR-M: IIA/IIR capabilities plus

- 2nd civil signal (L2C)
- M-Code (L1M & L2M)
  - Eliminates SA for denial
- Anti-jam flex power

IIF: IIR-M capability plus

- 3rd civil signal (L5)
- Anti-jam flex power

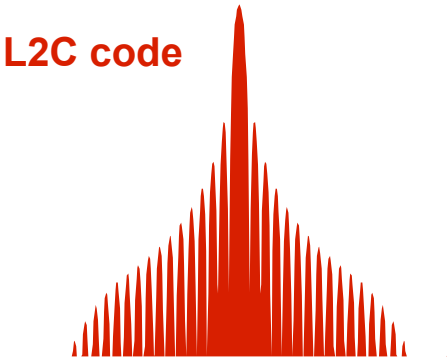
Block III

Block IIIA:

- Increased anti-jam power
- Increased security
- Increased accuracy
- Navigation surety
- Backward compatibility
- Assured availability
- Controlled integrity
- System survivability
- 4th civil signal (L1C)

Source: GPS Joint Program Office

Second Civil Signal (L2C)



Begins with IIR-M sats
24 Satellites: ~ 2012*

* Based on current schedule

- Could improve service for dual-frequency carrier phase users
- May enable higher civilian accuracy when combined with existing civil GPS signal (L1 C/A)
- Overcomes some limitations of L1 C/A
  - Higher effective power
  - Improved data structure
    - Reduce interference
    - May enable better indoor use

Third Civil Signal (L5)

L5 code

Begins with IIF sats
24 Satellites: ~ 2015*

* Based on current schedule

- **New signal structure for enhanced performance**
  - **Higher power (no less than -154.9 dBW)**
    - ✓ **Higher than other GPS civil signals**
  - **Wider bandwidth (1176.45 MHz +/- 10 MHz)**
  - **Improves resistance to interference**
- **Frequency located in Aeronautical Radionavigation Services band (1164-1215MHz)**

