GPS Acquisition Challenges

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21 Oct 09
Agenda

- The General Landscape
- The Acquisition Challenges
  - Segment
  - System
  - Other
- The Silver Lining
Where we were …

• Up until the mid-90s, we had:
  – Few users
  – Three signals (L1 C/A, L1 P(Y), L2 P(Y))
  – One NAV message
  – Only one competing GNSS (GLONASS)
  – One primary mission (PNT) and one secondary mission (NDS)
  – Few people interested in GPS acquisition
Where we are today…

• Now, we have:
  – GPS as a foundation for critical infrastructure
  – Many users, and more to come
  – Eight signals (L1 C/A, L1 P(Y), L1M, L1C, L2C, L2 P(Y), L2M, L5)
    ✷ modernized signals with two components each
  – Several NAV messages under development (LNAV, MNAV, CNAV, CNAV2)
  – Several additional GNSS (GLONASS, COMPASS, GALILEO, etc.)
  – Several new (or possibly new) secondary missions (SES, DASS, SLR)
  – Lots of people interested in how GPS is acquired
    ✷ DOD, DOT, DOS, DOC, NASA, IRT, FACA, GAO, etc.
Where we are going …

**Satellites**

**Legacy (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)

**GPS III**
- Increased accuracy
- Increased A/J power (up to 20 dB)
- Signal integrity
- Search and Rescue
- Common Galileo OS & GPS (L1C)

**Control Systems**

**Legacy**
- TT&C

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

**OCX Blk 1 (Modernized)**
- Flexible Architecture
- Mission Ops for all SVs
- Control 1 new signal (L2C, L5, or M-Code)
- Control Flex Power
- Signal Integrity Monitoring

**OCX Blk 2 (GPS III A)**
- Blk II & IIIA SV L&EO
- All new signals (including L1C)

**OCX Blk 3&4 (GPS III B/C)**
- Manage Spot Beam
- NAVWAR, GNOC
- Mission Planning
- Effects-Based Ops

**User Equipment**

**Legacy**
- Man Pack
- MAGR, PLGR
- RCVR-3A, 3S
- OH, UH
- FRPA, CRPA

**(Upgraded)**
- DAGR
- CSEL
- GAS-1
- MAGR2K
- GB-GRAM

**MGUE (Modernized)**
- Anti-Jam, Anti-Spoof
- Military exclusivity
- Handheld / Anti-Tamper
- Gnd & Avionics embed
- Auto OTA Rekeying

**Cornerstones to the Future GPS are GPS III, OCX, & MGUE**
Agenda

• The General Landscape
• The Acquisition Challenges
  – Segment
  – System
  – Other
• The Silver Lining
Acquisition Challenges

- Programmatic Challenges (applicable to all segments)
  - Staving off requirements creep (expectations are not requirements)
  - Executing within budgetary constraints
  - Successfully navigating the DoD/AF acquisition process
    - Competition Decisions
    - Milestone Decisions
Technical Challenges: Space Segment

• In general, Space Segment uses mature, tried and true technologies
  – Difficulty of making changes on-orbit
  – Cost of satellite and launch vehicle drives low risk approach
• Exceptions are areas unique to application and environment
  – Space-based atomic clocks
  – Space qualified electronics
• Main Technical challenges are maintaining industry bases and testing in realistic environments
  – Space-based atomic clocks, space-qualified components
• Additional challenge is determining at what point in capability addition is new design needed
  – e.g. more signals require more power, may require more redesign than simply retrofitting
  – New design implies additional testing
Technical Challenges: Ground Segment

• Ground segment tries to leverage commercial computer, network and software technologies
  – Problem is how fast ground technologies change
  – Problem exacerbated by the fact that large portion of system upgrades are allocated to ground segment
  – Problem further exacerbated by changing satellite blocks
  – Additional complications due to large and increasing number of interfaces to ground segment

• Main technical challenge is maintaining high rate of changes without impacting operations
  – Process challenge
  – Architectural challenge
  – Testing challenge


**Ground Segment Versions (Notional)**

- **AEP Phase 1**
  - Remote Site Upgrade
  - Upgrade MSRE h/w

- **AEP V5.0**
  - COTS Upgrade
  - Not an Operational release

- **AEP V5.2**
  - Operational
  - NMCS, AMCS, AllI
  - Integration of LADO function
  - New MCS
  - GA Remote site upgrades (KI-17)
  - Off-line Tools
  - Numerous out of scope DRs

- **AEP V5.5**
  - SAASM and IIF
  - New SAASM Workstations in NMCS/AMCS
  - AMCS
  - V5-V5 MOX
  - Flex Pwr Cmd
  - Legacy Tools
  - OB8/9/10/10.1
  - 2nd Cmdr Login
  - EPOT

