Space and Missile Systems Center

Update on GPS Modernization Efforts

2 June 2015

Brig Gen William T. "Bill" Cooley
Director, GPS Directorate

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UNCLASSIFIED

SMC SPACE OV-1

GEO
Geostationary Earth Orbit
Optimal for
Continuous Comm

MEO
Medium Earth Orbit
Optimal for Global positioning,
navigation & timing

LEO
Low Earth Orbit
Optimal for Earth Sensing

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

SPACE AND MISSILE SYSTEMS CENTER

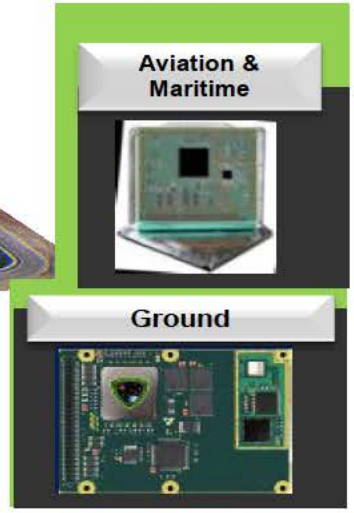
Mission:
Acquire, deliver and sustain reliable GPS capabilities to America's warfighters, our allies, and civil users



From left to right, a GPS IIA, IIR-M, and IIF satellite

BGen Bill Cooley
Director

Master Control Station
(located at Schriever AFB, CO)



Modernized GPS User Equipment
(MGUE) Components

How GPS Works

Keys to Performance

Time: Atomic Clocks
Position: Ephemeris (Kalman Filter)
Integrity: Worldwide monitoring
Availability: Number of satellites

GPS constellation consists of 24+ satellites orbiting the earth at ~10,900 nautical miles (Medium Earth Orbit, MEO) in 6 Orbital planes at 55° inclination,

L-Band

Navigation Data: ephemeris (orbit) & clock data; signals include:
- Civil: L1 C/A, L2C, L5, L1C (future)
- Military: L1/L2 P(Y), L1/L2 M

L-Band

Navigation Message uploads containing precise time and satellite position (ephemeris)

Tracking, Telemetry & Control (TT&C)

PNT Mission

Track Navigation Payload Health and Performance on L-Band Signals

2 Billion + GPS Users

S-Band

A user requires a minimum of four satellites to determine time and position (t, X, Y, Z)

Process data from Monitoring Stations and ground antennas. Generate commands to be sent to SVs through the ground antennas

Ground Antennas
(4 dedicated and 7 shared)

Provide information to MCS to allow orbit & clock estimation, ensure proper signal behavior and enable satellite message creation

Master Control Station (MCS)
(Schriever AFB, CO)

Monitor Stations
(6 Air Force,10 NGA)

Kalman Filter: heart of PNT Mission. Performs measurement updates every 15 minutes; estimates instantaneous state of GPS constellation

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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)

38 Satellites / 31 Set Healthy
Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age	Oldest
GPS IIA	3	21.5	24.4
GPS IIR	12	13.3	17.7
GPS IIR-M	7	7.7	9.6
GPS IIF	9	1.8	4.9
Constellation	31	9.5	24.4

AS OF 20 APR 15

Department of Defense

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

Spectrum

- World Radio Conference
- International Telecommunication Union
- Bilateral Agreements
- Adjacent Band Interference
- International Committee On Global Navigation Satellite Systems (GNSS)

Maintenance/Security

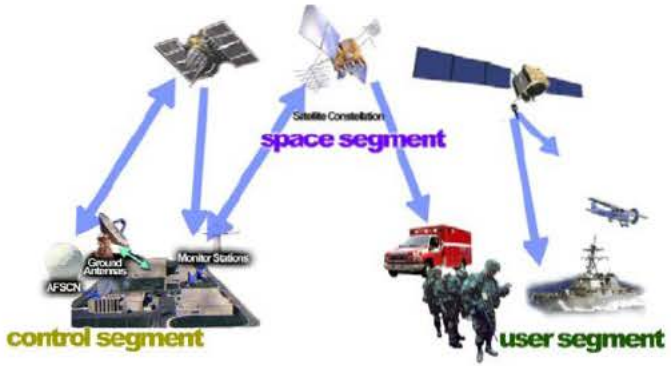
- All Level I and Level II
  - Worldwide Infrastructure
  - NATO Repair Facility
- Develop & Publish ICDs Semi-Annually
  - ICWG: Worldwide Involvement
- Update GPS.gov Webpage
- Load Operational Software on over 970,000 SAASM Receivers
- Distribute PRNs for the World
  - 120 for US and 90 for GNSS

