Impact of Extended Coherent Integration Times on Weak Signal RTK in an Ultra-Tight Receiver

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Outline

- Introduction
    - Motivation
    - Objectives
- Ultra-tight GNSS-IMU Integration
    - Ultra-Tight Receiver Architecture
    - Coherent Integration Issues
- Testing and Analysis
    - Test Description
    - Tracking Level
    - Measurement Domain
    - Position Domain
- Conclusions

Motivation

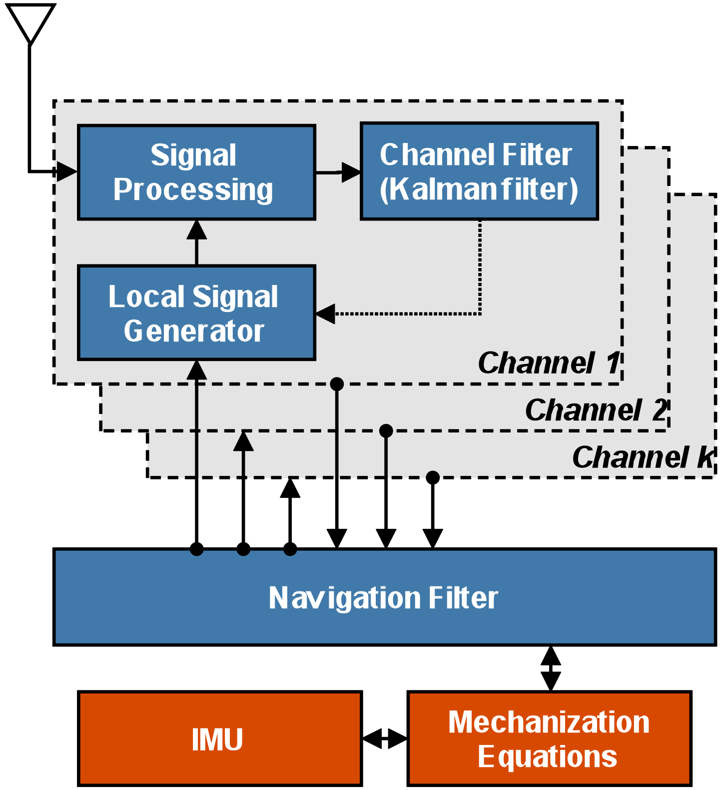
- GNSS RTK Positioning
  - “RTK” label implies high accuracy (≤ 10 cm)
  - Must use Differential GNSS
  - Must use carrier phase measurements (low noise and multipath), but…
  - Phase Lock Loops (PLLs) are the least stable under attenuated signals, and…
  - Phase measurements are ambiguous, with…
  - New ambiguity after each loss of phase lock…
  - To be evaluated as a real or integer number

Objectives

- **Investigate impact of extended coherent integration and oscillator quality on RTK performance in an ultra-tight configuration…**
- **Under attenuated signal conditions, and**
- **Confirm previous analysis on effect of**
  - **Oscillator quality**
  - **IMU quality**
- **Use of real data collected under foliage**
- ***Is the ultra-tight approach IMU or oscillator quality limited?***

Ultra-Tight Rx Architecture

- Each channel filter estimates tracking errors for a given signal → Estimator-based tracking
- Error estimates for all channels combined in navigation filter and …
- …signal parameters (code phase, Doppler) estimated by the navigation filter → Vector Tracking
- Inclusion of IMU data in navigation filter → Ultra-tight integration



Coherent Integration

- Increasing coherent integration time improves sensitivity by up to 25 dB, but…
- Challenges arise, namely…
  - Tracking errors
    - Doppler Error causes roll-off in power according to sinc squared law
    - Errors arise due to: dynamics, oscillator timing errors and thermal noise
  - Data modulation problem
    - Bit transitions = effective signal attenuation
  - Stability
    - For tracking – as product of integration time and bandwidth increases loop becomes unstable

Overcoming the Challenges

- Tracking Errors
  - Use of IMU to reduce dynamic errors
  - Use of high quality oscillator to reduce timing errors
  - Long integration reduces errors due to thermal noise
- Data modulation
  - Bit estimation techniques (unreliable at low C/N_0)
  - External aiding
  - Modernized signals (inherently dataless)
- Stability
  - Direct design in the digital domain
  - Modified filter structures extends stability margin
  - Kalman filter tracking

