

Multiple Antenna GNSS Receiver Design on Spin-Stabilized Rockets

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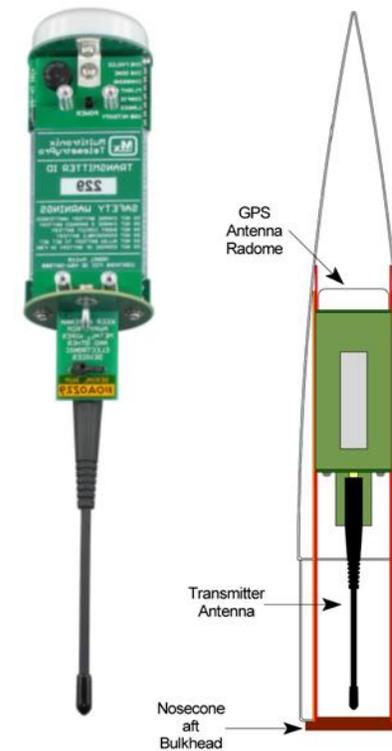
Overview

1. Motivation for the Project
2. Background
3. Approach and Methodology
4. Experimental Results
5. Conclusion and Future Work



Motivation

- Sounding rockets can be stabilized about its minor inertia axis by introducing a spin.
- GNSS and IMU used in guidance of rockets.
- GNSS antenna commonly mounted in the nosecone, but this is not always possible.
- Side mounted antennas is one solution but will require modification to the RF front end or receiver.
- Projects aims to investigate and implement promising RF front end/receiver designs.



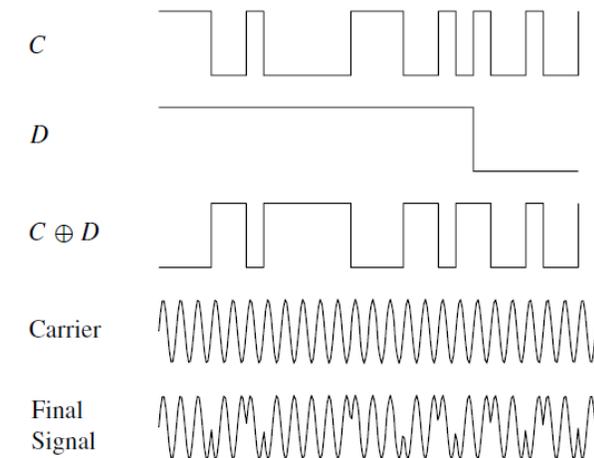
Multitronix Telemetry Pro® Transmitter



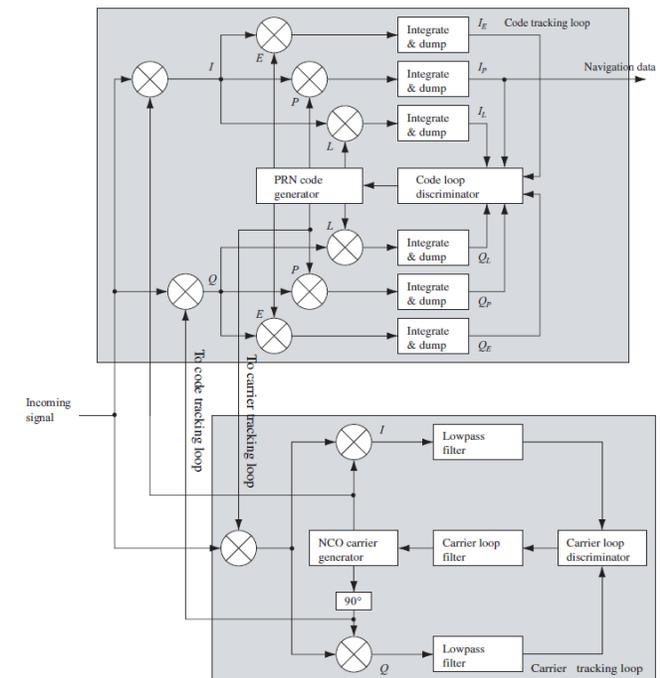
Wraparound antennas are ITAR restricted

Background

- GNSS works on the principle of trilateration.
- Doppler frequency and code phase must first be acquired.
- Locally generated chipping code is correlated with received code.
- Tracking loops used to track changes in carrier frequency and code phase.
- Receivers are commonly implemented in SDR allowing update of tracking loop and algorithms.

