“Long-Term Future of GPS”

Institute of Navigation (ION)

San Diego, CA

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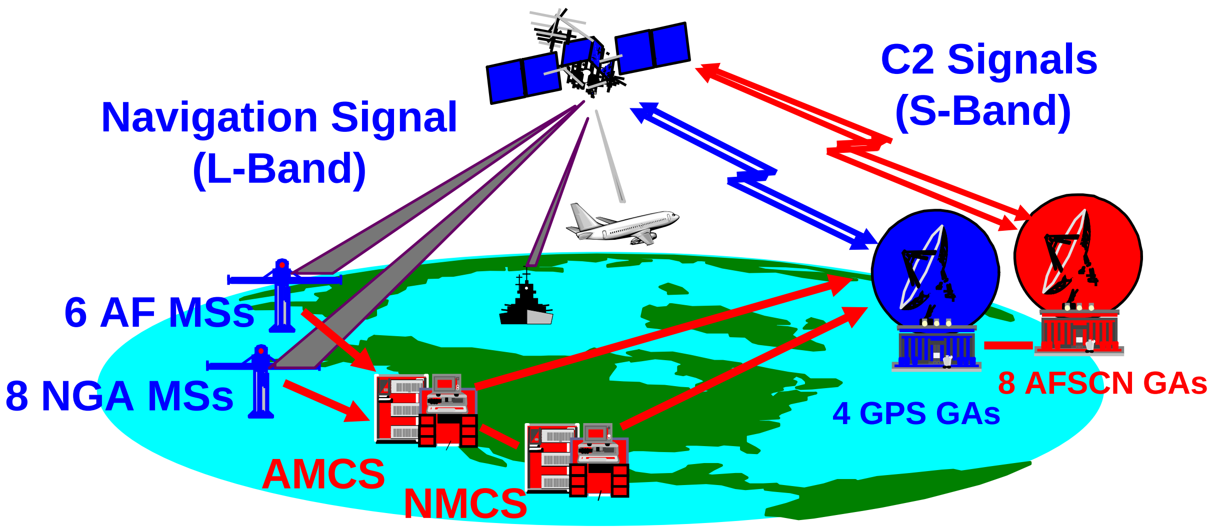
Overview

- **Present/near-term future:**
  - New GPS control segment & constellation performance
- **Mid-term future:**
  - Next generation control segment (OCX) & Block III SVs
- **Long-term future:**
  - Beyond GPS-III
  - Role of GPS in future system-of-systems

- **Transitioned to the new AEP OCS (10-14 Sep 07)**
- **IIR-17(M) launched (17 Oct 07) by new launch system**
  - Replaced previous Command and Control System (CCS)



Flawless transition of robust monitor & control network

GPS Constellation Status & Availability

as of 11 Jan 08

30 Healthy Satellites

Baseline Constellation: 24

- **13 Block IIA satellites**
- **12 Block IIR satellites**
- **5 Block IIR-M satellites**
  - 3 additional IIR-M satellites to launch
- **Since Dec 93, U.S. DoD met/exceeded GPS service performance commitments**
  - SPS & PPS Performance Standards
- **U.S. DoD committed to improving GPS service**

GPS Launch Update

- **Most Recent Launch**
  - IIR-18(M) – 5th modernized SV
    - Launched Wednesday, 20 Dec 07
    - SVN 57, PRN 29, slot C1
    - Set healthy on 2 Jan 08
- **Next Launches**
  - IIR-19(M) – Mar 08
  - IIR-20(M) – Jun 08
    - L5 demo payload
  - IIR-21(M) – Sep 08
- IIF-1 launch in 2009

GPS Block IIF Program

Program Status

SV1 TVAC1 test successful – Dec 07

Program Description

12 Satellites

Boeing – Seal Beach, California

2 Rubidium + 1 Cesium clock

12 year design life

Launch options: Atlas V or Delta IV

SPS signals: L1C/A, L2C, L5

PPS signals: L1-L2P(Y), L1-L2M

SV1 launch
Atlas V

SV2 launch
Delta IV

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GPS Modernization

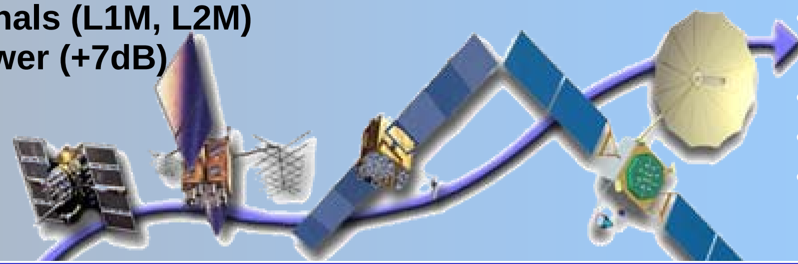
Space Segment

Block IIA/IIR
- Basic GPS
- C/A civil signal (L1C/A)
- Std Pos. Service
- Precise Pos. Service
  - L1 & L2 P(Y) nav
- NDS

