The Effects of L2C Signal Tracking on High-Precision Carrier Phase GPS Positioning: Implications for the Next Generation of GNSS Systems

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L2C Basics

- L2C: Civilian code on L2 carrier broadcast by 7 Block IIR-M SV's since 2005, and 3 Block IIF since 2010.
 - Unencrypted code tracked by civilian receivers without correlation.
 - > Provides 6-12 dB-Hz SNR improvement over P2, stronger than L1 C/A.
 - > Broadcast in quadrature (90° out of phase) with P2:



P2 Carrier (In Phase)



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C2 Carrier (Quadrature)

Quadrature Phase-Shift Key Modulation



- Do Phase Shifts Affect Carrier Phase Positioning?
 - Depends on who made your receiver

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- Depends on how you have configured your receiver
- Depends on how you translate and pre-process your data
- Depends on how you process the positions

GPS Receiver Tracking Configuration

Most receivers simultaneously track L2C and L2P(Y)

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- Can also be configured to track ONLY L2C if present (this is often the default)
- Some can only do one or the other (e.g. Ashtech ProFlex CORS, Trimble NetRS with older firmware (1.1-5)

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GPS Receiver Logging Configuration

- Some Data Formats Don't Allow for both L2C and L2P
 - > Trimble Record Type 17 (RT17)

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- > Default Topcon TPS Messages
- > BINEX Record 7f-03 (Leica and some Trimble Receivers)
- Just because you're TRACKING both L2 phases doesn't mean you're LOGGING both!

L2 Tracking Control ?		Data Format: • T00	OBinex	
L2-Y-code Only Y-code on L2 will be tracked. L2C or L2-Y-code L2C will be tracked if available. L2-Y-code will be tracked if L2C is not available. e L2C and L2-Y-code Both signals will be tracked simultaneously.	Trimble NetRS	T00 Options Measurement Interval	Smooth Code Phase	☑ Use Record Type 27

	L2 OFF	L2-Y-code only	L2C or L2-y-code	L2C and L2-Y-code
BINEX	No L2 at all	P2 only	C2 for block IIR-M/II-F satellites and P2 for the rest	P2 only for all satellites
T00/RT17	No L2 at all	P2 only	C2 for block IIR-M/II-F satellites and P2 for the rest	P2 only for all satellites
T00/RT27	No L2 at all	P2 only	C2 for block IIR-M/II-F satellites and P2 for the rest	C2 AND P2 for block IIR-M/II-F satellites and P2 for the rest



RINEX Translation Software

- Your RAW data contains BOTH L2C and L2P(Y)
- But RINEX 2.XX currently allows for a single L2 Phase and SNR (it does allow multiple pseudoranges)
 - RINEX 2.30 under development (UNAVCO/National Geodetic Survey) would allow both L2 phases and SNR's in the same file.
- For now, UNAVCO's teqc pre-processing software selects L2C phase and SNR when C2 observation is included in the RINEX file (+C2 flag in command line) since Sept 2009.

 2.11
 OBSERVATION DATA
 G (GPS)
 RINEX VERSION / TYPE

 teqc
 2012Jun06
 20110202 20:55:52UTCPGM / RUN BY / DATE

 8
 L1
 L2
 C1
 P1
 C2
 P2
 S1
 S2
 # / TYPES OF OBSERV

 $12\ 6\ 11\ 20\ 25\ 47.9600000\ 0\ 10G24G16G18G21G10G22G29G01G05G15$

125698938.93146 **<u>97947222.94443</u>** 23919710.560 23919709.860

23919708.380 40.700 <u>22.100</u>

108905294.44247**84861259.57448**20723987.56020723987.020**20723985.400**20723984.72045.500**48.000**



RINEX Translation Software

- If you do not control the receiver or pre-processing, how do you know which L2 information you have?
 - > Some translators prefer P2 phase when C2 is present.
 - May find SV's with NO L2 observations in some cases
 - > L2C 6-12 dB-Hz SNR improvement over P2.