Department of Transportation

- Federal Aviation Administration

Department of Homeland Security

- U.S. Coast Guard



International Cooperation

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

GPS Modernization Program

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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

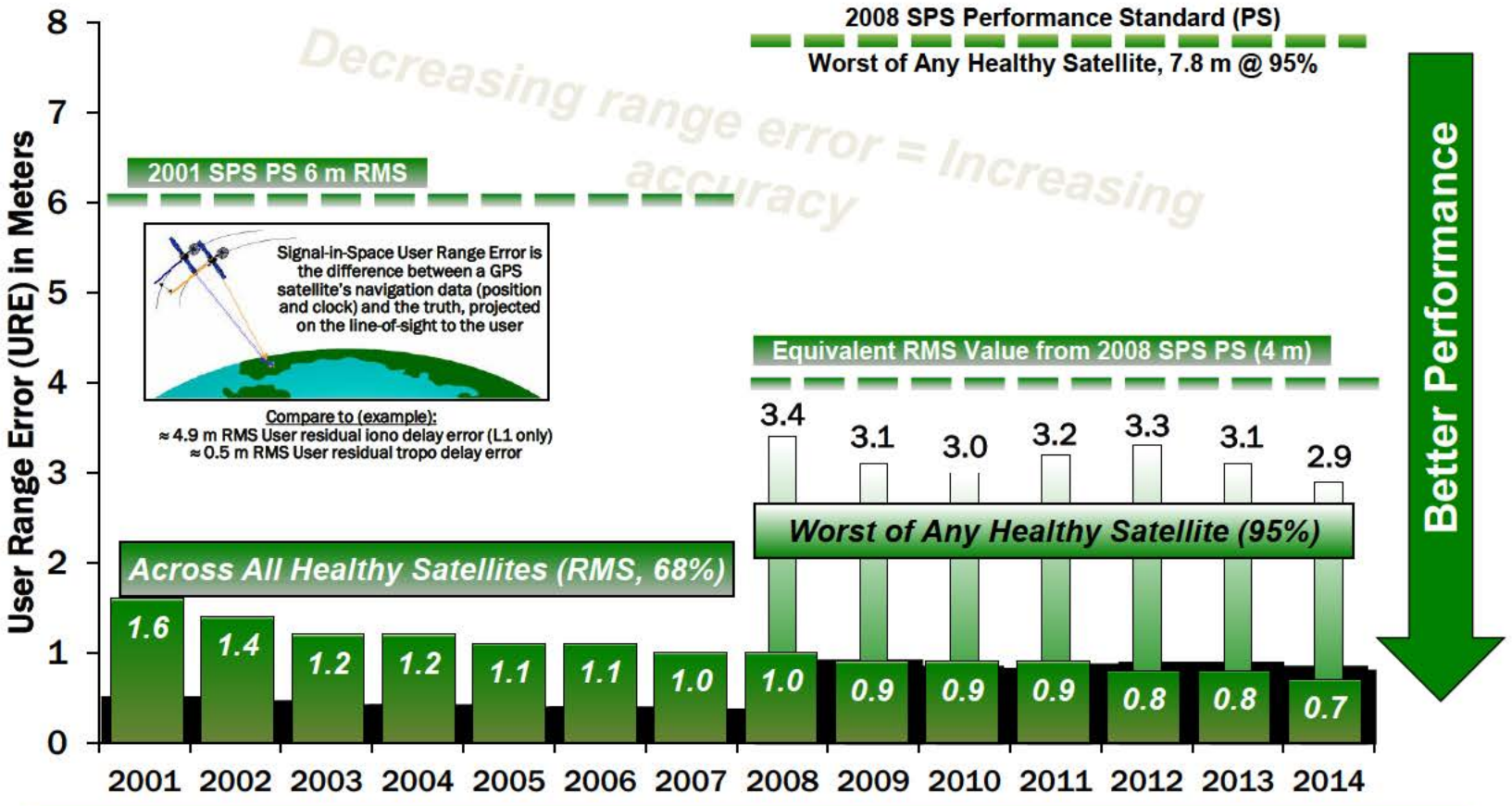
Modernized GPS User Equipment (MGUE)

