SVN 62 L5 carrier phase anomaly(?),
(SVN 49 Bonus)

Byron Iijima
Larry Young, Ruth Neilan, Dave Stowers

Jet Propulsion Laboratory,
California Institute Of Technology
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Introduction

• SVN 62 is first and only Block IIF satellite launched
• Montenbruck et al (DLR) found a semi-diurnal signature in “tri-carrier multipath combination” for SVN 62
• Most likely source is L5 carrier phase signature?
• What users are affected by L5 phase?
Outline

- Discuss multipath combinations with L5 (Simsky)
- DLR tri-carrier multipath combination data
- Looking at IGS data
- Due to L5? (or maybe L1&L2)

- SVN 49
- SNR

- Conclusions
L5

- Frequencies
  - L1 = 1575.42 MHz
  - L2 = 1227.60
  - L5 = 1176.45
- SVN 49 (PRN 1) Block IIR-M
- SVN 62 (PRN 25) Block IIF
The GPS range observables are
\[ \text{obs}(t) = R(t) + k\text{TEC}(t)/F^2 + \text{flat}(t) \]

- \( R(t) \) = non-dispersive range (geometric range, tropo, clock)
- \( \text{TEC}(t) \) = line-of-sight total electron content
- \( \text{flat}(t) \) = (hardware biases, multipath, antenna pattern, noise, phase windup, 2\text{nd} order iono, etc.)

Can make linear combinations of observables where \( R \) and \( \text{TEC} \) contributions cancel:
\[ \text{MP1} = \text{P1} - 4.091 \text{ L1} + 3.091 \text{ L2} \]
\[ \text{MP2} = \text{P2} - 5.091 \text{ L1} + 4.091 \text{ L2} \]
L5 and more multipath combinations

Any trio of observables defines a multipath combination

Unique up to normalization

\[
\begin{align*}
\text{MP1} &= \text{MP}(P_1,L_1,L_2) = P_1 - 4.09 L_1 + 3.09 L_2 \\
\text{MP2} &= \text{MP}(P_2,L_1,L_2) = P_2 - 5.09 L_1 + 4.09 L_2 \\
\text{MP}(P_1,L_1,L_5) &= P_1 - 3.52 L_1 + 2.52 L_5 \\
\text{MP}(P_1,L_2,L_5) &= P_1 - 19.09 L_2 + 18.09 L_5 \\
\text{MP}(P_5,L_1,L_5) &= P_5 - 4.52 L_1 + 3.52 L_5 \\
\text{MP}(L_1,P_2,P_5) &= L_1 - 19.09 P_2 + 18.09 P_5
\end{align*}
\]

Tri-carrier multipath combination (Simsky)

\[
\text{TCMP} = \text{MP}(L_1,L_2,L_5)
\]
Tri-carrier multipath (TCMP) combination

Tri-carrier multipath combination (Simsky)

\[ TCMP = MP(L1, L2, L5) = \alpha L1 + \beta L2 + \gamma L5 \]
\[ \alpha = (\lambda_5^2 - \lambda_2^2) / N \]
\[ \beta = (\lambda_1^2 - \lambda_5^2) / N \]
\[ \gamma = (\lambda_2^2 - \lambda_1^2) / N \]
\[ N^2 = (\lambda_5^2 - \lambda_2^2)^2 + (\lambda_1^2 - \lambda_5^2)^2 + (\lambda_2^2 - \lambda_1^2)^2 \]

Normalized so that RSS of coefficients is 1.

\[ TCMP = 0.1415 L1 - 0.7672 L2 + 0.6257 L5 \]
SVN 62

- Launched 2010-05-28
- First Block II-F, second GPS with L5
- L5 turned on briefly (5.5 hrs?) 2010-06-17
- L5 turned on permanently 2010-06-28

- DLR has extensive L5 network
GPS L5 networks
FIGURE 2. Triple-frequency carrier-phase combination ($M=0.142 \cdot L_1 - 0.767 \cdot L_2 + 0.626 \cdot L_5$) for SVN 62 has arbitrarily been shifted to obtain a near-zero mean during the final days of the entire arc.
DLR SVN 62 tri-carrier multipath combo

- Continuous temporal signature in TCMP common to all receivers
  - Spacecraft temporal signature
- Semi-diurnal TCMP signature
  - Temperature-driven hardware bias?
SVN 62 TCMP longer term (IGS only)

- 2010-07-01 – 2010-08-26
- Daily gap due to paucity of sites
GPS L5 networks
SVN 62 eclipse duration

Days past 2010-07-01 00:00:00

Sec
SVN 62 TCMP long term

- Sudden drop in signal size when eclipsing season ends
- Signal continues after eclipsing
- 2 large signal days long after eclipsing over (July 30, Aug 2)
  - Signature on those two days is nearly identical
Source of SVN 62 TCMP signature