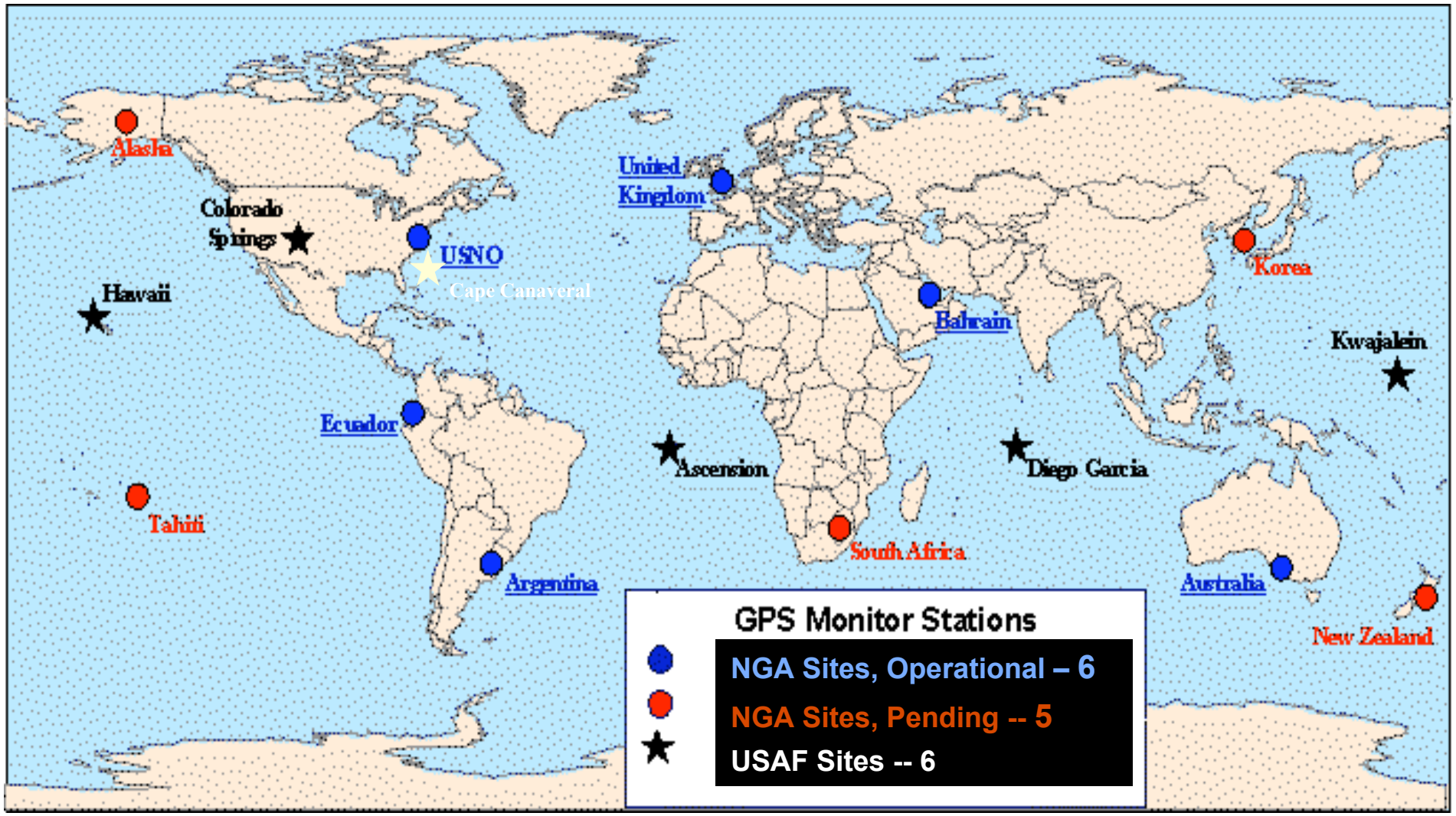
Ground Control Modernization

- **Upgraded Master Control Station (MCS) with:**
  - Improved operator interfaces
  - IIR-M and IIF capabilities
    - ✓ Monitoring all civil signals – L2C & L5 – full control
  - Launch and Early Orbit Anomaly Resolution and Disposal Operations
- **Fully mission capable Alternate MCS**
- **Legacy Accuracy Improvement Initiative (L-AII)**
  - Additional data from National Geospatial-Intelligence Agency (NGA) GPS Monitor Station Network, yielding improvement in:
    - ✓ Monitoring signal integrity and constellation performance
    - ✓ Accuracy of Kalman filter state estimates
    - ✓ Amount of data used for satellite time and position estimation, resulting in more accurate predicted satellite orbital position and clock data in the satellite broadcast message

Reference: GPS World, March 2006 – "New, Improved GPS – Legacy Accuracy Improvement Initiative"

Future GPS Monitoring Stations

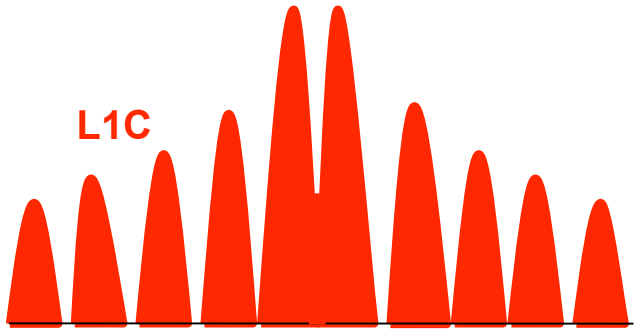
Accuracy Improvement Initiative (AII)



GPS III Goals

- Increased system accuracy
- Assured and improved level of unaugmented integrity
- Improved availability of accuracy with integrity
- Backward compatibility with existing receivers
- Support for new signals in combination with IIR-M & IIF satellites
  - L2C, L5, M-code (existing with IIR-M, IIF)
  - L1C and future options for new navigation messages, flexible power levels
- Smooth transition from GPS Block II to Block III