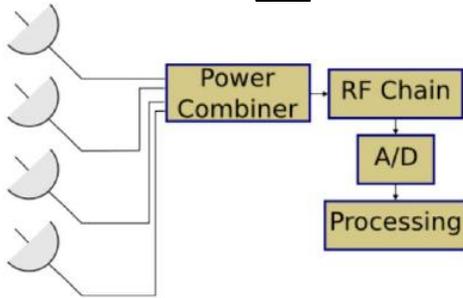


BPSK modulation of L1 carrier with C/A code and navigation data



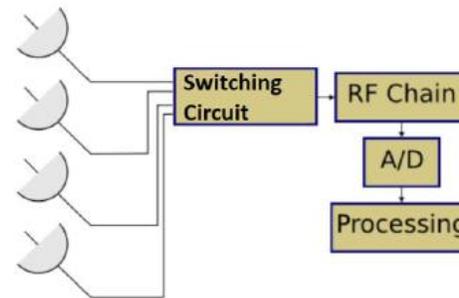
GPS L1 C/A carrier and code tracking loop

Designs Tested



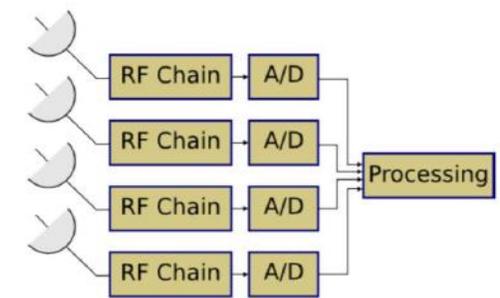
Summing Front End

- RF signal summed before sampled.
- Susceptible to constructive and destructive interference from overlapping antenna gain patterns.
- Phase, frequency and gain variations when spinning.



Multiplexing Front End

- Avoids constructive and destructive interference from adding signals.
- Navigational data will be attenuated.
- Multiplexing tested at 10kHz and 20kHz avoiding large windows where tracking loop can lose lock.

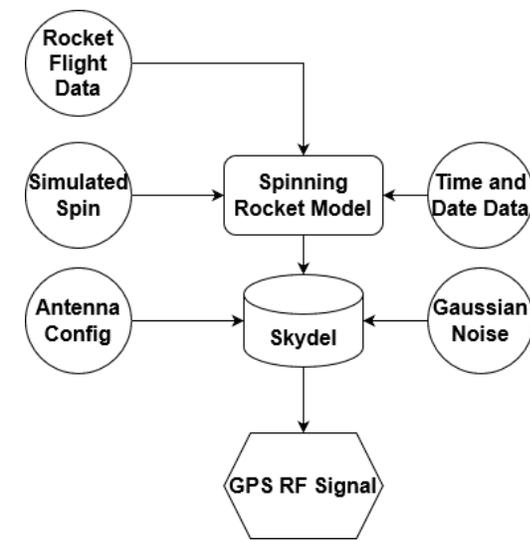


Diversity Architecture

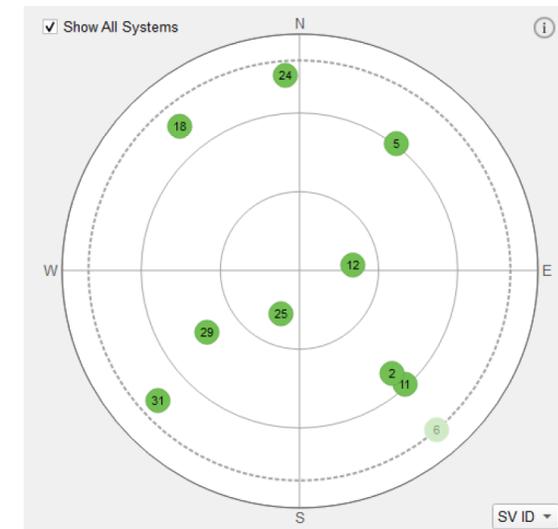
- Correlates all 4 signals separately and select the best one for tracking and tracking loop updates.
- Tracking loop mostly unchanged with 1 carrier and code oscillator.
- Hybrid mode where 2 signals are combined when correlation results is comparable.

Approach

- Orolia Skydel used to generate RF baseband I and Q signals.
- 4 antennas perpendicular to each other facing the horizon simulated.
- Antenna configuration, vehicle track and spin used to generate realistic GPS L1 C/A signals.
- Open source FGI-GSRx receiver used acquire and track Skydel RF signals.
- Likely 2nd order PLL and 1st order FLL tracking loop.
- Receiver modified to support diversity architecture.