Field Test Set-Up 1

- National Instruments front-ends
  - NI 5661 – Down-converter/Digitizer
  - 12.5 Msps (selectable up to 100 Msps)
  - Raw data streamed to disk
  - Two used: one per oscillator, L1

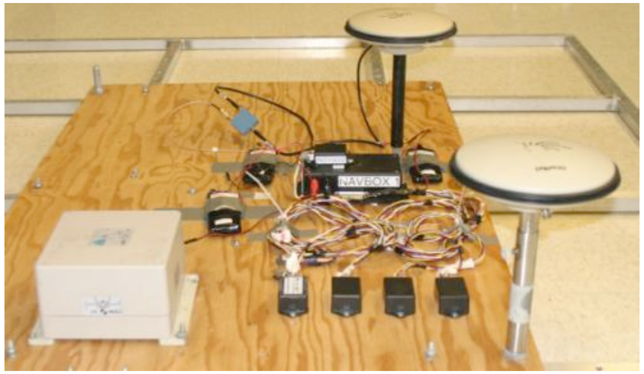
- IMUs
  - Tactical – Honeywell HG1700
  - MEMS Grade – Cloudcap Crista

Parameter	HG1700	Crista
Accelerometer Bias	1 mG	30 mG
Accelerometer Scale Factor	300 ppm	100,000 ppm
Gyro Bias	1 deg/h	1,800 deg/h
Gyro Scale Factor	150 ppm	N/A

- Oscillators
  - Oscilloquartz BVA OCXO
  - Micro Crystal TCXO

Parameter	Oscilloquartz	Micro Crystal
h_0	2.51e-26	1e-21
h_{-1}	2.51e-23	1e-20
h_{-2}	2.51e-22	1e-20

Field Test Set-Up 2



- Vehicle roof rigidly mounted antennas and IMUs
- Test routes 800 to 1000 m
- Up to 45 km/h
- Signals partly obscured
- LOS conditions for acquisition
- GPS reference rx 5 km away
- Eight SV, good geometry

Collection Environment

- Three routes in suburban Calgary

- Each route traversed twice
- Mixture of open sky and foliage

- Attenuation of up to 20 dB recorded

Data Processing 1

- Use of PLAN Group GSNRx™ software receiver
- Configured to operate in two modes
  - Standard (GPS standalone) – 20 ms coherent integration – <u>Baseline results</u>
  - Ultra-tight (UT) – extended coherent integration
- Scenarios
  - Successive integration times of 20, 40 and 80 ms (UT configuration)
  - Use of two different IMUs with two different oscillators
- Rx measurements processed with FLYKIN+™
  - To derive RTK solution

Data Processing 2

- Use of float solution from FLYKIN+™ for RTK analysis
- Performance metrics used:
  - Tracking level: Phase Lock Indicator (PLI)
    - Value of +1 is perfect lock, 0 is 90° phase error -1 is 180° phase error
  - Measurement domain: Magnitude of cycle slips
    - More/larger cycle slips = worse performance in RTK
  - Position domain: Estimated accuracies of float UT solutions relative to standalone solution

Tracking Level Analysis

- Increased PLI at low C/N_0 indicative of better phase tracking performance
- The following slides – representative subset of results

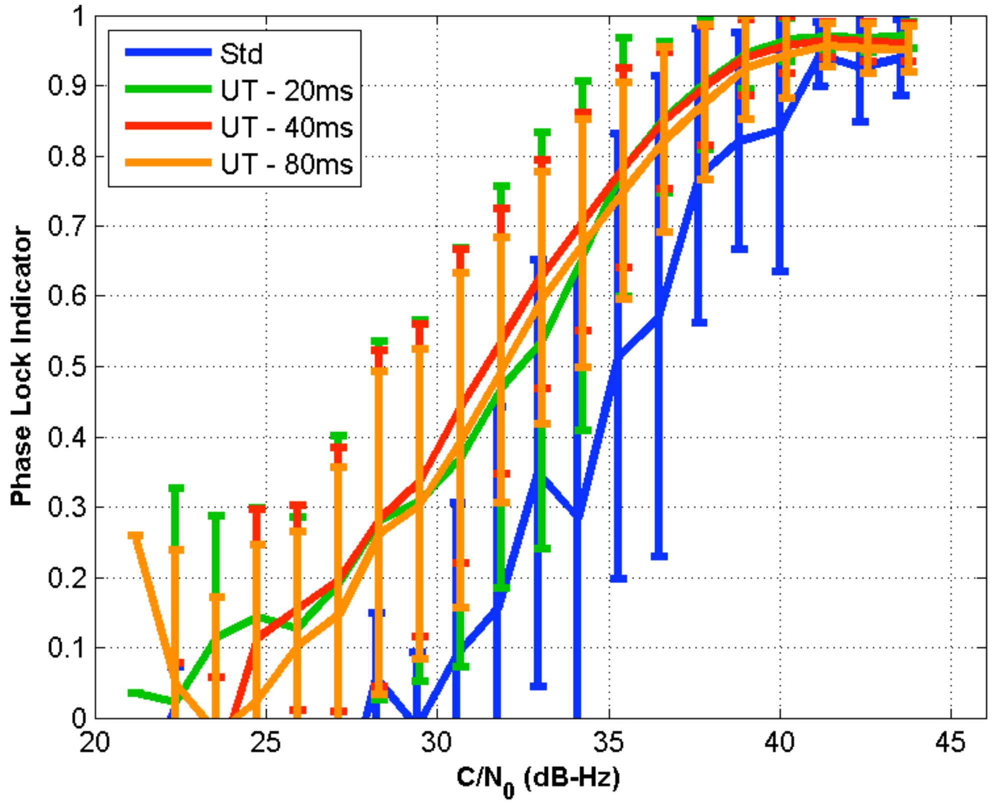
- All results from worst-case period of the tests
- Moving along street with most foliage