Block IIR-M
- 2nd civil signal (L2C)
- M-Code signals (L1M, L2M)
- Flex A/J power (+7dB)

Block IIF
- 3rd civil signal (L5)

Block III
- Increased accuracy
- Increased A/J power (up to 20 dB)
- Signal integrity
- Search and Rescue
- Common signal with Galileo (L1C)



Control Segment

Legacy OCS
- TT&C
- L1 & L2 monitoring

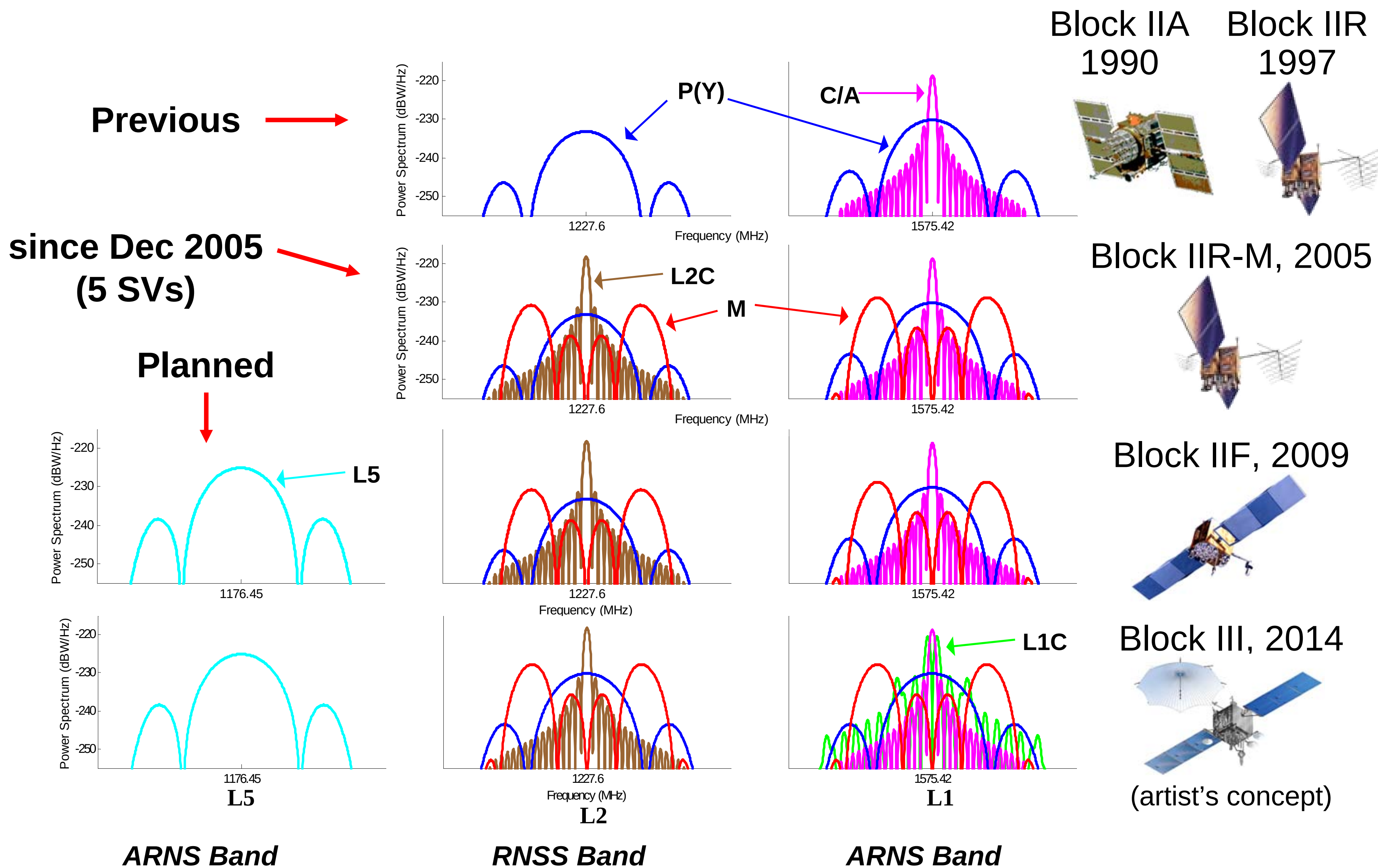
AEP
- IIR-M IIF TT&C
- WAGE, AII, LADO
- SAASM
- New MCS/AMCS

