# Update on GPS Modernization Efforts

**Presented at the Fifteenth Meeting, 11-12 June 2015, Annapolis, MD.**
AEHF = Advanced Extremely High Frequency System
AFSCN = Air Force Satellite Control Network
CCAFS = Cape Canaveral Air Force Station
DMSP = Defense Meteorological Satellite Program
DSCS = Defense Satellite Communications
DSP = Defense Support Program System
EPS = Enhanced Polar System
GEODSS = Ground-based Electro-Optical Deep Space Surveillance System
GPS = Global Positioning System
GSSAP = Geosynchronous Space Situational Awareness Program
JSpOC = Joint Space Operations Center
ORS = Operationally Responsive Space
SBIRS = Space-Based Infrared System
SBSS = Space-Based Space Surveillance System
SSA = Space Situational Awareness
SST = Space Surveillance Telescope
VAFB = Vandenberg Air Force Base
WGS = Wideband Global Satellite Communications
Global Positioning Systems Directorate

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

BGen Bill Cooley
Director

Master Control Station
(located at Schriever AFB, CO)

From left to right, a GPS
IIIA satellite.
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

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

Space and Missile Systems Center

38 Satellites / 31 Set Healthy Baseline Constellation: 24 Satellites

<table>
<thead>
<tr>
<th>Satellite Block</th>
<th>Quantity</th>
<th>Average Age</th>
<th>Oldest</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS IIA</td>
<td>3</td>
<td>21.5</td>
<td>24.4</td>
</tr>
<tr>
<td>GPS IIR</td>
<td>12</td>
<td>13.3</td>
<td>17.7</td>
</tr>
<tr>
<td>GPS IIR-M</td>
<td>7</td>
<td>7.7</td>
<td>9.6</td>
</tr>
<tr>
<td>GPS IIF</td>
<td>9</td>
<td>1.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Constellation</td>
<td>31</td>
<td>9.5</td>
<td>24.4</td>
</tr>
</tbody>
</table>

AS OF 20 APR 15

Publically Releasable
GPS Modernization Program

Legacy GPS IIA/IIR
- Single Civil Frequency (L1 C/A)
- P(Y)-Code (L1 & L2)

GPS IIR-M
- 2nd Civil Signal (L2C)
- M-Code (L1M & L2M)

GPS IIF
- 3rd civil signal (L5)
- 2 Rb + 1 Cs Clocks
- 12 year design life

GPS III
- 4th civil signal (L1C)
- 4x better User Range Error than GPS IIF
- Increased availability
- Increased integrity
- 15 year design life

Legacy Operational Control Segment (AEP / LADO)
- Mainframe system
- Command & Control
- Signal monitoring
- Launch and disposal

Next Generation Operational Control System (OCX)

OCX Block 0
- Launch & On-Orbit Checkout of GPS III

OCX Block 1
- Replaces AEP for constellation C2
- M-Code
- Robust cyber security
- New civil signals & monitoring
- Improved accuracy

Modernized GPS User Equipment (MGUE)
- Provides M-code access for military users
- Increased anti-jam/anti-spoof capabilities

PUBLICLY RELEASABLE
Accuracy: Civil Commitments

Standard Positioning Service (SPS) Performance Standard

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

- **2001 SPS PS 6 m RMS**
- **2008 SPS Performance Standard (PS)**
  - Worst of Any Healthy Satellite, 7.8 m @ 95%

**User Range Error (URE) in Meters**

- **Signal-in-Space User Range Error** is the difference between a GPS satellite’s navigation data (position and clock) and the truth, projected on the line-of-sight to the user.

**Compare to (example):**
- ≈ 4.9 m RMS User residual iono delay error (L1 only)
- ≈ 0.5 m RMS User residual tropo delay error

**Across All Healthy Satellites (RMS, 68%)**
- 2001: 1.6
- 2002: 1.4
- 2003: 1.2
- 2004: 1.2
- 2005: 1.1
- 2006: 1.1
- 2007: 1.0
- 2008: 1.0
- 2009: 0.9
- 2010: 0.9
- 2011: 0.9
- 2012: 0.8
- 2013: 0.8
- 2014: 0.7

**Equivalent RMS Value from 2008 SPS PS (4 m)**
- 2008: 3.4
- 2009: 3.1
- 2010: 3.0
- 2011: 3.2
- 2012: 3.3
- 2013: 3.1
- 2014: 2.9

**Worst of Any Healthy Satellite (95%)**
- 2001-2014
**Precise Positioning Service (PPS) Signal-in-Space Performance**

- **2007 PPS Performance Standard (PS)**
  - Worst of Any Healthy Satellite, 5.9 m @ 95%

**User Range Error (URE) in Meters**

- Across All Healthy Satellites (RMS, 68%)
  - 2001: 1.5
  - 2002: 1.3
  - 2003: 1.1
  - 2004: 1.1
  - 2005: 1.0
  - 2006: 1.0
  - 2007: 0.9
  - 2008: 0.9
  - 2009: 0.8
  - 2010: 0.8
  - 2011: 0.8
  - 2012: 0.7
  - 2013: 0.7
  - 2014: 2.8

**Signal-in-Space User Range Error**

- The difference between a GPS satellite's navigation data (position and clock) and the truth, projected on the line-of-sight to the user.