PLI - Low Elevation (< 18˚) PRN 13

- **Best combination: HG1700 IMU & OCXO Osc**

- **Results show advantages of ultra-tight integration**

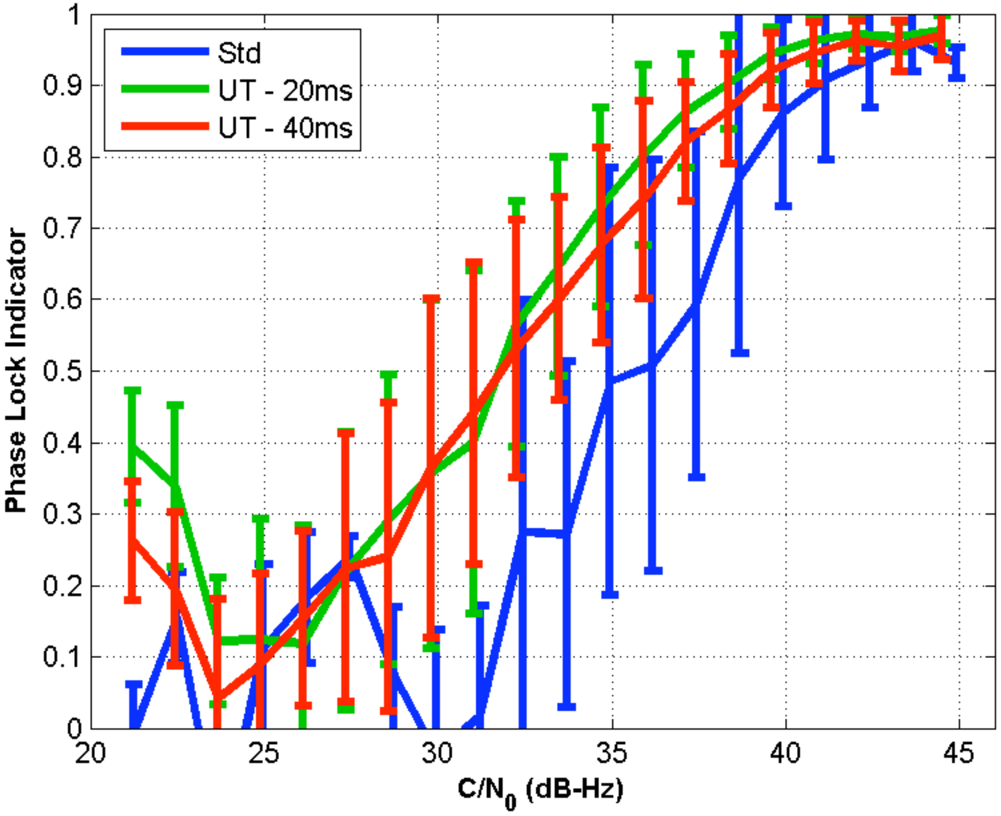
- **…but no discernible benefit of increased coherent integration**