- Not multipath, antenna pattern, windup, 2\textsuperscript{nd} order iono, receiver effects
- Temporal instrumentation phase bias signature on at least one of the frequencies
- Can we attribute to one of the 3 frequencies?
  - Use pseudorange multipath combinations
    
    \[
    \begin{align*}
    
    MP(P1,L1,L2) & = P1 - 4.09 L1 + 3.09 L2 \\
    MP(P1,L1,L5) & = P1 - 3.52 L1 + 2.52 L5 \\
    MP(P1,L2,L5) & = P1 - 19.09 L2 + 18.09 L5
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    \text{MP}(P1,\text{L1,L5}) &= P1 - 3.52 \text{ L1} + 2.52 \text{ L5} \\
    \text{MP}(P1,\text{L2,L5}) &= P1 - 19.09 \text{ L2} + 18.09 \text{ L5} \\
    \text{MP}(P2,\text{L1,L2}) &= P2 - 5.09 \text{ L1} + 4.09 \text{ L2} \\
    \text{MP}(P2,\text{L1,L5}) &= P2 - 4.34 \text{ L1} + 3.43 \text{ L5} \\
    \text{MP}(P2,\text{L1,L5}) &= P2 - 23.51 \text{ L2} + 22.51 \text{ L5} \\
    \text{MP}(P5,\text{L1,L2}) &= P5 - 5.32 \text{ L1} + 4.32 \text{ L2} \\
    \text{MP}(P5,\text{L1,L5}) &= P5 - 4.52 \text{ L1} + 3.52 \text{ L5} \\
    \text{MP}(P5,\text{L2,L5}) &= P5 - 24.51 \text{ L1} + 23.51 \text{ L5}
    \end{align*}
    \]
Roth – SVN62
2010-07-11
Source of SVN 62 TCMP signature

- Looking at data the first row it’s easy to imagine that all the TCMP signature is coming from L5, and that it is affecting the multipath calculation in MP(P1,L1,L5) and MP(P1,L2,L5), but not MP(P1,L1,L2).
- Looking at the data in the second row, one thinks the same thing.
- The third row is not so clear: It could be L2 as well.

- Reason – Separate location of L5 hardware?
Source of SVN 62 TCMP signature

- To get a clearer picture of which frequency the TCMP signature is coming from, I tried “correcting” the L1, L2, or L5 phase one at a time, and seeing what corrected the MP plots best.
Suppose the TCMP signature were due solely to a flaw in L5

\[ TCMP = 0.14L1 - 0.77L2 + 0.63L5 = 0.63\Delta L5 \]

\[ \Delta L5 = \frac{TCMP}{0.63} \]

\[ L5_{fixed} = L5 - \Delta L5 = L5 - \frac{TCMP}{0.63} \]
Roth – SVN 62
2010-07-11
“Fixing” L5
Roth – SVN 62
2010-07-11
“Fixing” L2
Source of SVN 62 TCMP signature

- “Fixing” L1 makes everything worse
- “Fixing” L5 seems to remove the TCMP signature from the multipaths
SVN 49 TCMP signature

- SVN 49 signature is similar in size to SVN 62
- Very different otherwise
  - Not continuous across stations
  - Strong function of elevation/nadir (no surprise?)
- Any azimuthal or temporal signature is smaller.
SVN 49 TCMP signature
SVN 49 TCMP signature
SVN 49 nadir angle signature

- SVN 49 TCMP is most likely due to L5
- Dominated by nadir angle effect, (like L1 and L2 pseudorange issues?) not temperature
- L5 antenna power pattern is quite different from L1 and L2
- L5 pseudorange has nadir angle signature, larger than L1 or L2 pseudoranges
SVN 49 SNR signature

- SVN 49 L5 elevation signature is different from L1 and L2
SVN 62 SNR signature

- SVN 62 looks as expected
Conclusions

• SVN 62 is the first Block IIF satellite

• SVN 62 has a strong semi-diurnal signature in its tri-carrier multipath combination. The most likely theory for the cause is a temperature-dependent hardware bias between the L5 and L1&L2 hardware.

• Must account for this in 3 frequency applications

• SVN 62 will have different dual-frequency clocks depending on whether one uses L1/L2 or L1/L5

• SVN 49, of course, has well-known onboard multipath problems with P1 and P2, and we see it has phase problems with L5 as well.
Who Cares? (and not) about SVN 62 type phase variations?

- L5 carrier phase is not coherent with L1 and L2 phases but same for all directions for SVN62, varies with angle for SVN49

- This is a problem for
  1. Stand Alone Trilaning (navigation within lanes on highway)
  2. Data editor programs that rely on coherent carriers
  3. Ionospheric science
  4. Estimate different clock for L1, L5 than for L1, L2, ISC not frequent enough to capture ~20 cm cycle over 12 hours
  5. ...

- This is not a problem for
  1. Stand alone users who only use phase to smooth pseudorange over few hundred seconds
  2. High accuracy network users who form differenced observables (SVN 62 problem cancels, but note SVN 49 carrier variation does NOT cancel)
  3. ...
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