L1 C/A GPS signal generation in Skydel

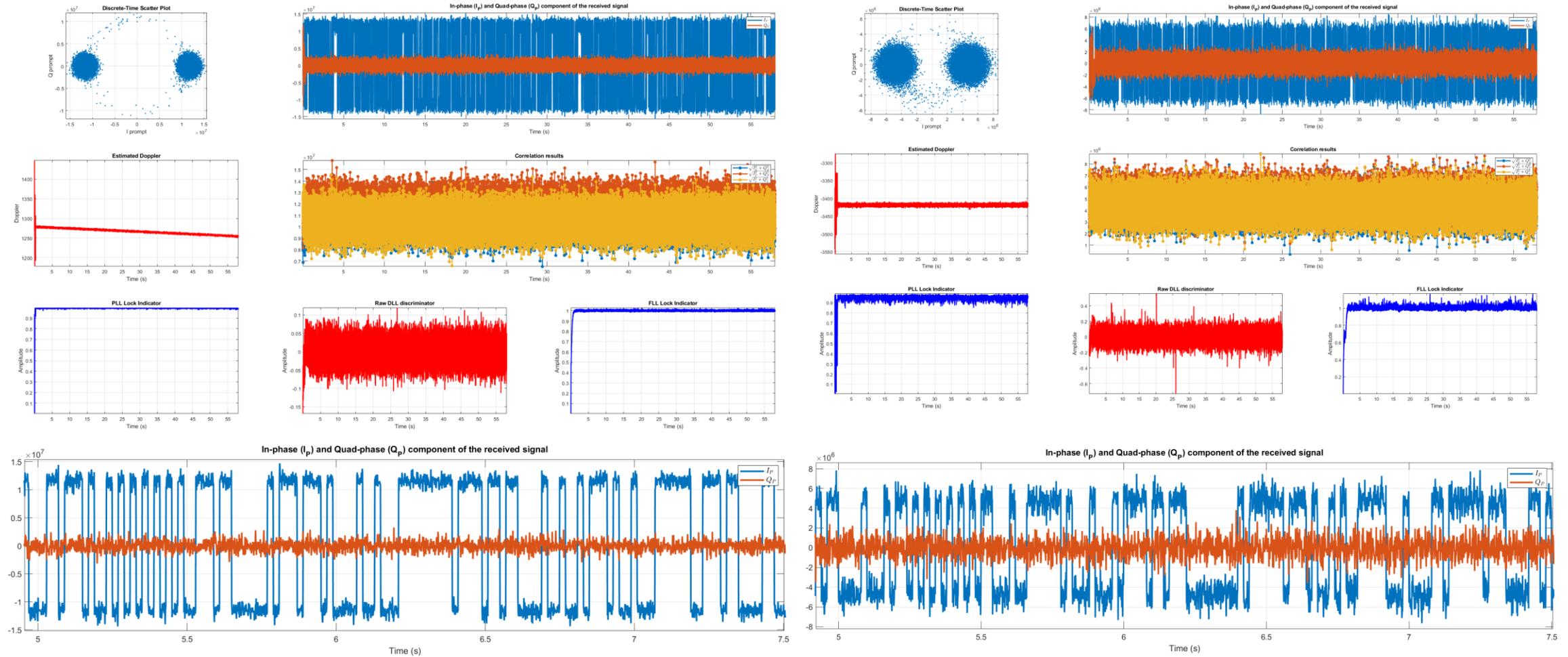


At a given position and time, Skydel calculates satellite position to provide accurate RF signals.

Methodology

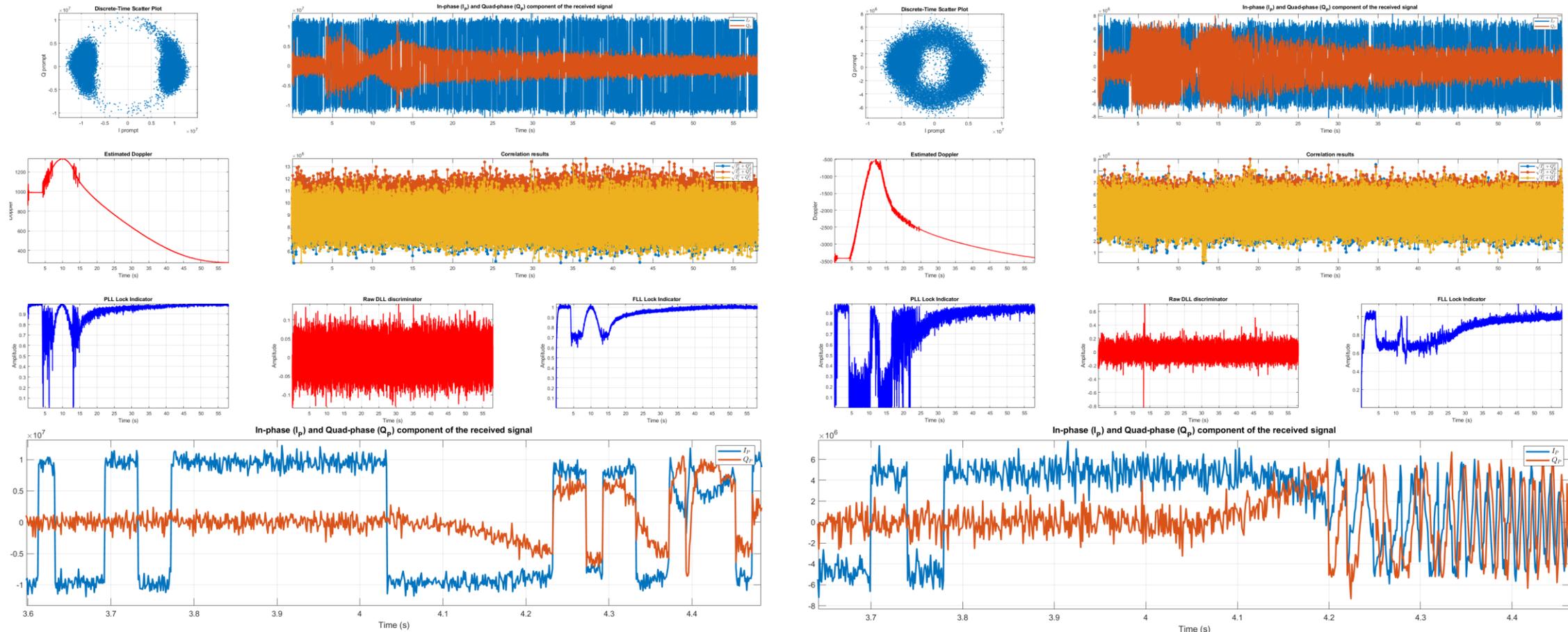
- Multiple scenarios tested and compared with ground truths generated from Skydel.
- Stationary, fixed rotating (0.5Hz) and rotating trajectory scenario tested.
- Rocket flight path travels to a peak altitude of 3.3km and 10km north.
- Nosecone antenna and individual side mounted used as reference scenarios.
- Gaussian noise and clockwise/counterclockwise rotation tested.
- Default FGI-GSRx receiver settings including loop bandwidths tested.