OCX V1
- New Architecture
- Signal Monitoring

OCX V2
- GPS III TT&C
- NAVWAR, GNOC
- L1C, L2C, L5
- Real-Time C2

GPS modernization process looks ahead beyond 2020

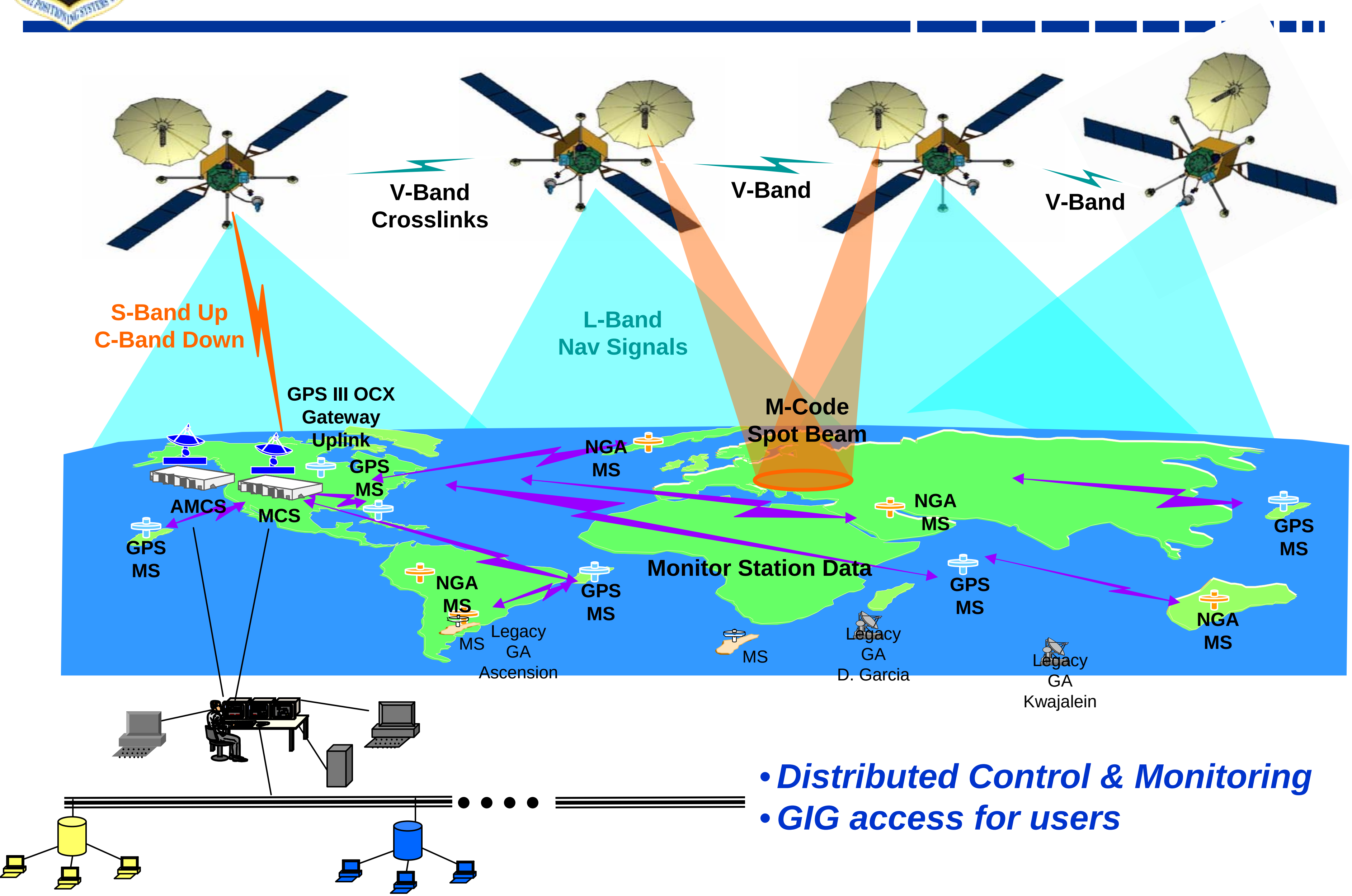
GPS Modernization – Spectrum



New Block III Signal for Civil Users – L1C

- **L1C will have the following benefits compared to L1 C/A:**
  - Separate pilot carrier without data (75% of L1C power)
    - Pilot carrier provides 4.8 dB better code & carrier tracking threshold
  - Advanced FEC – 1.4 dB better data demodulation threshold
  - More precise message structure (as with L2C and L5)
  - Longer PRN codes (better correlation performance)
  - Min L1C power specified to be 1.5 dB higher than C/A
- **EU & US teams designed new MBOC signal**
  - GPS TMBOC: BOC(1,1) chips time-multiplexed with BOC(6,1) chips
  - Provides more code transitions to enhance multipath mitigation
- **L1C draft specification, IS-GPS-800, available (http://www.navcen.uscg.gov/gps/modernization/default.htm)**
  - Final approval is expected soon
  - Wait for approved version before committing to silicon

