Ground-Based GPS Occultation Utilizing Modernized Signals
Outline

- Background
- Data Collection
- Post-Processing
- Open Loop Results
- Summary and Future Work
Background
Radio Occultation (RO)

- Measurement of the change in amplitude and phase of GPS signal due to atmospheric interference
- Technique used to derive refractivity, density, pressure, temperature, and humidity
New Generation RO Receiver

- JPL’s RO receivers aboard COSMIC satellites currently limited to GPS L1 C/A and L2 codeless tracking
- Exploring algorithms for a new occultation receiver architecture
  - Capable of tracking dual frequency measurements from new signals/constellations

Algorithm development is difficult without raw IF data from an occultation scenario!
Data collection from an elevated vantage point provides similar geometric aspects of RO from LEO
- Vertical profiling capability, although disturbances to signal are not as dramatic as space-based experiments
- Ample collection opportunities

Mountain-based and airborne RO experiments performed in literature
- Lulich et. al, Olsen et. al, Hu et. al, Aoyama et. al
Motivation

- Collect raw IF data from an occultation-like scenario for software-defined radio algorithm development and testing
- Demodulate GPS L1/L2/L5 signals
  - Develop open/closed loop tracking schemes
  - Estimate carrier frequency, signal strength

Main focus of this experiment is the development of signal processing algorithms from ground-based occultation scenarios
Data collection
Signals of Interest

GPS L2C
- Broadcast on Block IIR-M and Block IIF satellites
- Same chipping rate as L1
- Two longer (interleaved) PRN codes

GPS L5
- Broadcast on Block IIF satellites only
- Chipping rate 10x higher than L1
- Two PRN codes with additional Neuman-Hoffman modulation
- Higher powered signal

Limiting Factor: Collection of L5 signal
Only broadcast on PRNs 1 and 25
Collection Location and Time

- Trade study performed on various mountain locations to obtain “good” occultation profile from PRN 1 or PRN 25
- Optimal solution: eastward-pointing collection on the summit of Pikes Peak, Colorado on October 21, 2011
Hardware Setup

- Two antennas
  - Helix (horizontal) and Trimble dish (omni-directional)
- Four RF front-ends
  - Dual-frequency IF data from each antenna
- One Trimble NetR9
  - Verification of position and available constellation
- Two computers
- Data storage drive
- Rubidium clock
PRNs 1 and 17 chosen for fast setting geometries
- High sampling rate used to collect wideband L5 signal
- Bandwidth reduced at other frequencies

Eastward collection

<table>
<thead>
<tr>
<th>PRN/ SV</th>
<th>Freq</th>
<th>Time Start (UTC)</th>
<th>Duration (min)</th>
<th>Azimuth (deg)</th>
<th>BW (MHz)</th>
<th>Int Freq (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/63</td>
<td>L1/L5</td>
<td>17:30</td>
<td>42</td>
<td>38</td>
<td>4/20</td>
<td>420/450</td>
</tr>
<tr>
<td>17/53</td>
<td>L1/L2</td>
<td>20:15</td>
<td>60</td>
<td>100</td>
<td>2/2</td>
<td>100/100</td>
</tr>
</tbody>
</table>
Post-Processing
These acquisition schemes were used as a preliminary inspection of the data. The CL and L5 codes would be utilized to maximum power in future studies.
- Phase-locked loop (PLL) used to adjust frequency of replica based upon previous measurements
- Not optimal technique for tracking in lower troposphere
  - Need strong SNR and low dynamics
- Cannot be (easily) used for rising occultations
- Performed acquisition at set intervals to obtain estimates of carrier frequency and signal strength
  - Determined Doppler shift with model from IGS products
  - Limited frequency search space to main lobe about Doppler model
  - Applied least-squares sinc matching to fine-tune peak frequency estimate
Estimates Obtained

- Carrier frequency
  - Difference from initial frequency at first epoch
- Signal strength
  - Ratio of 1\textsuperscript{st} correlation peak to 2\textsuperscript{nd} highest peak
- Frequency comparison to Doppler model
  - Difference in Doppler frequency with respect to Doppler model (predicted from precise ephemerides and receiver position)
- Accumulated Phase Deviation
  - Integration of Doppler differences
OL tracking continues past geometric horizon.

Agrees with Doppler model until local horizontal, then the measured carrier frequency is more negative than the model – More delay to the signal.

Small negative bias between model and measured Doppler frequency.
Higher peak metric

Similar agreement to Doppler model, with analogous signal delay at local horizontal

Negative bias still apparent between measured and Doppler frequency
Weak signal power and additional signal found ~40 Hz below the main center frequency.

Signal delay at local horizontal not obvious. Note: Center signal shown for frequency comparison.

Negative bias still evident between measured and Doppler frequency.
Signal delay of approximately 15 meters found on both L1 and L5 signals

Signal delay of approximately 6 meters found on L2 signal
Summary and Future Work
Tracking succeeded to negative elevation angles with PRN 1
  - Higher signal strength (both L1 and L5)
  - L5 PRN codes better for correlation
Small signal path increase found
  - 15 meters on both frequencies from 1\textsuperscript{st} occultation
  - 6 meters on L2 from 2\textsuperscript{nd} occultation
Possible hardware issues, multipath, or atmospheric inversion on 2\textsuperscript{nd} occultation
Receiver Development

- Convert frequency measurements to atmospheric profiles
  - Compare with local radiosonde measurements
- Additional signals, frequencies, and modulations
  - GPS, GLONASS, Galileo, Compass
Questions