Global Positioning Systems Wing

GPS IIR-20 (SVN-49) Information

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Purpose for this briefing

- **Discuss SVN-49 signal problem with GPS community**
- **Provide information on potential mitigations**
- **Present way forward for SVN-49**

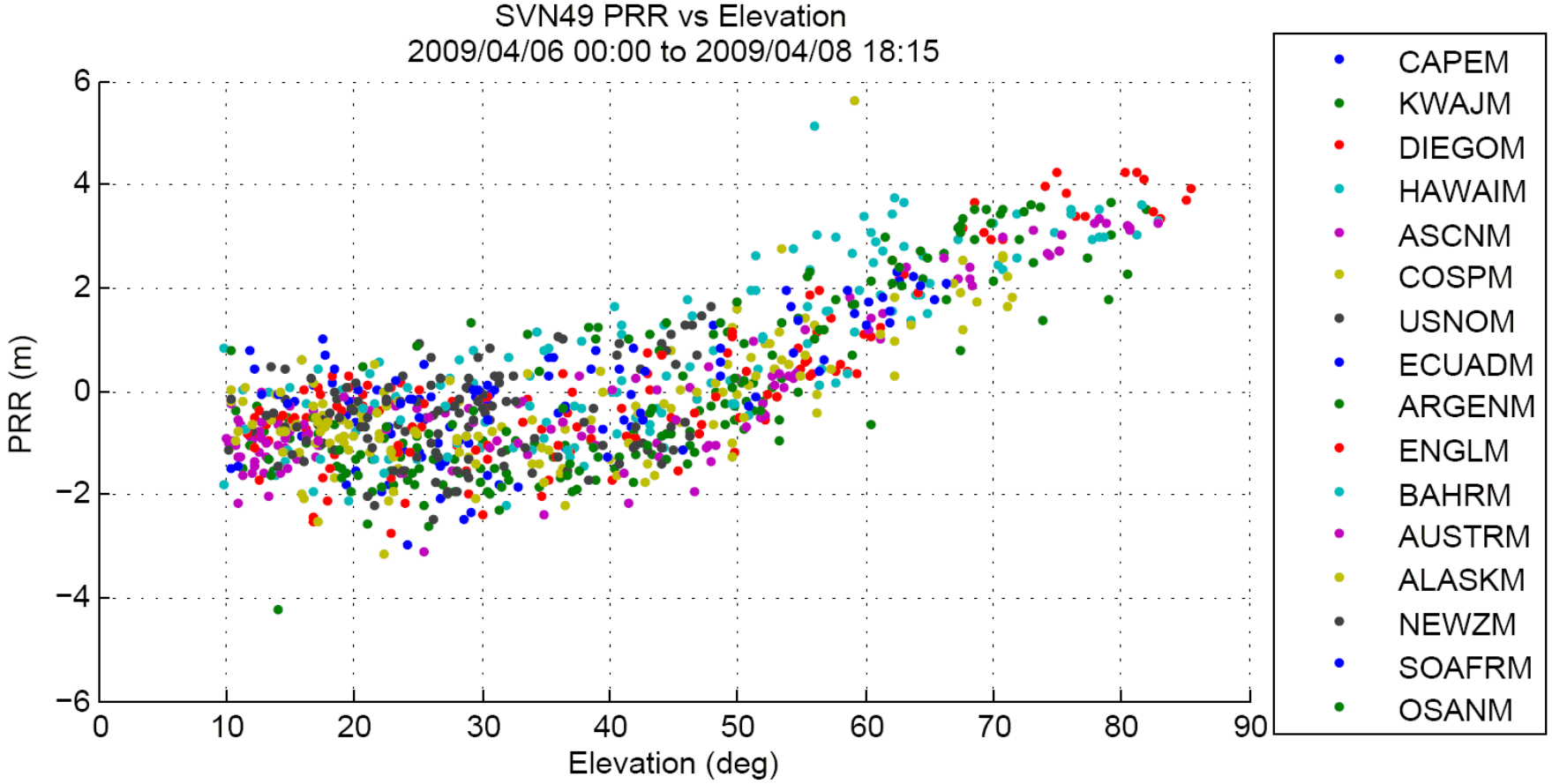
SVN-49 (PRN-01)