GPS III Block-Based Space Segment Features



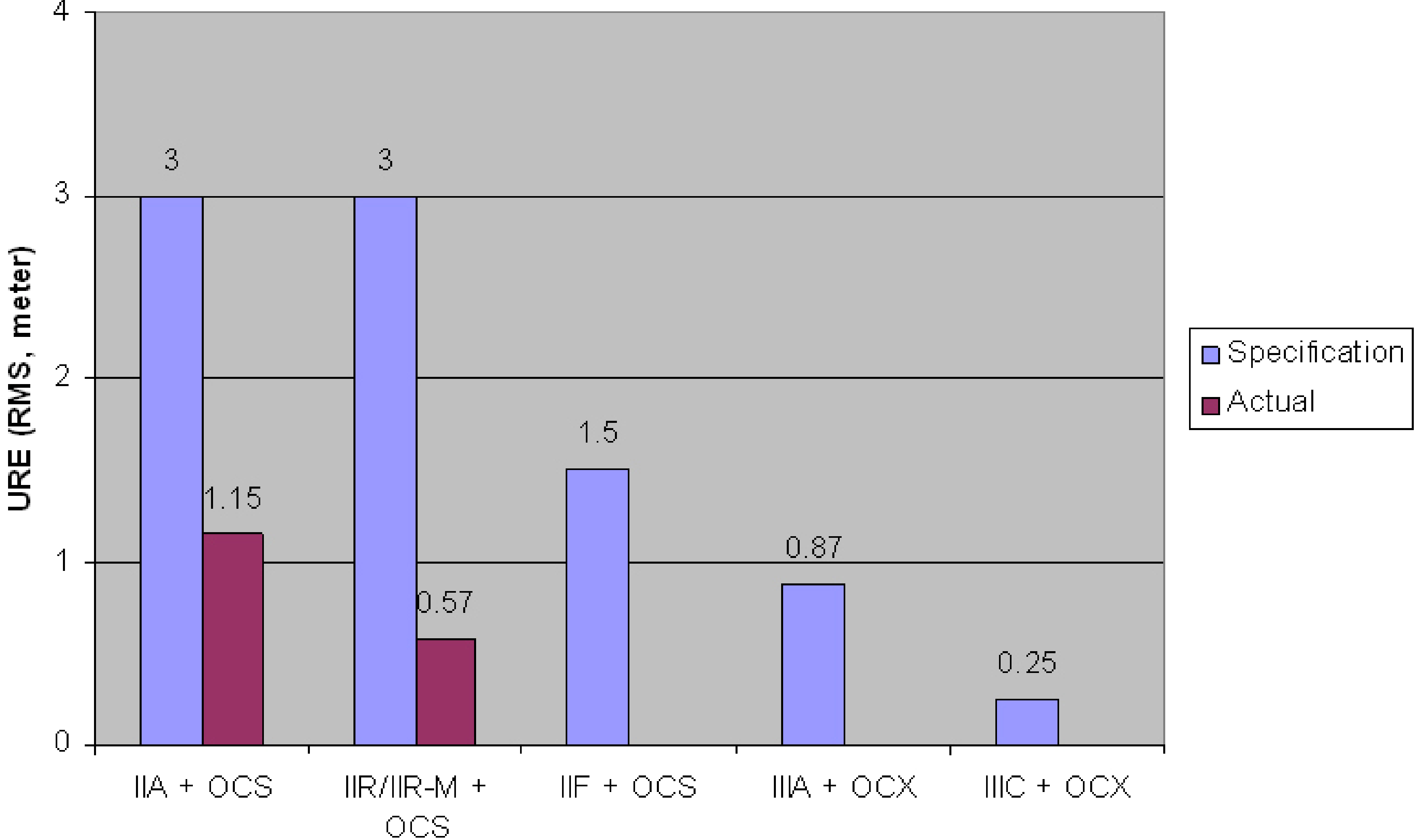
- *Distributed Control & Monitoring*
- *GIG access for users*

OCX – Next Generation Control Segment

- **Operational Control Segment (OCX)**
  - Enables modernized messaging (CNAV, CNAV-2, MNAV)
  - Controls larger (>32 SVs), more capable GPS constellation
  - Monitors all GPS signals
  - Air Force Space Command (AFSPC) is standing up a Community of Interest (COI) to implement net-centric operations using OCX
    - GPS COI is a forum for users to recommend the data and services that should accessible from the global information grid (GIG)
    - Organizations interested in participating in the COI should contact Robin Booker, AFSPC, at Robin.Booker.Ctr@peterson.af.mil
- **Two development contracts awarded – 21 Nov 07**
  - Northrop-Grumman & Raytheon

