Global Positioning Systems Wing

Request for Feedback on GPS IIR-20 (SVN-49) Mitigation Options

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Purpose for this briefing

- **Discuss SVN-49 signal problem with GPS community**
- **Provide information on potential mitigations**
- **Solicit user responses to mitigations (use template at end)**

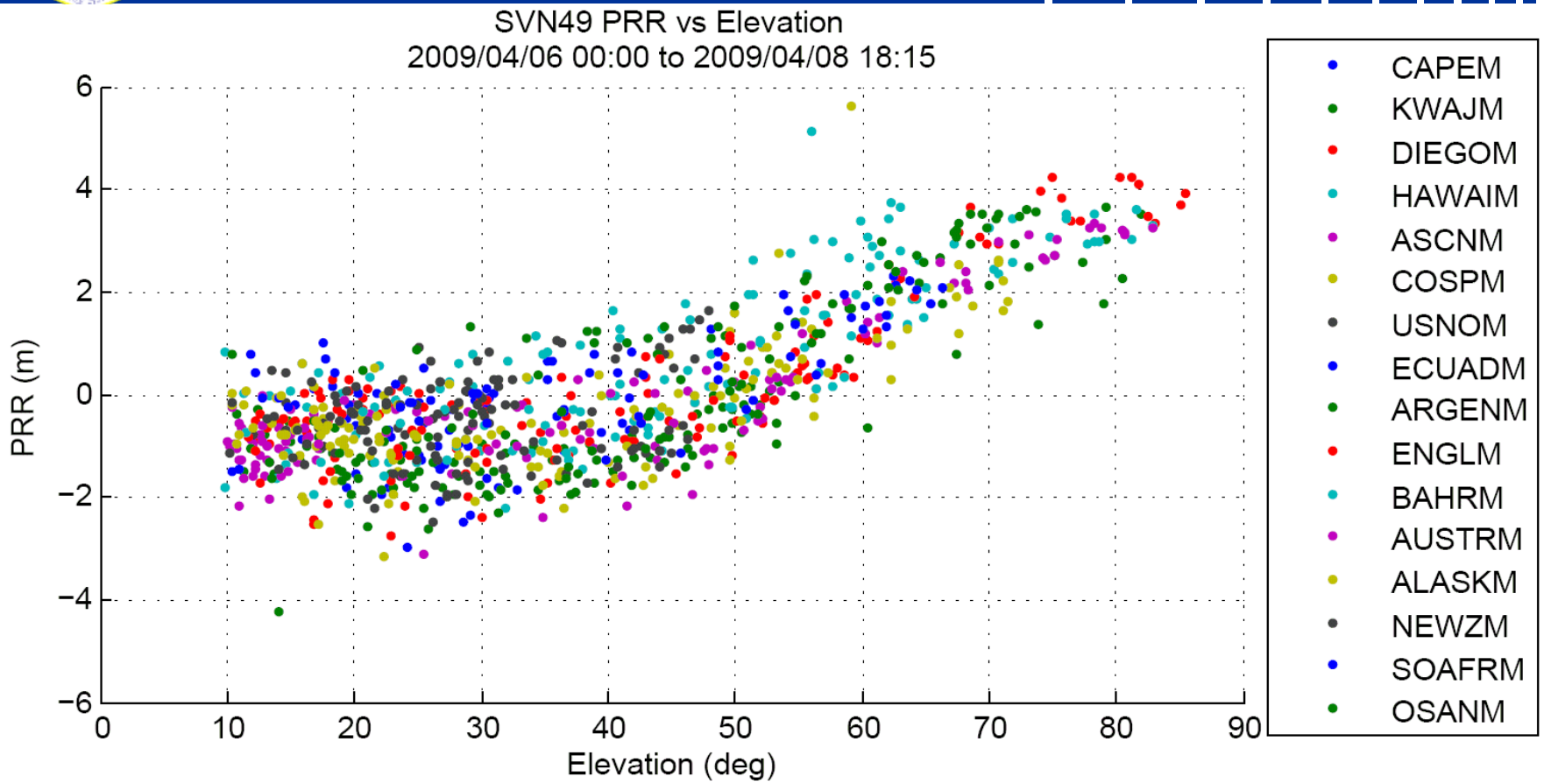
SVN-49 (PRN-01)