- **OCX 1**
  - Preliminary Modernization & GPS III
  - L2C
  - GPS IIIA
  - OP/IR SAA5M
  - Full IIF Uploads
  - IIF WAGE
  - IIF NAV Estimation, Secure, Upload
  - IIF upload format w/ IIA control element
  - IIF TT&C Crypto, Maneuver, CMD, Telemetry, BDP, CML
  - IIF Ephemeris Propagation
  - IIF Command Libraries/Time tagged cmds
  - IIF Memory Mgmt

- **OCX 2**
  - Full Modernization
  - L5, L1C
  - Integration of LADO function

- **New Satellite Block (IIF)**
  - New Satellite
  - Architecture Improvements
  - New mission capabilities

- **New Ground Segment has to provide:**
  - Architecture Improvements
  - Support to new Satellite blocks
  - New mission capabilities

- **Phase 2 and V3/4**
  - Mainframe to Distributed
  - not an Operational release

- **1999**
  - SPI
  - Upgrade MSRE h/w

- **2001**
  - 2005
  - 2009
  - 2010
  - 2012
  - 2014

- **2003**
  - 2007

- **2009**
  - 2010
  - 2012

- **2014**
  - SPI

- **V6**
  - M-code
  - JMSRE

- **V5.2**
  - Open Systems
  - Modernized GUI
  - Com/Message Handling Bus (OS/Comet v3.1)

- **V5.5**
  - New M-code
  - JMSRE

- **V6**
  - New Satellite
  - Architecture Improvements
  - New mission capabilities

- **New Ground Segment has to provide:**
  - Architecture Improvements
  - Support to new Satellite blocks
  - New mission capabilities

- **Remote Site Upgrade**
  - Replace System 1 with SCSR for remote site control (MS and GA)
Technical Challenges: User Segment

• Military User Equipment challenges are driven by protection requirements
  – Protection technologies are straightforward
  – Main challenge is size, weight and power
  – Other challenge is competition with commercial UE
  – Additional challenge is testing and fielding of upgrades

• Current approach/challenge
  – Developing approach for leveraging commercial UE features and integrate them with protection functions
  – Architectural challenge
Military UE Approaches

• Previous approach (2003): Study commercial devices and levy their benefits as requirements in a traditional military acquisition

DAGR – Defense Advanced GPS Receiver:
All-in-view, Second Generation Security, under 1 lb

• Pro: Strong military receiver performance
• Con: Interface and features are quickly outdated

Current approach and challenge (2012): Develop military components for insertion into COTS or non-COTS systems

Common GPS Module (CGM)

GPSW Builds Enabling “Engines” + Integrators Build Applications = Global Military GPS Use
• The General Landscape
• The Acquisition Challenges
  – Segment
  – System
  – Other
• The Silver Lining
System Level Challenges

• Ground – Space – User Segment integration
• Integration with other systems/agencies
• International spectrum management
Integration between Space, Ground and User Segments

- Allocation of accuracy and integrity requirements between the three segments
  - SV autonomous integrity check vs NAV message integrity flag
  - Better SV clocks vs faster (and shorter) uploads, vs crosslink ranging
  - How much accuracy improvement is enough?

- Moving functions from ground to space
  - State vector propagation and nav message building
  - Message design, algorithms on both sides, validation of message

- General TT&C and space to ground interface
  - Management of SV processor memory on the ground
  - IIR upload challenge of 2007

- Synchronization of capabilities across segments
  - Where should a given new capability be implemented first
  - Incremental deployment of each capability
System of System Integration

- Coordination with external interfaces: AFSCN, USNO, NGA, secondary missions, etc.
  - Upgrade, Testing, and Transition Challenges
- Coordination across gvt agencies: FAA, NASA, Army, etc.
  - Prioritization of capabilities (e.g. integrity)
- Absence of forum or process for public anomaly resolution
- De Facto Capabilities
  - Phase relationship between L2 P(Y) and L2C
  - Phase relationship between L1C and L1C/A
  - GPS Rollover, specified in IS-GPS-200, not implemented by some receiver manufacturers
  - PRN 32, (6-bit vs 5-bit PRN number), specified in IS-GPS-200, mis-implemented by some receiver manufacturers
August 23, 1999

Resetting of GPS Systems Leads to Some Problems in Japan

By REUTERS

OKYO -- Hundreds of people complained Sunday to Japanese car-navigator manufacturers about breakdowns caused by the resetting of time mechanisms in Global Positioning System satellites.