- Provides M-code access for military users
- Increased anti-jam/anti-spoof capabilities

Accuracy: Civil Commitments

Standard Positioning Service (SPS) Performance Standard

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



System accuracy better than published standard

Accuracy: Military Commitments

Precise Positioning Service (PPS) Performance Standard

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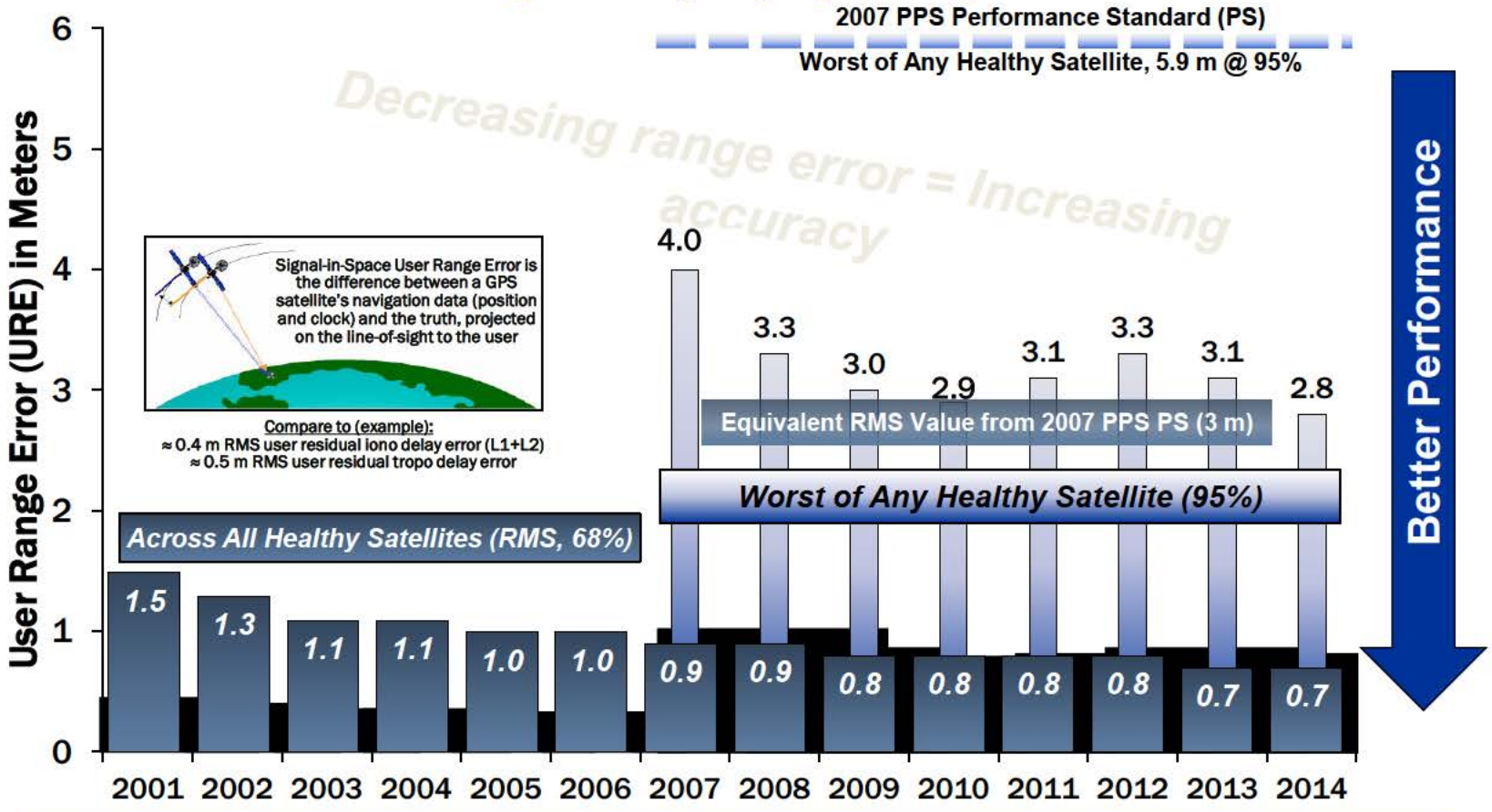
Precise Positioning Service (PPS) Signal-in-Space Performance