**Comparison**

- 0.4 m RMS user residual iono delay error (L1+L2)
- 0.5 m RMS user residual tropo delay error

**Worse Performance**

- Equivalent RMS Value from 2007 PPS PS (3 m)
- Better Performance

**Publicly Releasable**
Now on The Air: Modernized Civil Signals

- The U.S. initiated CNAV message broadcast (L2C & L5) on 28 Apr 14
  - Daily uploads (nominal procedure for satellite operations) began on 31 Dec 14
  - L2C message currently set “healthy”
  - L5 message set “unhealthy” until sufficient monitoring capability established
  - Position accuracy not guaranteed during pre-operational deployment

- User Range Error (URE) CNAV Performance Post
  - Daily uploads consistent with or exceed legacy navigation performance*
  - Inter-signal corrections enable single point positioning competitive with P(Y) receivers

- Full potential of signals require receiver manufactures’ adoption
  - Challenge: Industry taking advantage of these signals moves capabilities forward!

Modernized Space System: GPS IIF

- Nine total GPS IIFs on-orbit
- Four GPS IIF launches in 2014!
- Three additional GPS IIFs in the pipeline
  - SV-9 &12 are in storage; SV-11 at Cape
- Prime: The Boeing Company
- Upcoming launch dates:
  - GPS IIF-10 (SV-11): 15 Jul 15
  - GPS IIF-11 (SV-12): 30 Oct 15
  - GPS IIF-12 (SV-9): NET 3 Feb 16
Modernized Space System: 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
- SV-1 – SV-8 on contract; SV-9 & 10 approved
- Navigation payload panel delivered 1 Nov 14
- Updated Mission Data Unit delivered 9 Mar 15
- SV-1 System Module Core Mate completed 9 Apr 15
- SV level thermal vacuum scheduled for Fall 2015
- SV-1 available for launch Aug 2016
Current Control Segment: OCS

• Current system Operational Control Segment (OCS)
  – Flying the GPS constellation with both the Architecture Evolution Plan (AEP) and the Launch & Early Orbit, Anomaly Resolution, and Disposal Operations (LADO) software systems
  – Cyber security / information assurance enhancements in progress
  – Prime: Lockheed Martin
Modernized Control Segment: OCX

- Next Generation Operational Control System
  - Modernized command & control system
    - GPS III command & control
    - M-Code
    - Robust cyber security infrastructure
    - Modern civil signals & monitoring
    - Improved PNT performance
  - Prime: Raytheon (Aurora, CO)
  - OCX Block 0: launch & checkout for GPS III
    - Currently in test; delivery expected May 2016
    - Successfully completed four launch exercises
  - OCX Block 1: replaces AEP, adds modern features
    - Currently in design, delivery expected 2019
  - OCX Block 2: adds advanced NAVWAR and Civil Signal Performance Monitoring capabilities
    - Delivery expected in 2020
Modernized User Equipment: MGUE

- Military GPS User Equipment (MGUE) is using a commercial market driven acquisition approach
- Accelerated from TD phase into testing and lead platform integration
- Increment 1 program's 2366b certification is pending
- Successful Preliminary Design Reviews (PDRs) for all 3 MGUE Inc 1 contractors
  - Rockwell Collins (Cedar Rapids, IA): 06 Aug 14
  - L-3 Communications (Anaheim, CA): 04 Sep 14
  - Raytheon (El Segundo, CA): 17 Sep 14
- Security Certification Underway
- Integrating Service Lead Platforms
  - Air Force: B-2 Spirit (B-2)
  - Army: DAGR Distributed Device (D3) / Stryker
  - Marines: Joint Light Tactical Vehicle (JLTV)
  - Navy: Arleigh Burke Class Guided Missile Destroyer (DDG)
GPS Director’s Focus

- Delivering new signals to military and civilian users (M-Code, L2C, L5)
- Accelerating Military GPS User Equipment (MGUE)
- GPS III production, following 2-year delay, due to Navigation Panel issues
  - Thermal Vacuum test (Fall ‘15) final development hurdle
- Next Generation Ground (OCX) program challenges continue
  - Cybersecurity & systems engineering issues drove schedule and cost overruns
  - Contractor working closely with Gov’t to deliver, but challenges remain
Team GPS thanks you for your support!