- **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 GPS users world-wide
  - Root cause studied and established
    - Signals reflecting off L5 filter and transmitted through satellite antenna
    - Installation method is unique to this satellite – other GPS satellites will not be affected
    - SVN-49 signal is not compliant with IS-GPS-200 for the spurious transmission specification, but does meet all other specifications and requirements
  - 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

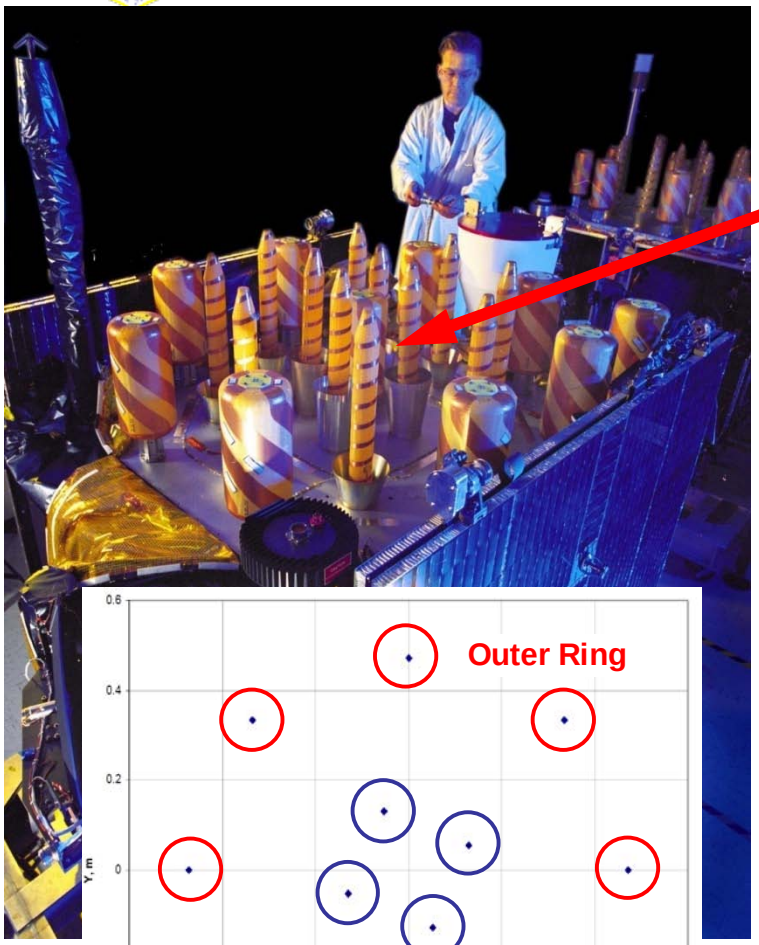
- **Current Status**
  - SVN-49 set unhealthy but still operated as part of GPS constellation
  - Control segment parameters temporarily adjusted to allow 2SOPS to continue to include SVN-49 in operational constellation (152 meter antenna phase center offset)
  - Considering modification of Kalman Filter to accommodate SVN-49 without impacting users
    - This is a software update to improve the control segment only
  - GPSW and 50 SW exploring additional mitigation steps and eliciting user feedback
  - Potential mitigation steps include
    1. Set healthy with current 152m Antenna Phase Center (APC) and associated clock offsets
    2. Set healthy with factory APC and clock offset
    3. Users switch to multipath-resistant receivers
    4. Modify receiver software to use look-up table corrections
    5. 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
    6. Remove data modulation from L2 P(Y)-code to mitigate impact to high precision users
    7. Change L2C PRN code to a “unique sequence”
    8. Change SVN-49 from PRN-01 to PRN-32
    9. Use spare health code so future users could use SVN 49 despite unhealthy setting