L1C Signal



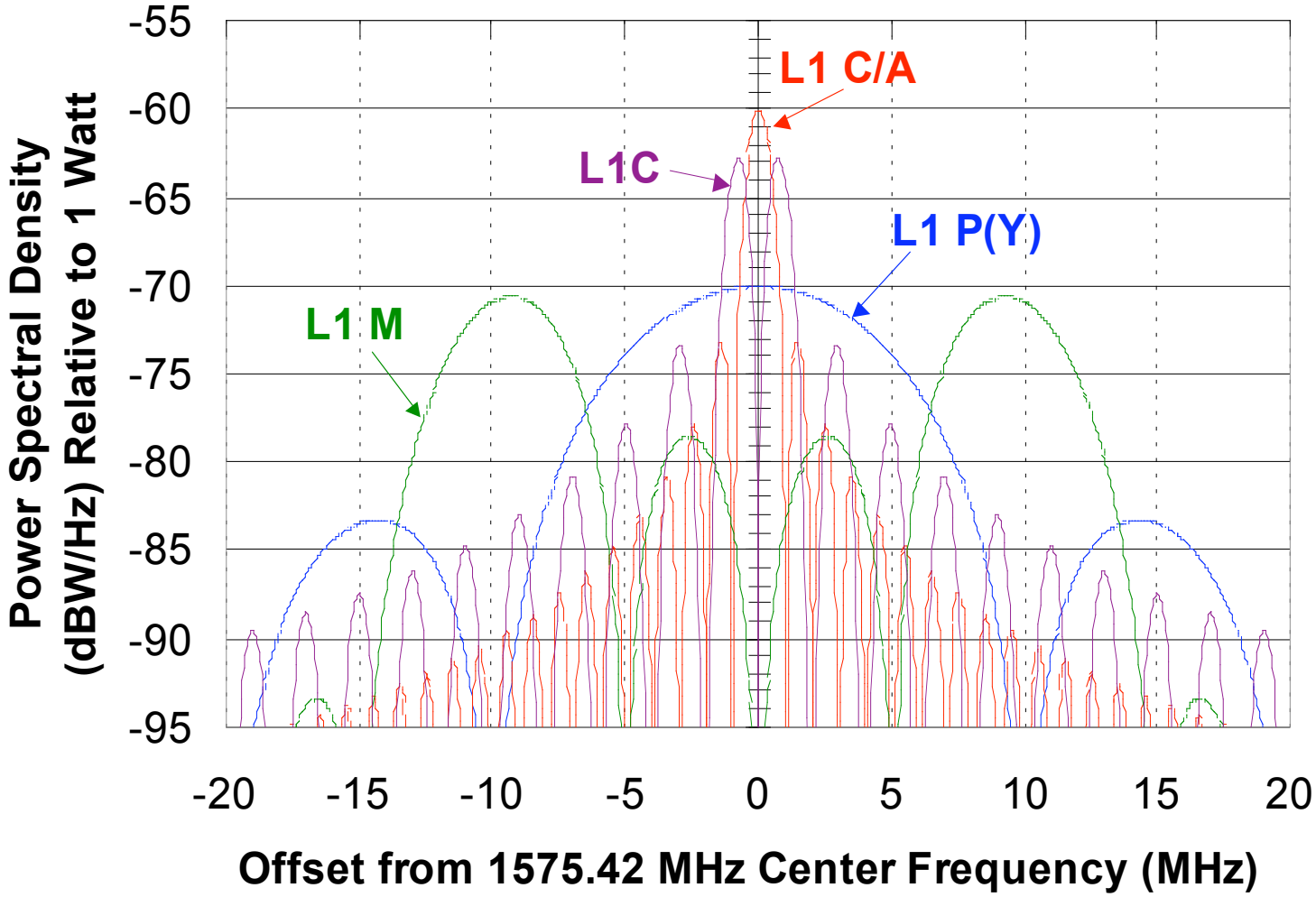
Begins with GPS III sats
First launch: ~ 2013*

* Based on current schedule

- **Modernized L1 civil signal**
  - **In addition to C/A code to ensure backward compatibility**
  - **Binary Offset Carrier [BOC] (1,1) modulation**
    - ✓ **Increased robustness**
- **Proposed as a common baseline L1 open service signal for GPS & Galileo**