System accuracy better than published standard

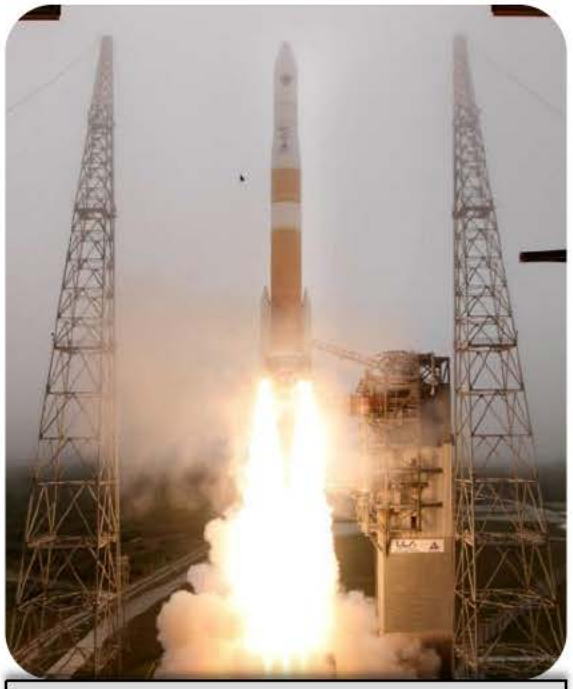
Now on The Air: Modernized Civil Signals

- 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!

* Data from “Performance Evaluation of the Early CNAV Navigation Message”, Pstreigenberger, O. Montenbruck, U. Hessels; Study conducted in Europe.

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



25 Mar 15: IIF-9

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

Lockheed Martin (Waterton, CO) – Prime

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

Monitor Station

Ground Antenna

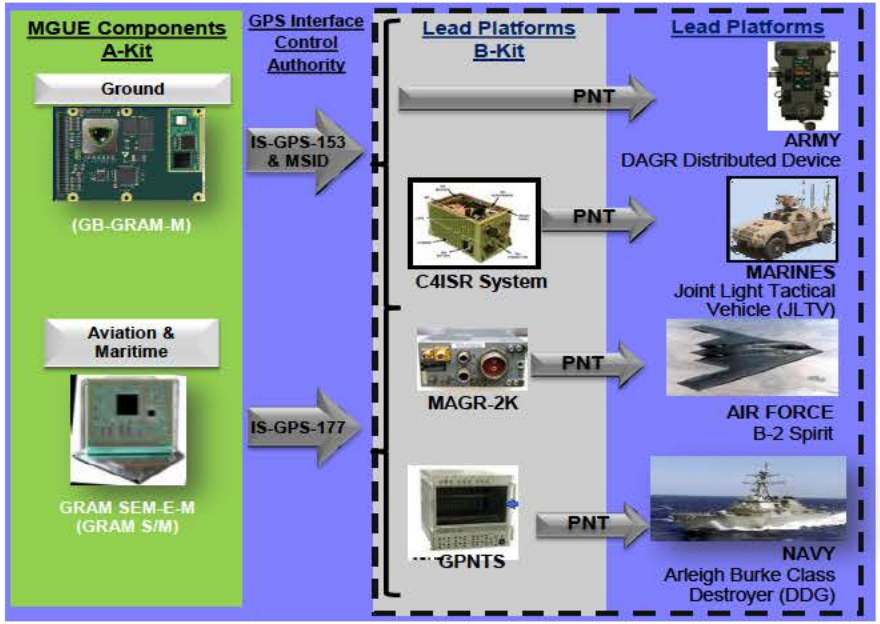
2SOPS Ground Control (Schriever AFB)

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)



L3 communications
Raytheon
Rockwell Collins

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!