PLI - Low Elevation PRN 13

- **Worst combination: MEMS IMU & TCXO Osc**

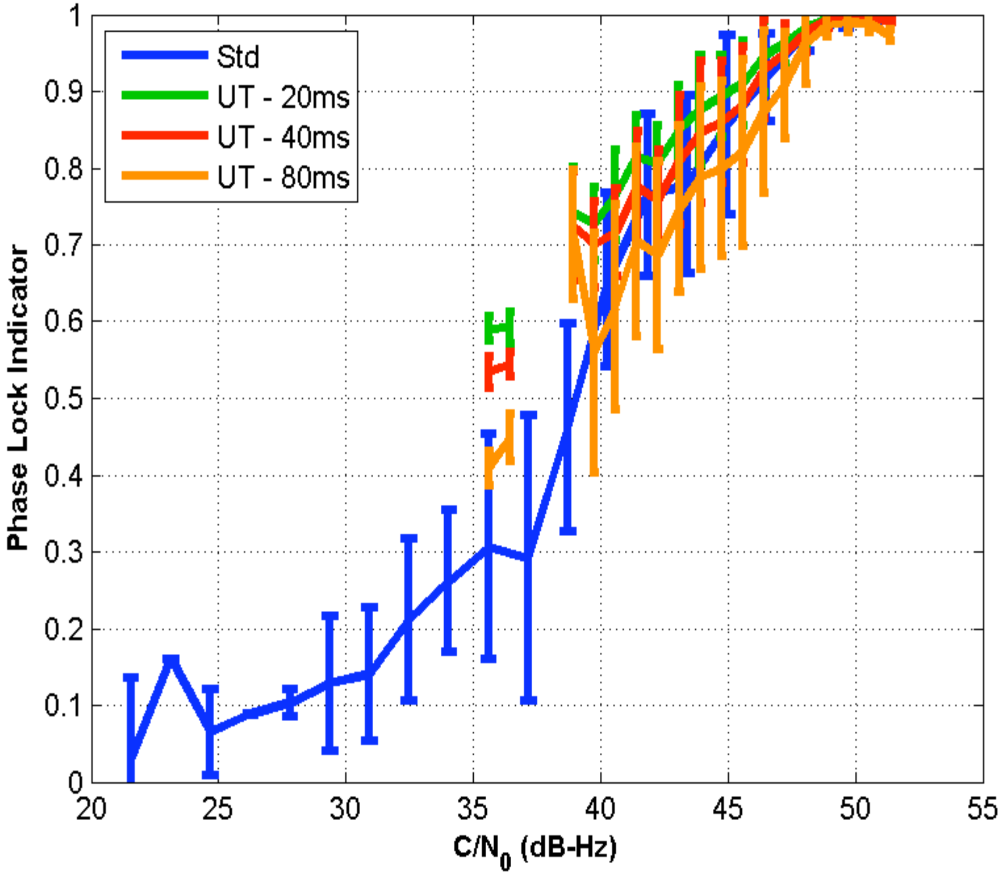
- **Similar to best case combination**
- **No 80 ms coherent integration – unable to track in this case**
- **Confirm previous analysis**