Current & Forecast GPS Accuracy Depends on User Range Error (URE)

URE contains space & control segment errors including clock and ephemeris



"User Range Error" will continue to dramatically improve

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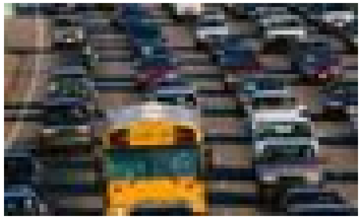
Trends in civil Global Navigation Satellite Systems (GNSS)

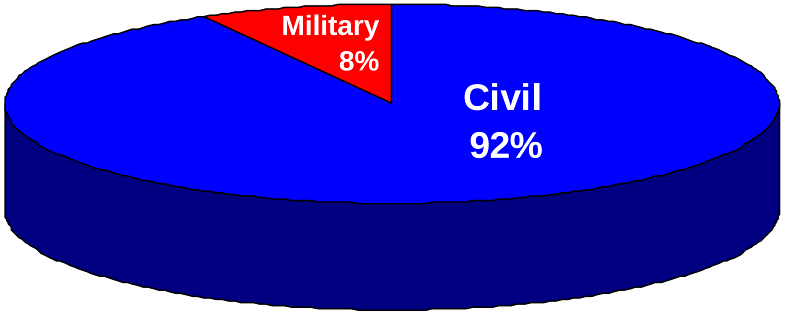
- **Increasing number of GNSS service providers**
  - GPS, GLONASS, GALILEO, QZSS, COMPASS
  - Increased GNSS augmentation services
- **Widespread civil uses**
  - Automobile, aviation, maritime, railroad, etc.
  - Search and rescue
  - Surveying and mapping
  - Tracking services: cell phones, freight, etc,
  - Surveying, mapping, agriculture
  - Banking and finance
  - Offshore drilling
  - Fishing, boating, and general recreation
- **Growing expectations from mass-market users**
  - More affordable, lower power receivers
  - Greater positioning accuracy (meters to sub-meter ranges)
  - Better availability in impaired environments



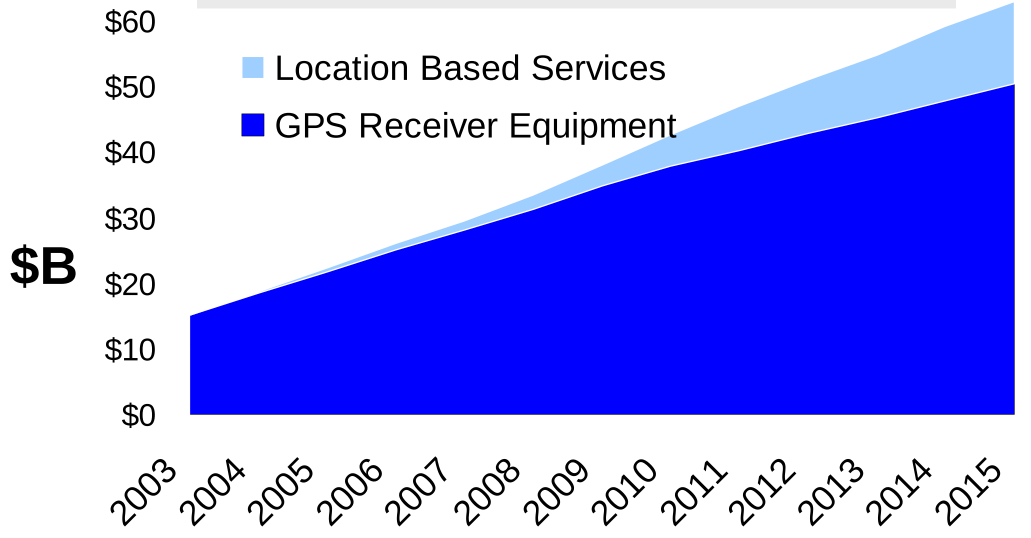
2004 GPS market and projected growth

- **GPS receiver market is predominantly civilian**
- **GPS civil receiver market growth will be significant**