For additional information contact: **L1C_GPS@USGS.gov**

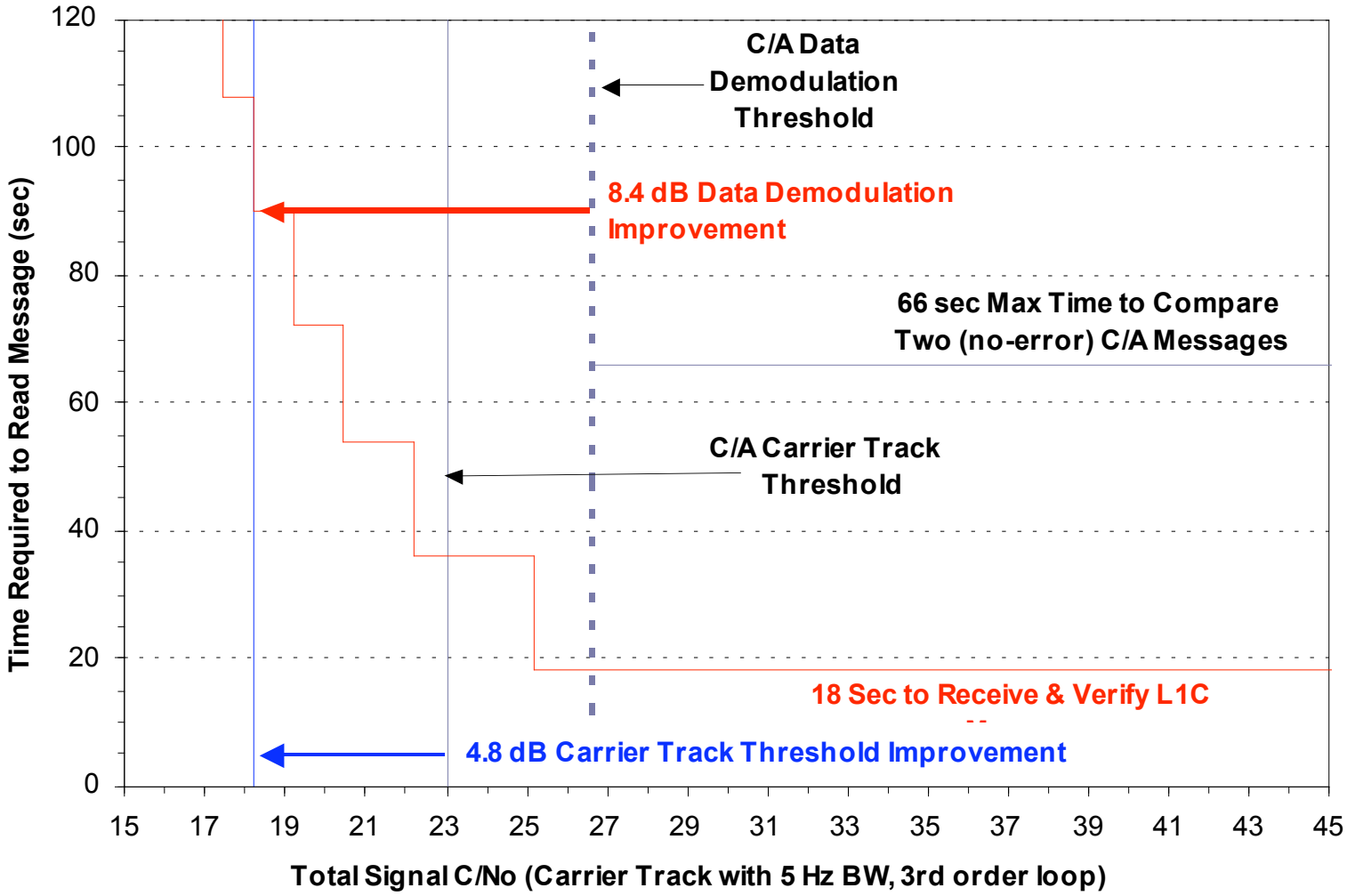
L1 GPS Spectrum



Key L1C Characteristics

- **Pilot carrier** with 75% of L1C signal power
  - For 1.8 dB better code and carrier tracking
  - Or to track at 2.25 times higher acceleration
- **Data rate** = 50 bps; Symbol rate = 100 sps
  - Message length = 900 bits/50 bps = 18 sec
  - LDPC FEC block encoding
    - Message demodulation at 25.2 dB-Hz C/N_0 (total signal)
    - Clock & Ephemeris bit combining down to track threshold
  - Symbol interleaving to mitigate brief signal losses
- Weil spreading codes
  - 10,230 chip base codes match data symbol length
  - Provides excellent correlation properties
  - 1800 chip pilot overlay code frames message