Nosecone Reference Scenario



Left: PRN25 with the strongest received GPS signal at +6dB with respect to -130dBm (reference power level).
 Right: PRN24 with the weakest received GPS signal at -1dB.

Nosecone Launch Scenario



Left: Tracking results of PRN29 (+4.4dB), smallest Doppler change (335Hz) in a Gaussian noise enabled launch scenario.

Right: Tracking results of PRN24 (-1 dB), largest Doppler change (2855Hz) in a Gaussian noise enabled in a launch scenario.

Boosting the signal strength of PRN24 has no effect on recovered navigational data.

Impact of High Dynamics

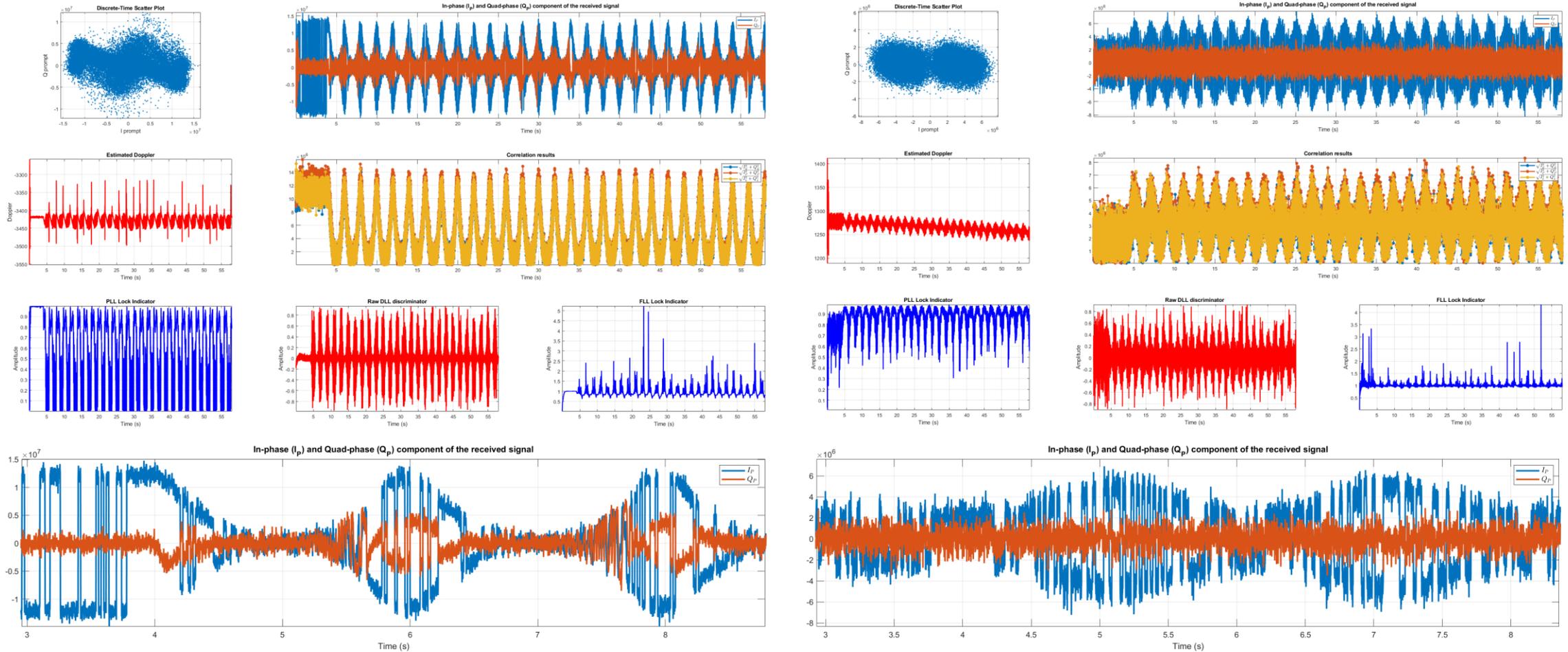
Satellite PRN	Elevation (Degrees)	Azimuth (Degrees)	Doppler Shift (Hz)
2	37.1	138.3	500
5	29.3	37.4	2565
11 (NAV 81)	30.6	137.1	750
12	69.3	84.9	1675
18 (NAV 78)	19.2	320.5	2385
24	15.5	356.1	2855
25	71.9	201.6	910
29	47.8	236.1	335
31	16.9	227.1	1140



Notice how PRN 5 and PRN11 have similar elevation and azimuth deflection from east.