Elsewhere, few problems were reported after the timing system for the 24 satellites of the Global Positioning System, which is widely used by planes and ships for assisting with navigation, was switched back to zero just before 7 P.M., Eastern time, on Saturday.

The rollover was necessary because the system, which uses radio signals from satellites to provide navigation data, was designed to ignore calendar dates but keep precise time measured in seconds and weeks. Only 1,024 weeks were allotted from Jan. 6, 1980, before the system had to be reset to zero.
International GNSS Spectrum Challenges

• The Air Force and the GPS Wing help manage and defend the GNSS spectrum for the U.S. Government

• There are three main elements to manage
  – Compatibility of Open Service signals
  – Interoperability of Open Service signals
  – Spectral Separation of Authorized and Military signals

• Each are managed in a different venue
  – Compatibility in the International Telecommunications Union (ITU)
  – Interoperability in the International Committee on GNSS (ICG)
  – Spectral Separation in bilateral negotiations

• The linkages between the three make it impossible to manage the whole in any one venue
  – The process therefore tends to be iterative
Three Interrelated Challenges

Compatibility
No unacceptable harm to other open signals - International Telecommunications Union (ITU)

Interoperability
Common open signals from multiple sources to improve performance at minimal cost - International Committee on GNSS (ICG)

Spectral separation of Authorized and Military signals - Bilateral agreements
International GNSS Coordination

Signal Modernization

GLONASS

Galileo – C: Current Signals

1.3 Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Carrier Frequency (MHz)</th>
<th>Bandwidth (MHz)</th>
<th>PRN code chip rate (Mgps)</th>
<th>Signal modulation</th>
<th>Navigation data bit rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1601.098</td>
<td>4.092</td>
<td>2.048</td>
<td>QPSK</td>
<td></td>
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<tr>
<td>B1-E</td>
<td>1599.742</td>
<td>4.097</td>
<td>2.048</td>
<td>QPSK</td>
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<tr>
<td>B2</td>
<td>1577.134</td>
<td>2.4</td>
<td>10.22</td>
<td>QPSK</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>1561.532</td>
<td>2.4</td>
<td>10.22</td>
<td>QPSK</td>
<td></td>
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<tr>
<td>B1-BOC</td>
<td>1679.42</td>
<td>18.068</td>
<td>1.022</td>
<td>MBOC (14. L, 32)</td>
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</tr>
<tr>
<td>B2-BOC</td>
<td>1657.11</td>
<td>30.63</td>
<td>5.121</td>
<td>BOC (10, 5)</td>
<td>500</td>
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<tr>
<td>B3-BOC</td>
<td>1630.52</td>
<td>35.508</td>
<td>2.0875</td>
<td>BOC (15, 2, 5)</td>
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</tr>
<tr>
<td>L5</td>
<td>1176.46</td>
<td>24</td>
<td>10.22</td>
<td>QPSK</td>
<td></td>
</tr>
</tbody>
</table>

GLONASS-K

L1CR, L5R: pending final decision

4. Planned Signals

Planned Signal List for QZSS

<table>
<thead>
<tr>
<th>Generic Signal Name</th>
<th>Center Frequency</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1+C/A</td>
<td>1575.42MHz</td>
<td></td>
</tr>
<tr>
<td>L1C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2C</td>
<td>1227.6MHz</td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td>1176.45MHz</td>
<td></td>
</tr>
<tr>
<td>L1-SAIF*</td>
<td>1575.42MHz</td>
<td></td>
</tr>
<tr>
<td>LEX</td>
<td>1278.75MHz</td>
<td></td>
</tr>
</tbody>
</table>

*L1-SAIF: L1-Submeter-class Augmentation with Integrity Function

IRNSS SERVICES & CENTRE FREQUENCIES

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Signals</th>
<th>Frequency Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Positioning</td>
<td>1 MHz</td>
<td>L5 (1176.43 MHz) S (2492.08 MHz)</td>
</tr>
<tr>
<td>Service</td>
<td>BPSK</td>
<td>L5 (1176.43 MHz) S (2492.08 MHz)</td>
</tr>
<tr>
<td>Precision Service</td>
<td>BOC(5,2)</td>
<td>L5 (1176.43 MHz) S (2492.08 MHz)</td>
</tr>
</tbody>
</table>

QZSS

IRNSS

Compass

International Committee on Global Navigation Satellite System:
• The General Landscape
• The Acquisition Challenges
  – Segment
  – System
  – Other
• The Silver Lining
Other Challenges

• Flow of money and rockets
• Next generation of PNT engineers and scientists
Agenda