2004 GPS Market Segments



Projected Civil Global Market Size



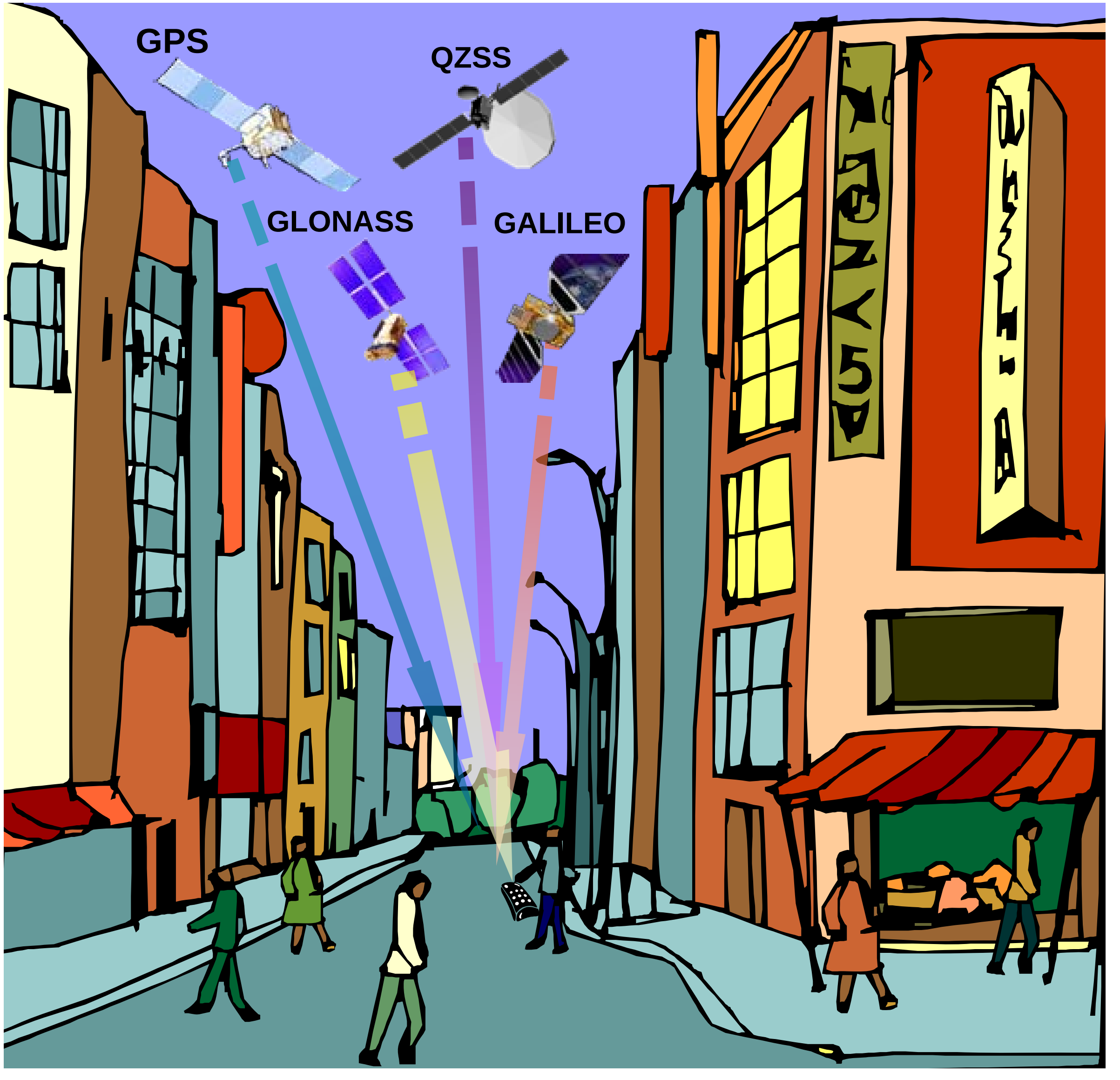
Source: ABI 2005 “GPS World Markets”, ABI 2004 “Location Based Services,” Monitor Analysis

Implications of future trends

- **Users will obtain better availability and accuracy by using multiple systems**
- **<u>Low cost</u> GNSS receivers are vital for mass market applications**
  - GNSS signals should be <u>highly interoperable</u>
  - Implies common center frequencies & similar modulation (CDMA)
- **GNSS service providers can work together to benefit users**
  - Sustain radio frequency compatibility
    - One GNSS service doesn’t unacceptably degrade another service
  - Modernize systems for best interoperability
    - Enable superior, combined GNSS navigation solutions

Users would benefit from greater GNSS interoperability

GNSS Interoperability: Seamless Navigation



GNSS Interoperability

Characteristic	*Interoperability Benefit*
Common carrier frequencies	Common antenna and receiver front end—lower power and cost; common carrier tracking for higher accuracy
Similar spreading modulation spectra	Lower cost; common-mode dispersive errors removed in navigation solution for higher accuracy; front-end filter will work for all signals; same analog-to-digital sample rate
Common time and reference frames, or broadcast offsets	Navigation solutions can more easily use measurements from different systems