- **Background**
  - SVN-49 unlike other GPS IIR Satellites had L5 R&D Demonstration Payload
    - Demo payload made use of Auxiliary Payload port
  - No impact on L1 and L2 signals was intended or expected
  - "Out of family" elevation angle dependent Pseudo Range Residuals (PRR) seen at monitor stations and by other GNSS users world-wide
  - Root cause studied and established
    - Signals reflecting off L5 filter and transmitted through satellite antenna
  - Result is permanent, static multipath signal within satellite
  - Signal distortion is user elevation angle dependent
    - Little or no distortion at low elevation angle
  - Signal distortion impacts receivers differently depending on unique designs
  - Non IS-GPS-200 compliant receivers greatly complicate the issue
  - Varying impacts prevent a single solution for all forms of user equipment

SVN-49 (PRN-01) Continued

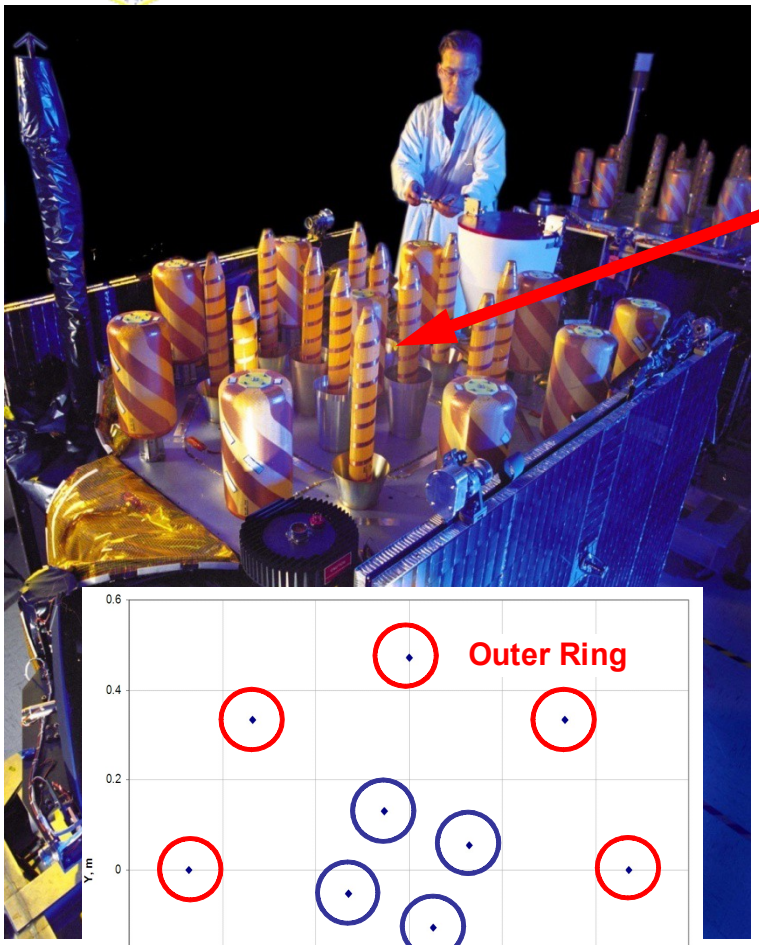
- **Current Status**
  - SVN-49 set unhealthy but still operated as part of GPS constellation
  - Control segment parameters temporarily adjusted to allow 2SOPS to continue to include SVN-49 in operational constellation (152 meter antenna phase center offset)
  - Will permanently modify Kalman Filter to accommodate SVN-49 without impacting users
  - GPSW and 50 SW exploring additional mitigation steps and eliciting user feedback
  - Potential mitigation steps include
    - Increase SVN-49 User Range Accuracy (URA) – change bits in GPS data message that allow user equipment to de-weight or exclude SVN-49 signals
    - Change SVN-49 PRN code to one outside range used by current user equipment
    - Modify SVN-49 signal configurations to mitigate impact to high precision users
    - Leave vehicle unhealthy but usable by some users by adjusting bits in nav message