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Recent Successes

- Very robust constellation
  - 30 space vehicles currently set healthy
  - 1 GPS IIR-M pending signal distortion mitigation
  - 3 additional satellites in residual status
- Two successful launches this year
  - The last 2 IIRMs
- IIF pathfinder intersatellite testing complete
- IIF-1 approaching factory ship date, launch anticipated for spring 2010
- Successful GPS IIIA PDR, currently conducting CDR campaign
- Ground Segment upgrade (AEP 5.5) planned for deployment in November 2009
- OCX released final RFP, currently in Source Selection
Current GPS Accuracy

- **SPS Signal-in-Space (SIS) User Range error (URE):** One-year RMS through 9/09: .90 meters
- **SPS Zero Age-of-Data (AOD) URE:** One-year RMS through 9/09: 0.50 meters

Selective Availability (SA)

Continuing to set high standards and high expectations
Thank You
Back-Ups
“Because of (1) the criticality of the GPS system to the military, various economic sectors, and the international community and (2) schedule risks in the current program, we are recommending that the Secretary of Defense appoint a single authority to oversee the development of the GPS system, including space, ground, and user assets, to ensure that the program is well executed and resourced and that potential disruptions are minimized. The appointee should have authority to ensure space, ground, and user equipment are synchronized to the maximum extent practicable; and coordinate with the existing positioning, navigation, and timing infrastructure to assess and minimize potential service disruptions in the event that the satellite constellation was to decrease in size for an extended period of time.”

Excerpted from GAO report on GPS, 30 April 2009
Background:

L5 Demonstration Payload on SVN-49

- SVN-49 (PRN 01), includes L5 Demonstration Payload
  - Purpose to “bring into use” the GPS L5 frequency filing with ITU-R
  - Not intended for operational use
  - Successfully transmitted L5 on 10 April 2009, securing GPS filing
- L5 Demo used L-band antenna Auxiliary Payload interface adapter
- No impact on L1, L2 signals was intended or expected
- L1, L2 signal distortion detected shortly after payload activation
SVN-49 Pseudorange Residuals (Monitor Station PR – Predicted PR)

- Dual frequency ionosphere refraction corrected pseudoranges
- Relative to “best fit” orbit during initial test period (6 April 2009)
  - Roughly 4+ meter spread from 10 to 80 degrees
- Smaller elevation-dependent trends seen on other IIR/IIR-M SVs
GPS IIR L-Band Antenna with L5 Demo Filter

L-Band antenna array with 12 helical elements

162 In. Cable

L5 Filter

Outer Ring

Inner Ring

ION GNSS SVN-49 Panel Presentation 23 Sep 09
Alternatives Under Consideration

• Control Station Mitigation Alternatives
  – Pseudorange model correction for Kalman Filter
    ▶ Model the elevation-dependent pseudorange errors
    ▶ New capability could be applied to any GPS SV, as desired
  – Antenna Phase Center offset with SV clock adjustment
• Increase User Range Accuracy (URA) for SVN-49
  – Would allow receivers which process URA to de-weight measurements from SVN-49, or possibly exclude it
• User Equipment Mitigation Alternatives
  – Process URA to de-weight or exclude SVN-49 measurements
  – Implement application-specific correction for distortion
• Whether and when to set SVN-49 healthy
SVN-49 Signal Distortion Facts

- Signal distortion is internal multipath and is permanent
- Impact on users is variable and application-specific
  - Single or dual frequency, correlator spacing, type of correlator, local differential or not, phase-based or code-based application
  - Therefore, mitigations for distortion are very application-specific
- No universal solution identified
- SVN-49 not needed for coverage at this time
- SVN-49 specification compliance under investigation
  - SVN-49 meets SPS and PPS Performance Standards
  - IS-GPS-200 compliance being evaluated
- Minimal signal distortion below 60° elevation angle
  - RMS URE over all elevation angles comparable to a GPS IIA SV
Summary of Feedback from Manufacturer Surveys

Initial Feedback:

- 152m APC offset may adversely impact some users
- URA increase may provide positive benefits
Key Considerations for SVN-49 Way Forward

- Updating software in fielded UE very challenging
  - Some UE may be impossible to update

- No consensus in feedback from manufacturers

- Users are designing to (and expecting) recent actual GPS system performance, not specified performance

- Constellation is very robust today, so Air Force can afford a longer term focus and solution
Way Forward for SVN-49

• We intend to set SVN-49 healthy

• SVN-49 will be kept unhealthy until mitigations in place
  – Allows time to develop and implement OCS, Civil and Military receiver mitigations

• GPSW will continue outreach to users for SVN-49
  – Will provide technical data to interested users to develop mitigations