Smallest Doppler shift is experienced when the orthogonality of the rocket's velocity vector to the velocity vector of the satellite is maximized while the projection of the rocket's velocity along the rocket satellite position vector is minimized.

Side Mounted Antennas and Rotation



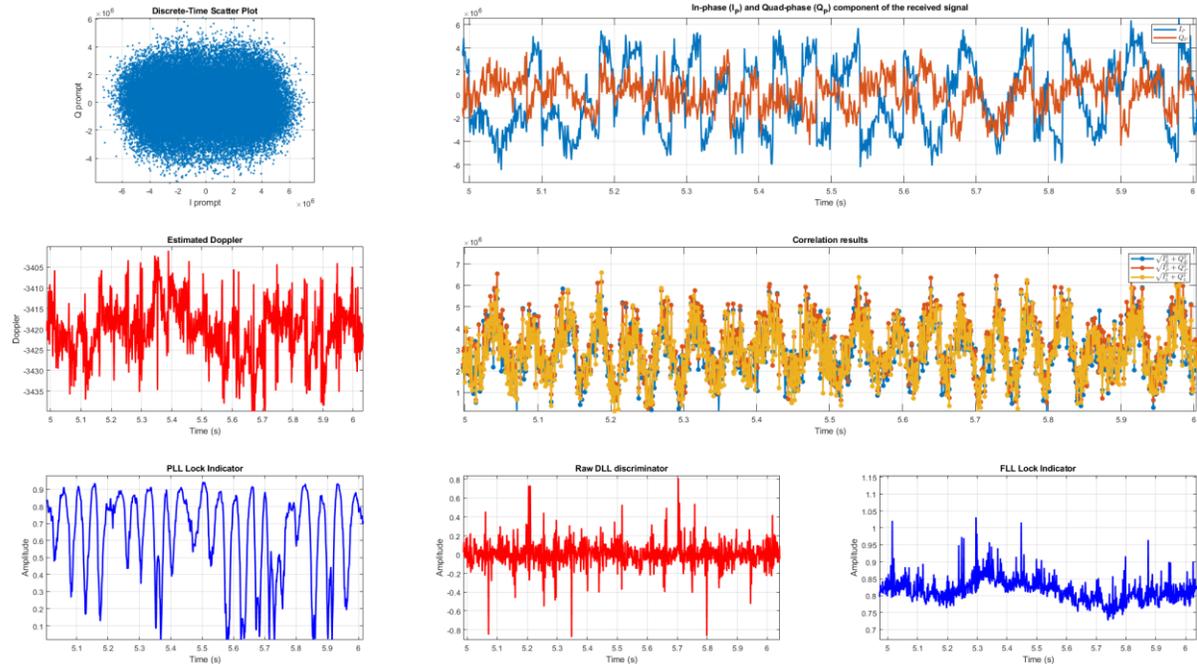
Left: Tracking results of PRN24, the GPS signal closest to the horizon with Gaussian noise enabled in a rotating fixed scenario.

Right: Tracking results of PRN25, the most elevated GPS signal with Gaussian noise enabled in a rotating fixed scenario.

Due to antenna gain pattern degrading navigational data, PVT unable to be calculated. Loss of carrier tracking occurs in launch scenarios.