SVN-49 Pseudorange Residuals (Monitor Station PR – Predicted PR)

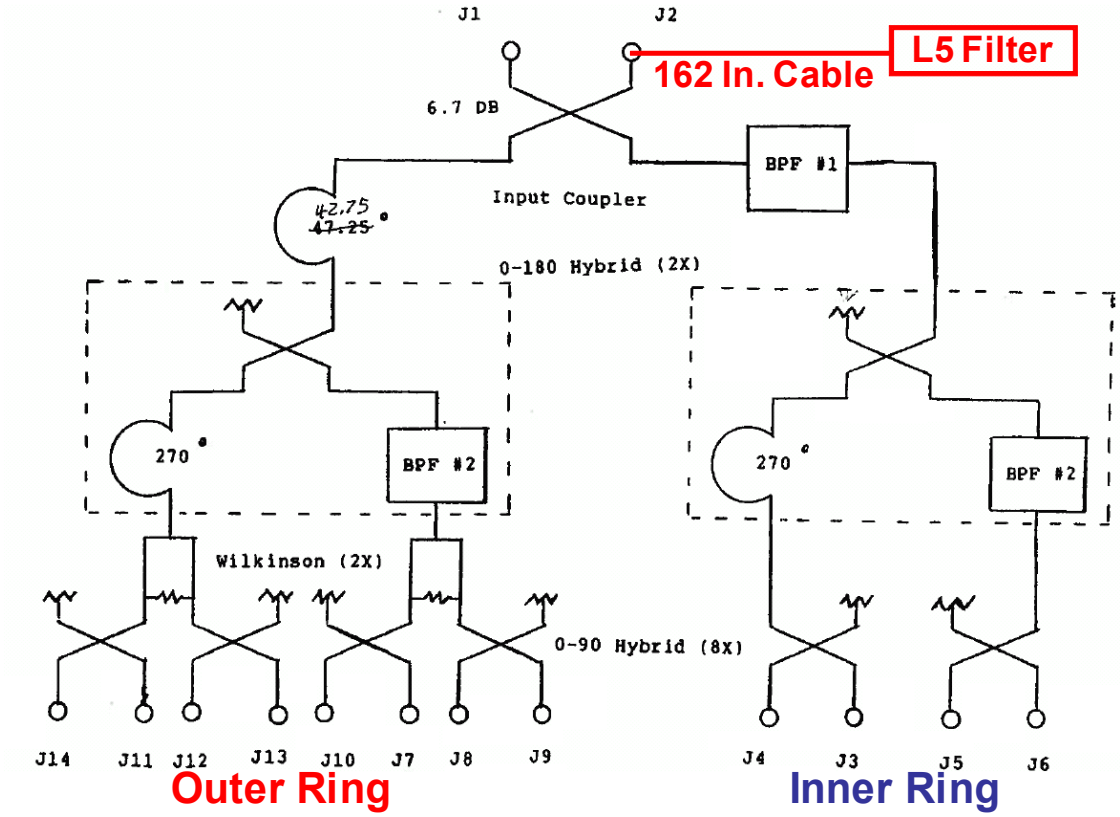


- **Dual frequency ionosphere refraction corrected pseudoranges**
- **Relative to "best fit" orbit during initial test period (6 April 2009)**
- **Roughly 4+ meter spread from 10 to 80 degrees**
- **Smaller elevation-dependent trends seen on other IIR/IIR-M SVs**

GPS IIR L-Band Antenna with L5 Demo Filter



L-Band antenna array with 12 helical elements



Operational Mitigation Methods

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- CS-internal software change to use look-up table corrections
- Fine tune T_{GD}/ISC values for non-L1/L2 P(Y)-code receivers

ptional mitigations (any and all combinations are possible)

1. Users switch to multipath-resistant receivers
2. Modify receiver software to use look-up table corrections
3. Increase URA index to a minimum value of ‘3’
4. Remove data modulation from L2 P(Y)-code
5. Change L2C PRN code to a “unique sequence”
6. Change SVN-49 from PRN-01 to PRN-32