GPS + WAAS = Successful Interoperability Example

GPS & the System of Systems Evolution

- **GPS has long been combined with other sensors & systems**
  - Inertial measurement unit (IMU), altimeter, speed, heading, clock, . . .
  - Local area and wide area DGPS corrections
  - GPS-GLONASS integrated receivers
  - Assisted GPS (AGPS) aiding signals
- **GPS has been the stable core of a PNT "system of systems"**
- **Opportunities are increasing for other combinations**
  - Lower cost, better performing sensors, e.g., MEMS IMU
  - Integration with communication links
    - For aiding, ephemeris, or traffic information
    - Augment GPS navigation with terrestrial ranging signals
  - Other GNSS services
    - Galileo, QZSS, IRNSS, more interoperable GLONASS signals, etc.
- **GPS Wing welcomes these combinations**
  - GNSS international compatibility & interoperability working groups

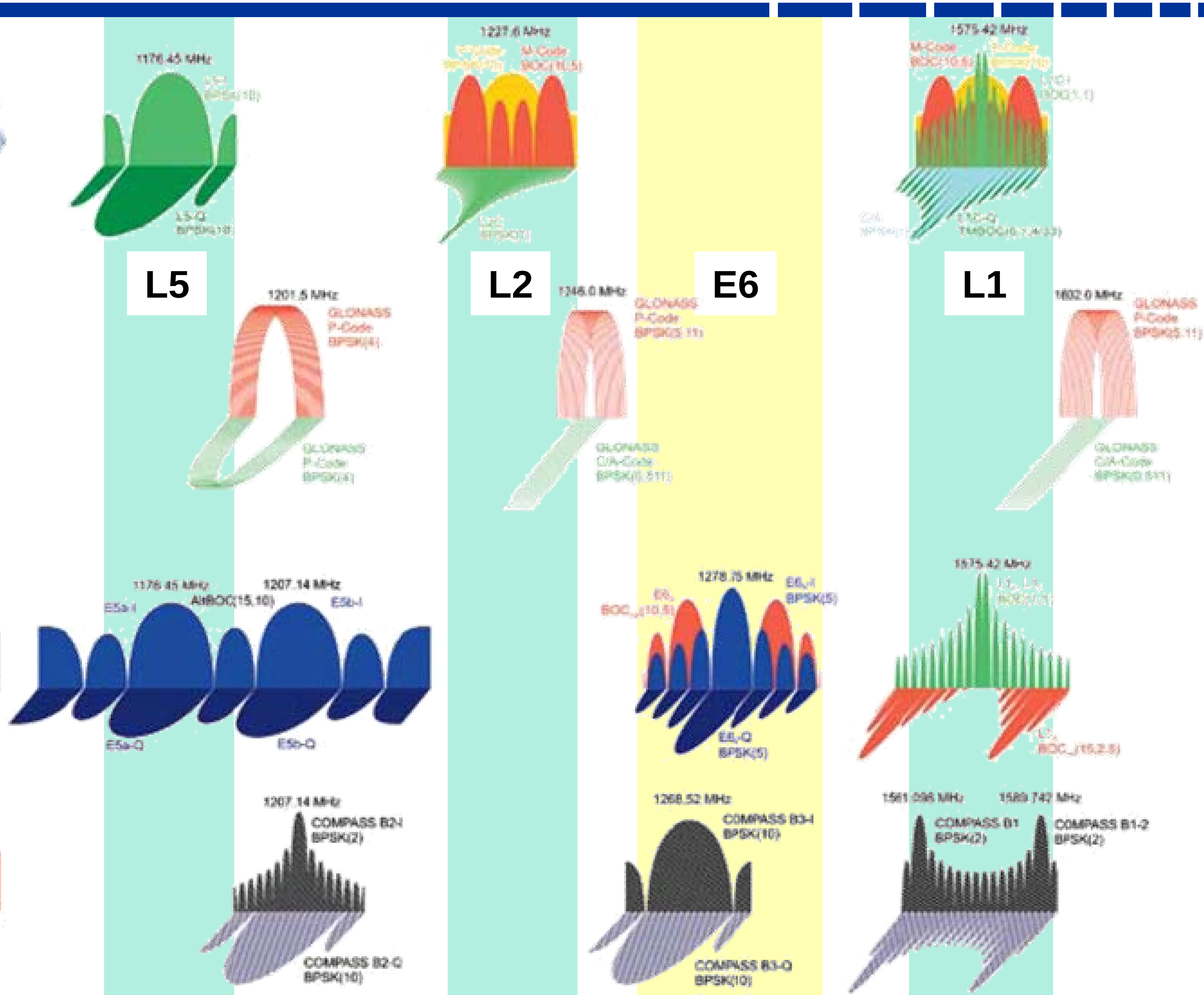
Current GNSS Frequency Plans

GPS

GLONASS

Galileo

COMPASS



Green and blue signals: Open or commercial signals
Red signals: Military signals, Public Regulated Services
Grey signals: Usage of filed signal not yet defined officially