Multiplexing Front End

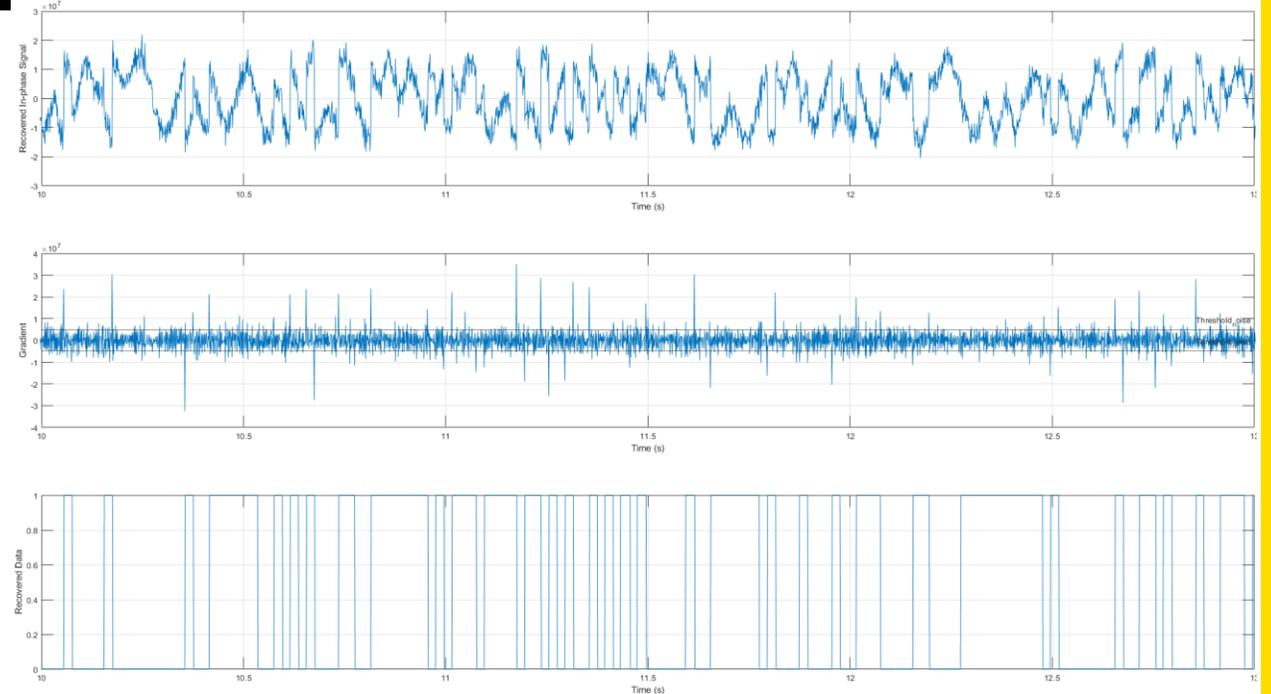
- Fine grained multiplexing results in tracking loop failing to lock onto carrier in many scenarios.
- Weak bit transitions and phase reversal making it nearly impossible to recover navigational data.
- No difference between 10kHz and 20kHz switching frequencies.



Fixed rotating, Gaussian noise enabled multiplexing results showing unclear bit transitions.

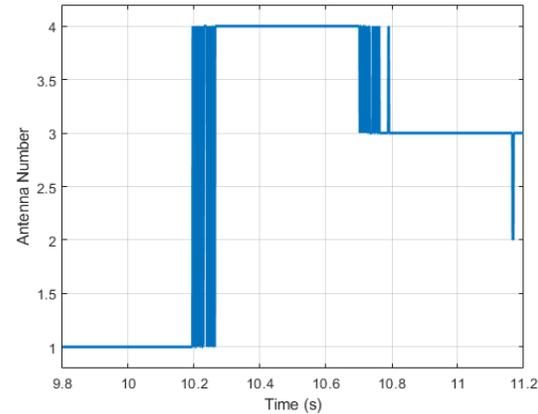
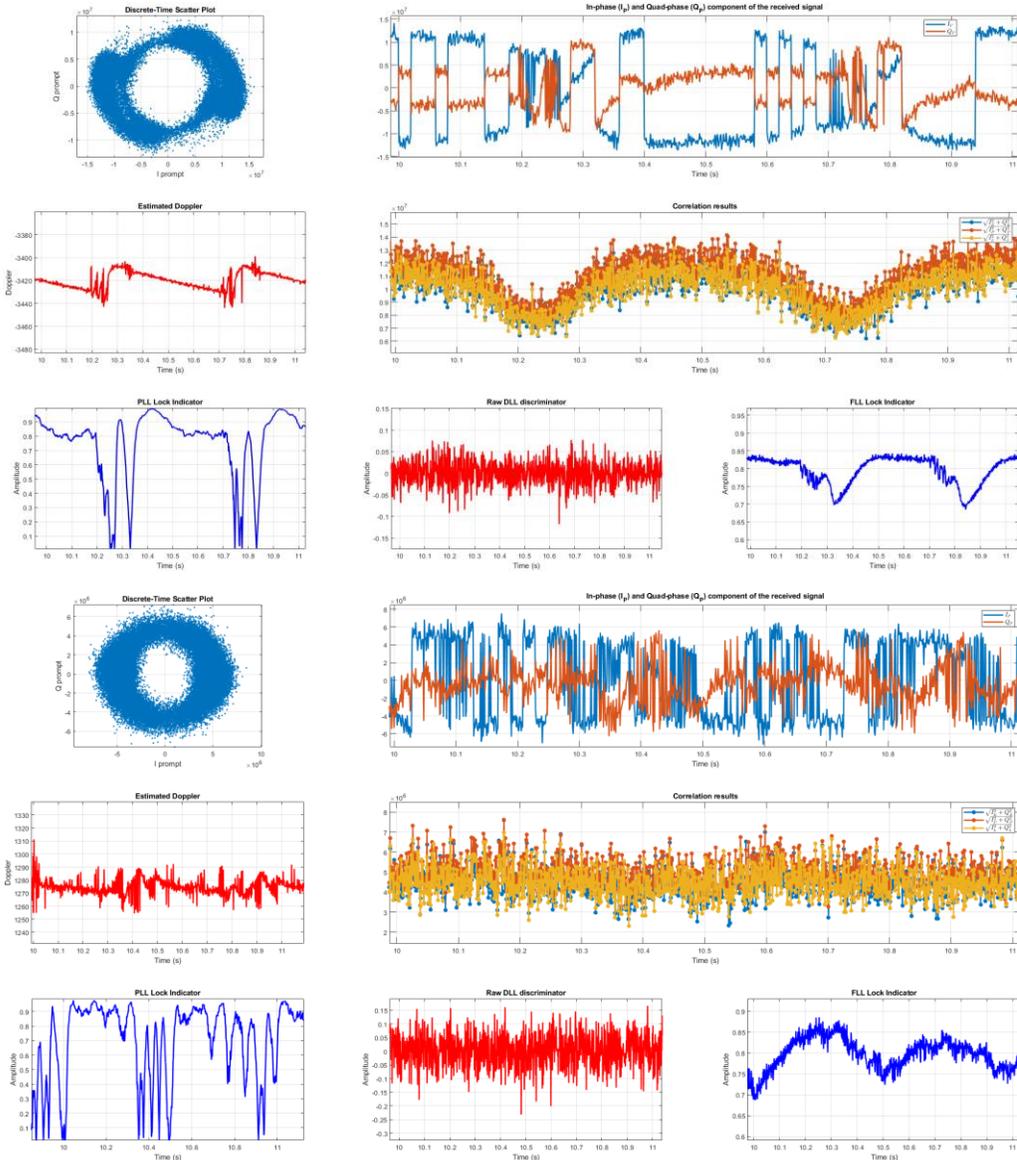
Summing Front End