1) Switch to Multipath-Resistant Receivers

Some high-end receivers with advanced multipath mitigation technology are not affected by SVN-49's spurious signals

- **This mitigation will be expensive for some users**
  - However, it is best way to overcome the anomaly
- **Some users already have these high-end receivers**
  - Users who really need to obtain the best accuracy
    - Multipath is a fact of life for GPS receivers
    - Many users already mitigate multipath
- **Multipath errors on par with single-frequency iono model errors**
  - Multipath mitigation unlikely to be found in a single-frequency receiver

2) Modify Receiver Software to Add Look-Up Table

UE software updates to add look-up table to compensate for the elevation angle dependent error for specific receivers

- **This mitigation may be difficult or expensive for some receivers**
  - However, it is second best way to overcome the anomaly
- **Look-up table corrections tailored for specific receiver characteristics**
  - Frequency/code or frequencies/codes tracked
  - Front-end bandwidth
  - Correlator spacing (if E-L correlator)
  - Correlator type (especially if not E-L correlator)
- **Maybe put "standard model" look-up tables in CNAV message?**

3) Increase URA to '3'

Increase the User Range Accuracy (URA) index to a value of '3' to alert receivers to de-weight SVN-49 measurements

- **URA is used by many receivers to weight the inputs from each satellite in the navigation solution**
  - Thus automatically using SVN-49 in the most appropriate way
  - An index of 3 means 4.85 < URA ≤ 6.85 meters
- **Unfortunately URA is ignored in many systems**
  - Considered unnecessary when differential corrections are available
  - Some systems simply ignore IS-GPS-200 parameters
  - Thus not a "universal" mitigation

4) Remove L2 P(Y)-Code Data

Remove data modulation from L2 P(Y) to prevent most semi-codeless receivers from using SVN-49

- **Several industry observers have expressed serious concern about receiver-specific code errors that prevent carrier phase ambiguities from being resolved or, worse, being resolved incorrectly**
  - This problem is expected only under poor geometric conditions
  - Problem is caused by different PR errors from different receivers
  - Dual-frequency PR error differences of a meter have been seen
- **Mitigation would prevent L2 measurements on SVN-49 by most types of semi-codeless receivers**
  - Thus preventing worst case situations from occurring
  - Some types of semi-codeless receivers are not affected

5) Change L2C PRN Code Sequence

Change the L2C PRN code to unique sequence so only receivers with updated software which corrects the pseudorange errors can use SVN-49

- **Similar mitigation & rationale as for removing L2 P(Y)-code data**
  - To overcome different PR errors from different receivers in DGPS operation:
    - Use high-end multipath mitigation in both base station and rover
    - Update base station and rover software to correct for SVN-49 anomaly
    - Avoid use of SVN-49 altogether
- **With changed L2C PRN code and updated DGPS receivers/software:**
  - SVN-49 as useful as any other satellite for precision DGPS operation

6) Change SVN-49 From PRN-01 to PRN-32

WAGE corrections are useless for SVN-49 as PRN-01, WAGE does not provide corrections for PRN-32; SVN-23 currently broadcasts as PRN-32, WAGE corrections would be beneficial for SVN-23 if it broadcasts as PRN-01

- **WAGE is a built-in wide-area DGPS capability for PPS receivers**
  - WAGE is not currently available for SPS users
    - However, WAGE capability is coming with L2C, L5, and L1C
- **Switch SVN-49 to PRN-32 and SVN-23 to PRN-01**
  - Improve accuracy of SVN-23 for PPS users
  - Avoid inference that SVN-49 accuracy is improved by WAGE
- **This mitigation will benefit current PPS users only**

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**
- **Minimal signal distortion below 60° elevation angle**
  - RMS URE over all elevation angles comparable to a GPS IIA SV

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**
  - *Non IS-GPS-200 compliant receivers greatly complicate the issue*
- **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

- **Way Ahead**
  - Use the National Space-Based PNT Systems Engineering Forum (NPEF) and other meetings to vet mitigation options to ensure right approach for users and operator
  - Continue transparent engagement with media and user communities world-wide
  - Plan to set SVN-49 healthy once proper coordination of mitigations options takes place or an operational need arises