L1C Improvements Relative to C/A



L1C Improvements Relative to C/A *(1 of 2)*

Shared with L2C and L5

- Separate pilot & data signals
  - 3 dB better track threshold
  - No half cycle ambiguity
- Ten times longer spreading codes – 10,230 chips
  - Better crosscorrelation properties
- Forward error correction
  - 2 to 5 dB better data threshold
- Better predicted ephemeris precision
  - ~3 cm vs. ~40 cm URE
- CRC message assurance
  - Each message validated

L1C Improvements Relative to C/A *(2 of 2)*

L1C Unique

- Demodulate ephemeris and clock down to tracking threshold by bit combining across messages
- 75% of power in pilot
  - Further improves tracking threshold by 1.8 dB
  - Or improves acceleration tracking by factor of 2.25
- 1800 bit overlay code on pilot carrier frames message and improves crosscorrelation
- Better spreading codes and forward error correction
- Data interleaving to protect against short fades
- Long-lasting ephemeris for quick fixes after one read

IS-GPS-800: L1C Signal Design Initial (pre-ICWG) Review Stage

DRAFT

NAVSTAR GLOBAL POSITIONING SYSTEM

INTERFACE SPECIFICATION

Draft IS-GPS-800

28 March 2006

Navstar GPS Space Segment/User Segment L1C Interfaces

System Program Director
GPS JOINT PROGRAM OFFICE

Headquarters
Space and Missile Systems Center (SMC)
Navstar GPS Joint Program Office (SMC/GP)
2420 Vela Way, Suite 1866
El Segundo, CA 90245-4659
U.S.A.

IS-GPS-800 Initial Review & Process

- US-Galileo WG 'A' distribution for signal design review (Oct. 2005)
- US-Japan EWG distribution for signal design review as mutually agreed (Jan. 2006)
- US internal government pre-review (1 March 2006)
- IS-GPS-800 publicly released for review (20 April 2006)
- Comments due: 5 June 2006
- Document available at GPS JPO Public website:

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

IS-GPS-800: Contents

Contains Detailed L1C Signal Design:

Ranging & Overlay Codes

Message Characteristics

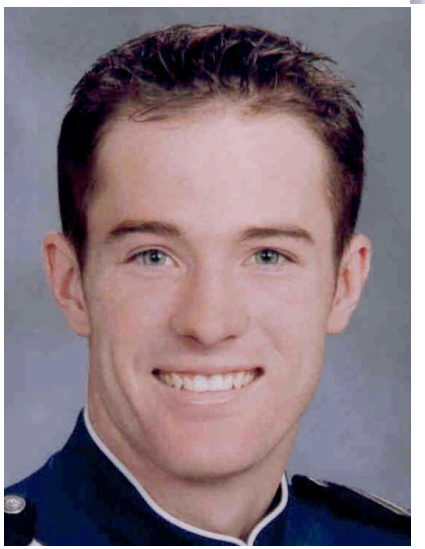
- CRC, LDPC, Interleaver

Draft document is 134 pages (19 figures and 30 tables); pending initial reviews prior to public release (expected 20 April 2006)