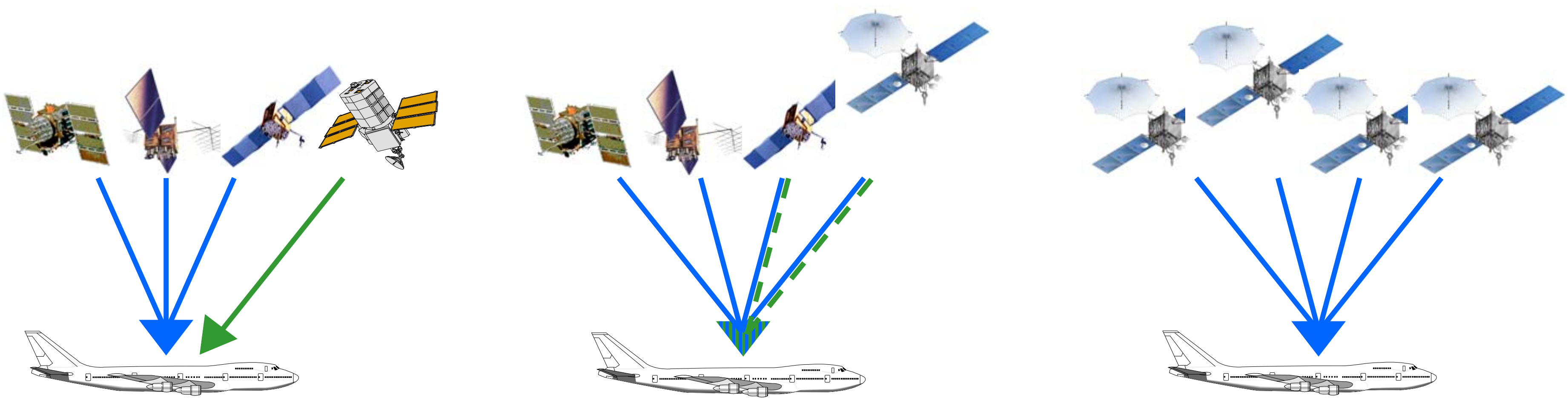
Source: Hein, et. al, “Envisioning a Future GNSS System of Systems,” *Inside GNSS*, Jan/Feb 07

Improvement Ideas Beyond GPS III – Space Vehicles (SVs)

- **Eliminate the need to transmit clock corrections (A_0, A_1, A_2)**
  - Ground steers SV clocks to GPS time
- **Add interoperable civil signal at 1278.75 MHz**
- **Capability to broadcast messages from SVs**
- **Greater SV signal integrity**
  - GPS Evolutionary Architecture System & ADS-B

Greater Signal-in-Space Integrity

- **GNSS Evolutionary Architecture Study (GEAS)**
  - FAA sponsored, aviation centric, WAAS related
- **Some major findings:**
  - GPS-III requirements provide enough integrity for aviation
  - May be feasible to transition from GPS+WAAS to GPS-III
  - Early transition via hybrid system appears possible



PRESENT	INTERIM HYBRID	FUTURE
GPS + RAIM	**GPS + RAIM**	**GPS-III**
GPS + WAAS	**GPS + Relative RAIM + Slow WAAS** **GPS + Absolute RAIM + Slow WAAS**	**(GPS-III + RAIM)**

Improvement Ideas Beyond GPS III – Operational Control System (OCX+)

- **Closer fusion of communications, navigation, & networks**
  - Ground-based distribution of Nav data & corrections
  - Expand utility of “net-centric” service-oriented architecture
- **OCX+ would post long-duration (e.g., 24 hour) NAV message data on the Internet at each update (~ 15 minute updates)**
- **Service providers get clock & ephemeris corrections and make this information available to users in appropriate format**
  - For example, distribution by cell phone providers
  - Faster time to first fix by eliminating need to acquire NAV message from each satellite
    - Useful when driving in an urban environment
    - Significant improvement of GPS service
  - Improved accuracy for some applications
  - Source data for AGPS services

Improvement Ideas Beyond GPS III – User Equipment

- **Comm/Nav/Network Fusion**
  - Benefit in comm/nav user equipment integration
  - Better accuracy, reduced time uncertainty, data stripping, network interference detection/location
  - A variety of approaches to comm/nav integration exist today and should be studied further
  - Additional investment and prototyping is required
- **Chip Scale Atomic Clocks**
- **Software defined receiver**

Summary

- **Success in GPS sustainment & modernization**
  - New capabilities delivering enhanced performance
  - Developments on track to enhance space and control segments
- **GPS is an excellent global navigation utility**
  - Excellent cooperation with augmentation service providers
  - Improving interoperability/compatibility for GNSS
- **GPS is boldly moving forward into the future**
  - To remain the pre-eminent space-based PNT service
  - GPS will continue to lead the future GNSS system-of-systems