PLI - High Elevation PRN 27

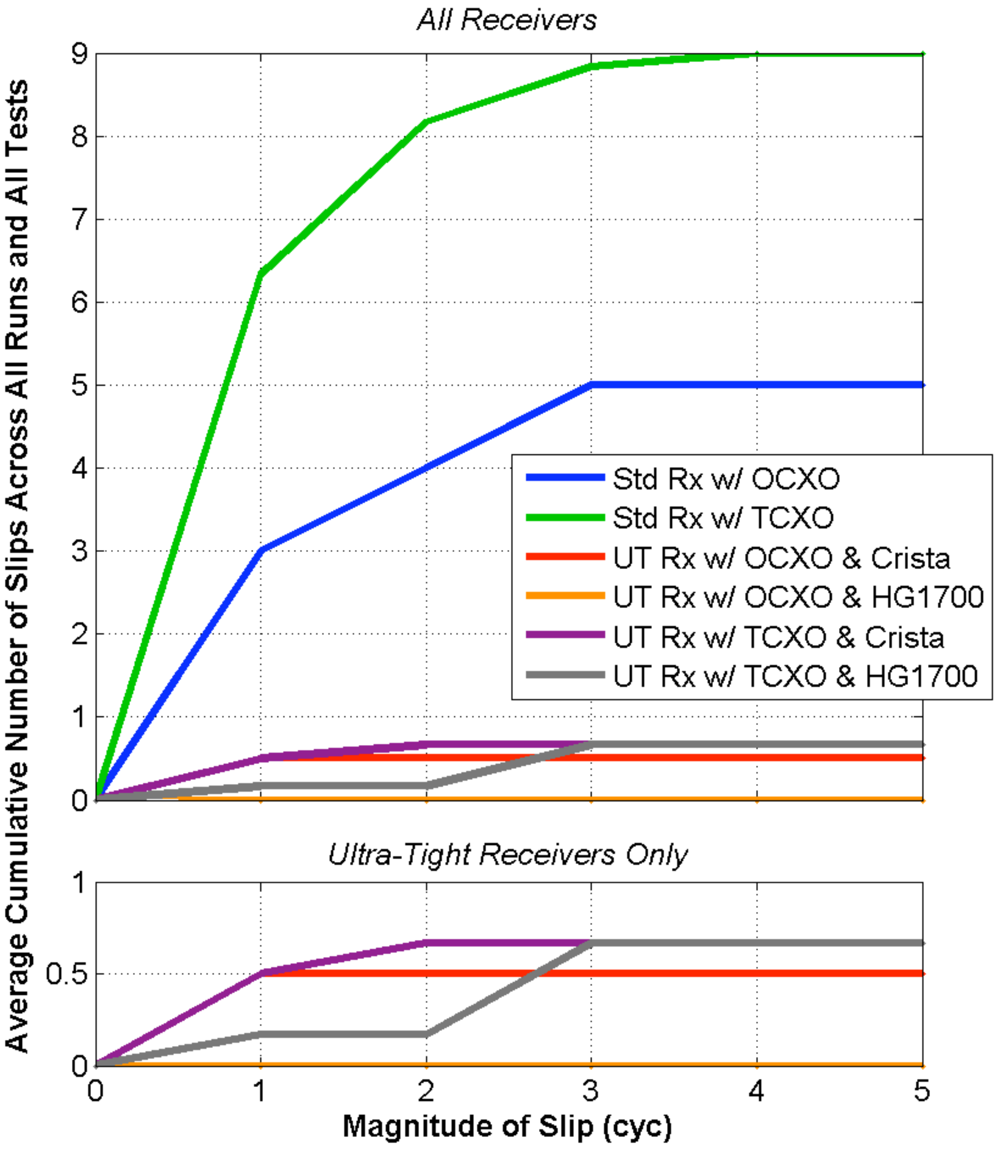
- HG1700 IMU & OCXO Osc

- Little difference between standard and ultra-tight modes
- Larger number of low C/N$_0$ values due to loss of lock during brief obstructions in GPS standalone mode



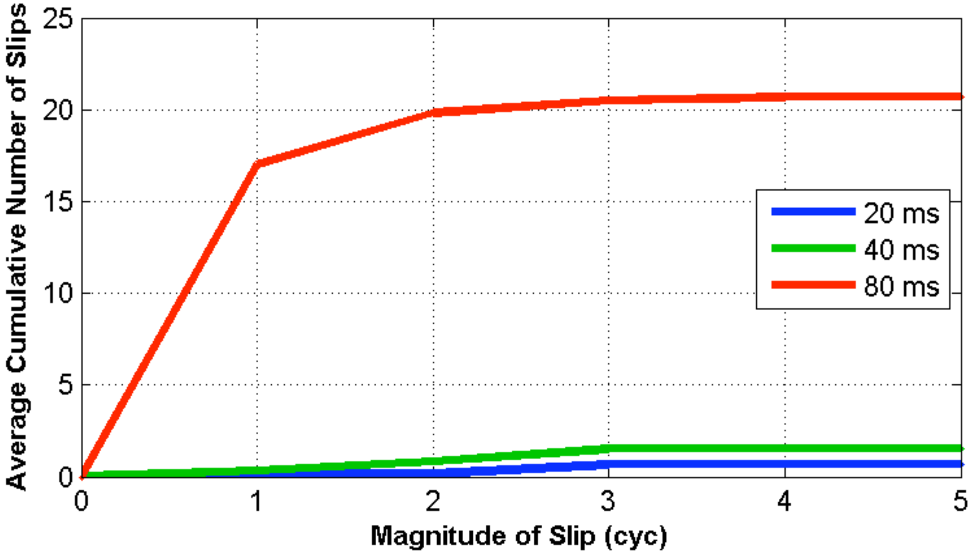
Measurement Domain Analysis 1

- Mean number of cycle slips ≤ given magnitude – averaged over all data sets
- Very clear advantage of UT integration
- Small difference between different IMU/Oscillator combinations