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

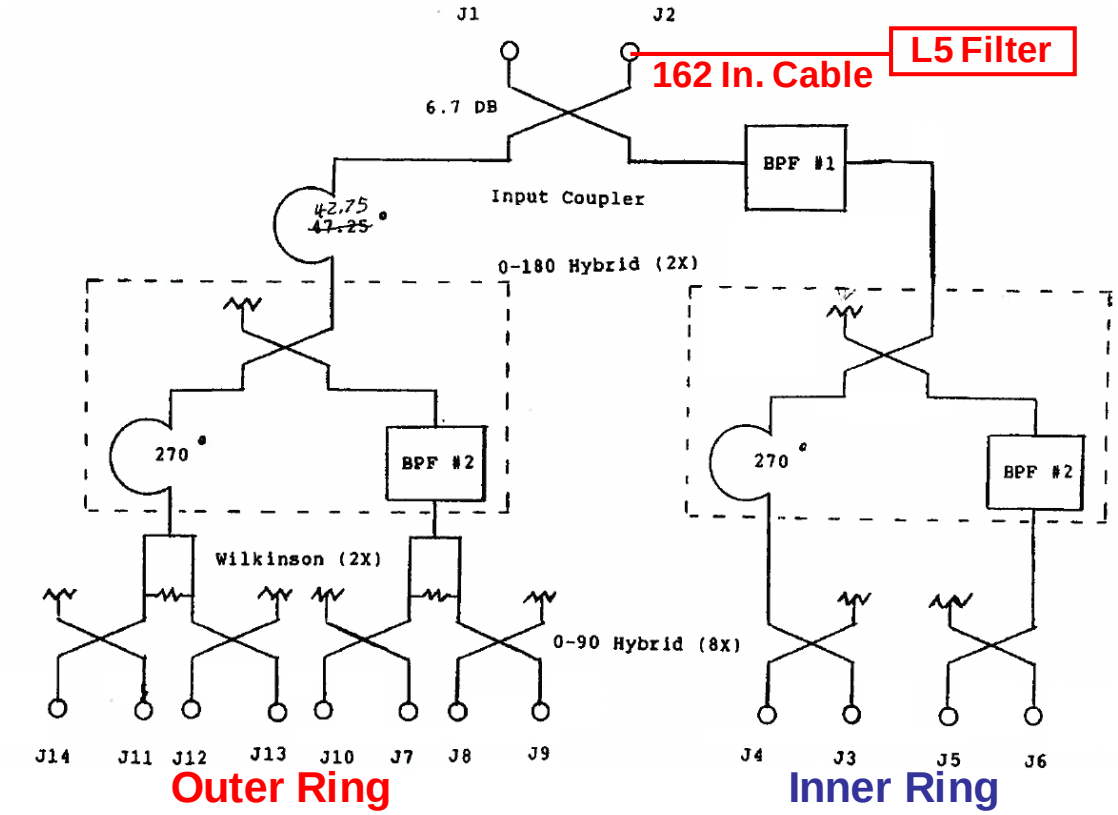


- **Dual frequency ionosphere refraction corrected pseudoranges**
- **Relative to “best fit” orbit during initial test period (6 April 2009)**
- **Roughly 4+ meter spread from 10 to 80 degrees**
- **Smaller elevation-dependent trends seen on other IIR/IIR-M SVs**

GPS IIR L-Band Antenna with L5 Demo Filter



L-Band antenna array with 12 helical elements



Operational Mitigation Methods

- **Necessary mitigations**
  - Fine tune T_{GD}/ISC values for non-L1/L2 P(Y)-code receivers
- **Optional mitigations (any and all combinations are possible)**
  1. Set healthy with current 152m Antenna Phase Center (APC) and associated clock offsets
  2. Set healthy with factory Antenna Phase Center (APC) offset
  3. Users switch to multipath-resistant receivers
  4. Modify receiver software to use look-up table corrections
  5. Increase URA index to a minimum value of ‘3’
  6. Remove data modulation from L2 P(Y)-code
  7. Change L2C PRN code to a “unique sequence”
  8. Change SVN-49 from PRN-01 to PRN-32
  9. Use spare health code so future users could use SVN 49 despite unhealthy setting

1) Implement 152m Antenna Phase Center (APC) and Associated Clock Offsets

Employ 152 m orbit height and clock offsets to reasonably match the anomaly effect on many types of L1/L2 receivers

- **Currently in use with the satellite set unhealthy**

- **Reduces the maximum error seen by Control Segment reference station receivers from > 4 m to < 1 m**
  - Prevents reference station measurements from disrupting normal Control Segment operations

- **Reduces error for many dual frequency code receivers in use today, just as it does for the reference receivers**
  - May slightly increase error for single frequency receivers and for dual frequency carrier receivers
  - Increases error for modern receivers with advanced multipath mitigation capability
  - L1C/A users can use the satellite but may see increased errors in their solutions

2) Set Healthy with Factory APC

Simply set SVN 49 with standard Antenna Phase Center offset. Do not implement any mitigation techniques.