- Multiple tones cause the tracking loop to switch leading to oscillations and data bit errors.
- Partial data recovery possible with zero crossing and gradient detector.
- Change in phase matches the distance antenna traverses. Immune to change due to launches.
- May be related to tracking loop bandwidth.

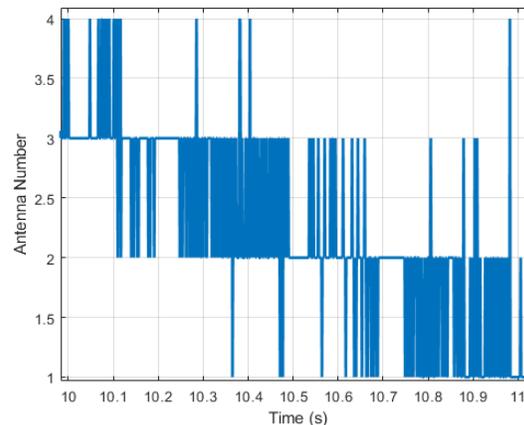


Gaussian noise enabled fixed rotating summing front end with edge recovery

Diversity Architecture



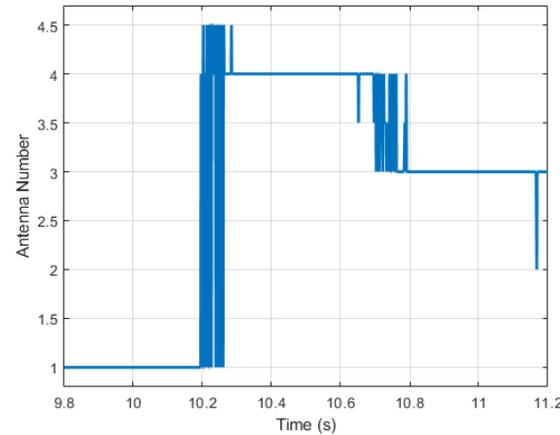
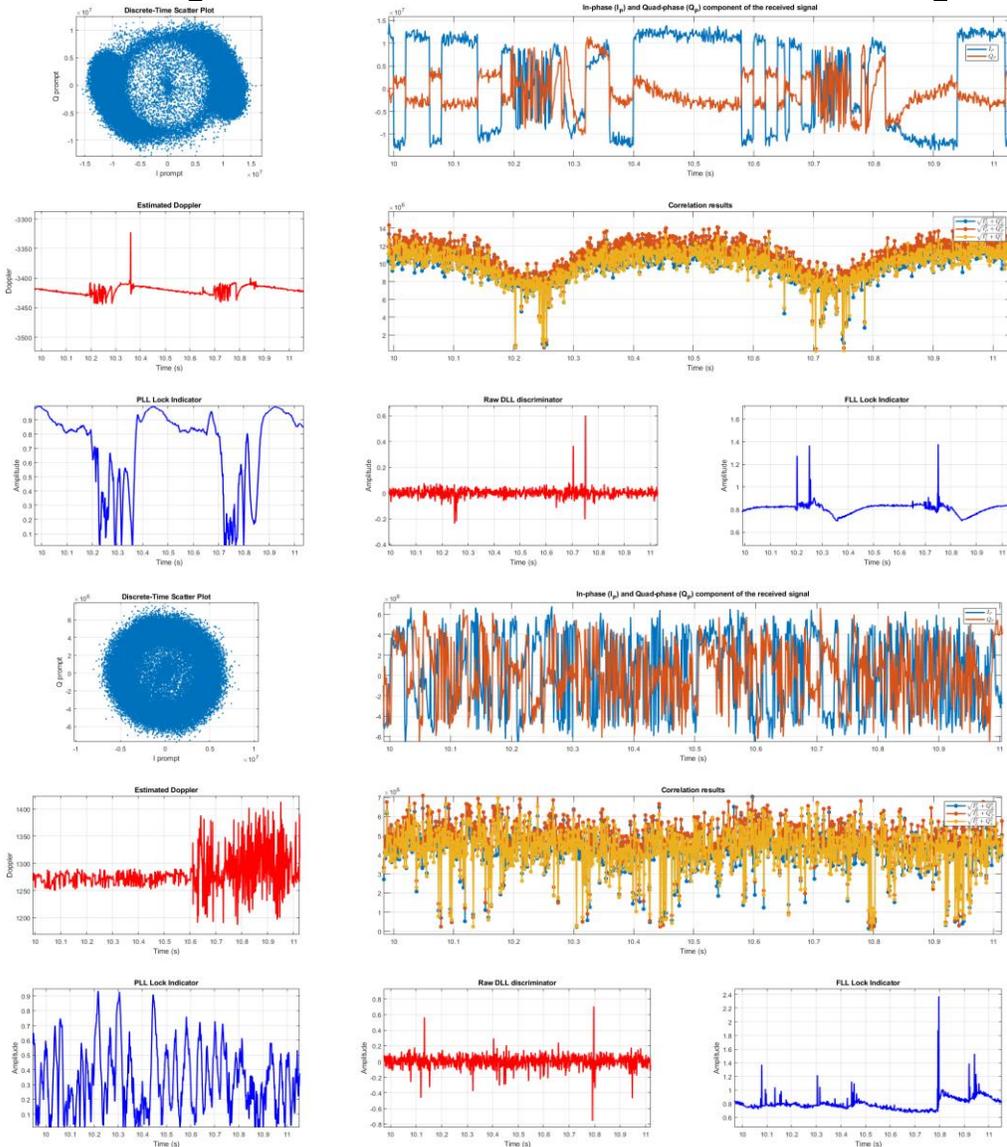
PRN24 close to the horizon with Gaussian noise enabled.