L1C Team Leadership

Dr. Ken Hudnut
Co-Chair, USGS

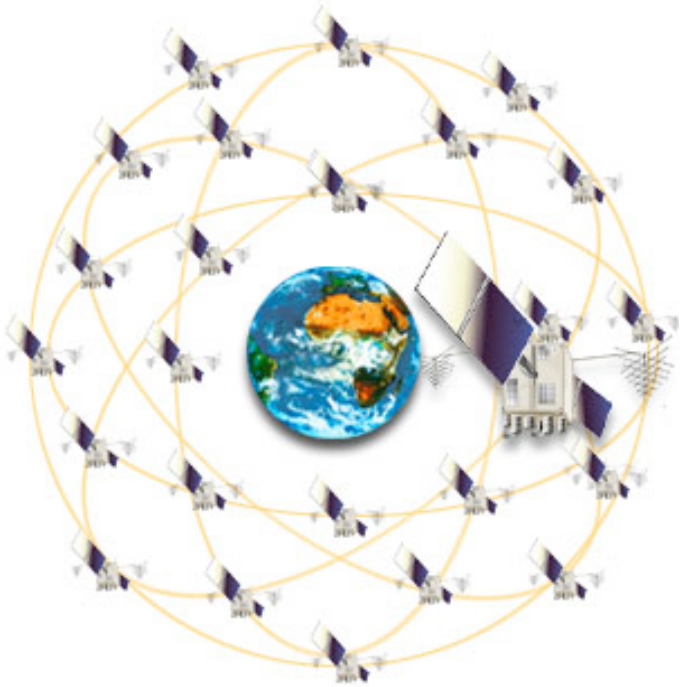
Capt. Amanda Jones
Co-Chair, GPS JPO



1Lt. Sean Lenahan
GPS JPO

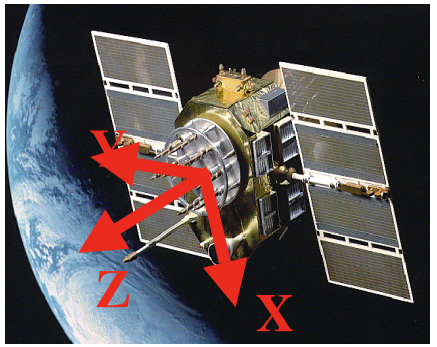
Tom Stansell
Coordinator

Concerns

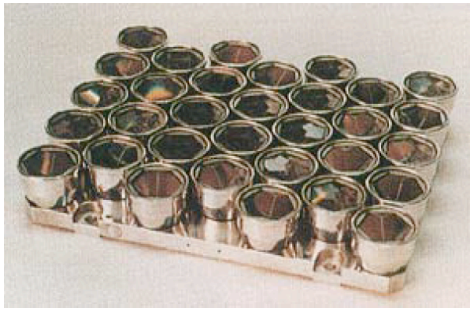


GPS at Risk of Losing SLR Capability Soon

- GPS will lose SLR capability in the near future!
  - SVs 35 and 36 nearing end of life
    - ✓SV 35 - launched August 1993 (12+ years)
    - ✓SV 36 - launched March 1996 (10+ years)



- No plans for Block IIR, IIR-M, or IIF vehicles to carry retro-reflectors
- No existing requirement for GPS III to support laser ranging
  - Consideration pending



Timetable for GPS III may be delayed?

- **Reference: 6 May 2006 – report in "The Wall Street Journal"**
- **Delay in acquisition – 1+ years**
  - **Consequence of US Government new space-acquisition policy**
    - ✓ **Reduce technical & budget risks**
    - ✓ **Considers the fact that GPS satellites lasting longer than expected**
- **However, goal continues to launch 1st GPS III by 2013**

GPS Modernization Program Status

Activity	Implementation Date
SA set to zero	May 2000
GPS IIR-M Enhancements - **New L2 civil (L2C) signal** - **M-code on L1 & L2**	1st satellite operational on December 16, 2005 **2nd Launch 14 Sept. 2006**
GPS IIF Enhancements - **L2 civil (L2C) signal** - **M-code on L1 & L2** - **New L5 civil signal**	1st launch currently scheduled for **May 2008**
GPS III Enhancements - **L2 civil (L2C) signal** - **M-code with greater power** - **L5** - **New L1C civil signal**	**1st launch ~ 2013**
OCS Enhancements	On-going

Summary

- GPS continues to evolve as a key part of the global space-based PNT infrastructure
- Civil service continues to exceed performance standards
- Modernization is underway
  - IIR-M launch with L2C and M-code
  - IIF satellites with L2C, L5 and M-code
- Modernization - future
  - GPS III - enhancements will continue
    - ✓ L1C
- Sustainment of constellation is number one priority
- Civil users engaged in defining the way-ahead for GPS sustainment and modernization

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