- **Easily accomplished by the control segment**
- **Multipath from SVN 49 signal degrades control segment ability to provide quality navigational uploads**
- **Error increased for all users**
  - Impact varies with program and application
  - Dual frequency receiver navigation solutions experience greater error than single frequency users
  - Some users will seek mitigations to avoid including SVN 49 in their solutions

3) 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 difficult for some users**
  - However, it may be the 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**

4) 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 for some receivers**
  - However, it is one of the best ways to overcome the anomaly
  - The Air Force Control Segment is actively considering this option for their use
- **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)
- **Users could examine SV block type and PRN assignment to uniquely identify SVN 49 for their own mitigation technique**

5) Increase URA to '3' or Higher

Increase the User Range Accuracy (URA) index to a value of '3' or higher 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 permitting de-weighting of SVN-49 in an appropriate fashion
  - An index of 3 means $4.85 < \text{URA} \leq 6.85$ meters
  - Higher values of URA indicate higher levels of error
- **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

6) Remove L2 P(Y)-Code Data

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

- **Data removal on L2 P(Y)-code, ONLY on SVN49**

- **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 L2 data removal

7) 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

8) 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 another SV to broadcast 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-2 capability is coming with L2C, L5, and L1C
    - WAGE-2 will include corrections for PRN 32
- **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**

9) Use Spare Nav Code so Future Users Could use SVN 49 Despite Unhealthy Setting

Leave SVN 49 unhealthy, but use a spare health message to allow future user equipment (UE) to use SVN 49

- **Should not harm existing UE**
  - Does not harm users who do not want to include SVN 49 in solution
  - Spare code identified in IS-GPS-200, Table 20-VIII
- **Requires UE update to include "Unhealthy but Usable" satellite in solution**
  - Current UE cannot use SVN 49 without a software modification
  - Unknown user cost and schedule to modify software

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^{o} 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

- **Note to the Users**
  - The mitigations described in this brief are the best potential courses of action we have at this time
  - Results from user feedback may lead to adjustments of these mitigations

- **Way Ahead**
  - Use the National Space-Based PNT Systems Engineering Forum (NPEF) and other meetings to gather feedback on mitigation options to ensure right approach for users and operator
  - Continue transparent engagement with media and user communities world-wide
  - Plan to further investigate mitigation options to support decision when to set SVN-49 healthy unless an exceptional operational need arises

Tentative Schedule for SVN-49
(Exact Dates and Times TBD)

Date	Event (Telecon call-in number is: 1-800-366-7242 passcode: 6530000#)
Mar 10	DoT public release of SVN 49 mitigations
26 Mar 10	Q&A Telecon hosted by GPSW (4pm Eastern Time)
30 Apr 10	Q&A Telecon hosted by GPSW (4pm Eastern Time)
28 May 10	Collect final responses from Civil & Commercial community
TBD	Review of Responses with Civil Representatives at GPSW
TBD	Official Meeting with Civil Gov for Review of SVN 49 mitigations
TBD	Final Civil & Commercial Feedback posted
TBD	Brief NPEF (date still TBD, possibly scheduled with EXCOM)
TBD	Brief GPSW & 50th SW leadership – Responses & Recommendations
TBD	Brief SMC & 14th AF leadership – Responses & Recommendations
TBD	Brief AFSPC leadership – Responses & Recommendations
TBD	Brief EXCOM (date still TBD)
Sep ’10	AEP 5.5.4 Installed at 2SOPS (date still TBD)
Sep – May’11	Mitigation Studies performed
Jun ‘11	SVN 49 Set Healthy Decision

SVN49 Mitigation Response Template

- **Use this template when responding to these proposed mitigations**

Responding POC & contact info:	**<<insert your contact info here>>**						
Mitigation	Feedback (pros/cons/impacts)	L1C/A impacts	L1C/A semi-codeless impacts	# units / users affected	Time to accommodate mitigation	Cost to accommodate mitigation	Platforms affected
1. Set Healthy with 152m APC & clock offsets							
2. Set Healthy with factory APC							
3. Use Multipath Receivers							
4. User equipment software updates							
5. Increase URA to 3 or greater							
6. Remove L2P(Y) data modulation							
7. Change L2C PRN							
8. Change SVN49 PRN from 01 to 32							
9. Unhealthy but Usable w/ spare nav code							