PRN25 overhead with Gaussian noise enabled.

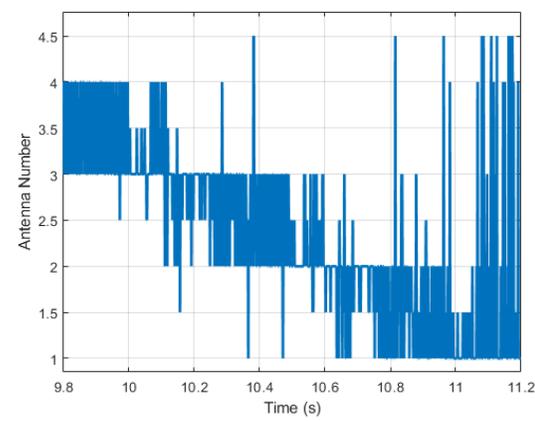
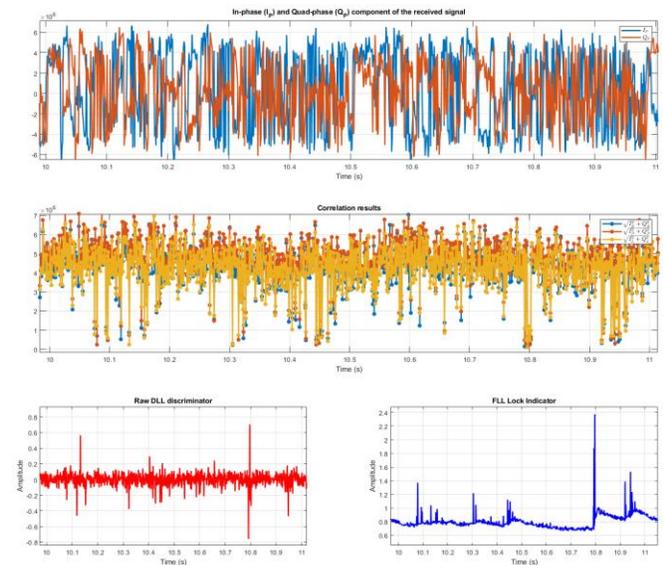
- Navigational data recovered to a satisfactory degree.
- Diversity mode performs best when signal originates close to the horizon.
- Noise leads to tracking loop switching between antennas.
- No improvement in high Doppler scenarios.
- Hardware timeout can reduce transition uncertainty.

Hybrid Diversity Architecture



PRN24 close to the horizon with Gaussian noise enabled.

- Diversity mode leads to more transitions increasing navigational data uncertainty.
- We can conclude the less transitions, the better.



PRN25 overhead with Gaussian noise enabled.

Conclusion and Future Work

- Receiver performance heavily dependent on tracking loop architecture especially in high dynamics scenarios.
- Multiple tones in summing yield poor recovery of navigational data but can be partially recovered.
- Multiplexing causes issues with tracking loop locking onto signals.
- Diversity architecture is promising and with a hardware timeout to reduce switching due to noise, it may be suitable for rotating scenarios.
- High dynamics still an issue and tracking loop modifications required to reduce impact.
- Test with helical antennas to observe overhead satellite performance.
- Integrate with IMU to aid tracking or smarter diversity switching.