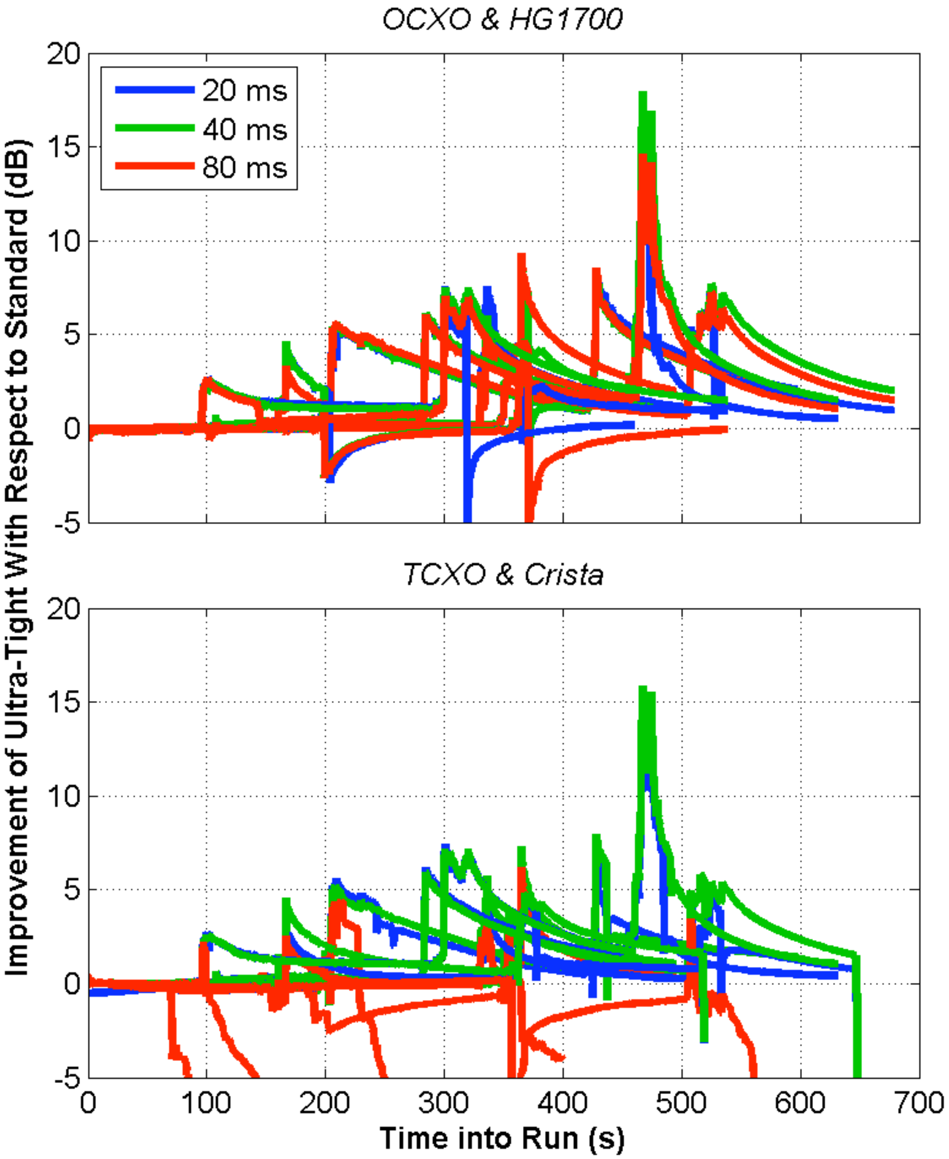
Measurement Domain Analysis 2

- Comparing results for different coherent integration times
  - HG1700 IMU & TCXO Osc
- 80 ms integration leads to more and larger cycle slips
  - Effect of lower quality oscillator



Position Domain Analysis

- **Ratio of estimated 3D accuracies from float solution (in dB)**
  - **+ → ultra-tight better**
  - **- → standard has better accuracy**
- **Steps due to filter resets in float solution**
- **Ultra-tight performs up to 5 dB better, with some exceptions**



Conclusions

- Significant benefit in ultra-tight integration for DGPS RTK positioning
- Increasing coherent integration time does not appear to yield significant benefits
  - Can in fact degrade performance with lower quality oscillator
- Ultra-tight RTK solution primarily a function of oscillator quality
  - To a lesser extent: IMU quality
- *UT integration is more oscillator limited than IMU limited*