SNR for L2C is higher than L1-C/A



Receiver Quadrature Phase Correction

- L2C Phase is ¼-wavelength out of phase with L2P(Y)
- Some manufacturers *correct* for this in the raw logged data by subtracting 0.25 from observed phase.

> Ashtech, Septentrio, Trimble

• Others *don't correct:* Javad, Leica, Topcon



How do Receivers Track L2C and L2P?

- Receivers use separate correlators for each L2 carrier phase.
 - > Instrument noise is independent, reveals Rx digitizing resolution

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Trimble NetRS: Banding at 1/256 cycle ≈ 1 mm (8-bit A-D)

How do Receivers Track L2C and L2P?

- Receivers use separate correlators for each L2 carrier phase.
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Leica GR10, Topcon Net-G3A: Banding at 1/512 cycle ≈ 0.5 mm (9-bit A-D)

How do Receivers Track L2C and L2P?

- Receivers use separate correlators for each L2 carrier phase.
 - Instrument noise is independent, reveals Rx digitizing resolution

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Trimble NetR9, Javad SIGMA: Banding at 1/1024 cycle ≈ 0.25 mm (10-bit A-D)

How Does This Affect Position?

• Zero-Baseline (same receiver, different L2 phase used)

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24-hour TRACK Solution: No net bias, noise depends on L2C visibility

How Does This Affect Position?

TRACK phase residuals for L2C Satellite

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Lower figure shows difference between L2C (red) and L2P (blue)

How Does This Affect Position?

TRACK phase residuals for non-L2C Satellite

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This case demonstrates that L2C noise does not affect other satellites

Direct Comparison of L2C-L2P Position

GAMIT Solution Using L2-P(Y) Phase (GREEN) vs. L2C Phase (BLUE)



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Same Receiver (Trimble NetRS) – L2C enabled on day 100

Direct Comparison of L2C-L2P Position

• Sub-millimeter differences in L2C and L2-P(Y) GAMIT Solutions



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Same Receiver (Trimble NetRS) – L2C enabled on day 100

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Direct Comparison of L2C-L2P Position

0.01

0.008

0.006

0.004

0.002

-0.002

-0.004

-0.006

-0.008

-0.01

Elevation Dependent Phase Residuals between L2C and L2P GAMIT Solutions



L2C Noisier at Low Elevations – Increased Multipath due to SNR (remember this!)

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-100 --150 L 0

10 km Baseline – Mixed Receivers

Carrier Phase Position Comparison for L2-P(Y) and L2C



10

hours

15



L2P – BLUE L2C - RED

Trimble NetRS to Trimble NetR9 TRACK Processing: Both correct Quadrature in L2C

20

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10 km Baseline – Mixed Receivers

Carrier Phase Position Comparison for L2-P(Y) and L2C





L2P – BLUE L2C - RED

Trimble NetRS to Leica GR10 (no quadrature correction) TRACK Processing

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Conclusions

- L2C Is Not Yet Suitable For Use in Carrier-Phase Positioning
 - > Only Partial Constellation Available
 - Confusion over receiver configuration and pre-processing
 - Improper receiver configuration and/or translation can result in loss of L2-P Phase information and missing observations
 - Fundamental Incompatibility of receiver brands
 - IGS and RTCM should encourage universal quadrature correction as has been done with L1P and L1-C/A
 - Problems in kinematic processing with mixed receivers
 - Real-time issues (not discussed here) are worse!
- Recommendations:
 - L2C phase <u>not</u> be used in "production" RINEX files used for position time-series.
 - Log both L2-P(Y) and L2C iff raw data format allows, and use separate pre-processing flows for positioning and special uses.



Questions:

- If adopting something as "simple" as a new carrier on an existing frequency is so difficult, what about:
 - New GPS frequency: L5?
 - Existing GNSS Constellation: GLONASS?
 - Future constellations: Galileo, Compass?
 - Most GNSS signals have phase-shifted carriers
- Issues to address:
 - > Upgrade timeline of existing infrastructure
 - Receivers & Antennas (disrupt time-series)?
 - Data Formats and metadata
 - RINEX 3 (not (yet) supported by teqc)
 - Data Analysis software
 - Carrier phase and multi-code analysis