PERFORMANCE COMPARISON of GPS L5 SIGNAL ACQUISITION METHODS UNDER PHASE SCINTILLATIONS

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TRAINING RESEARCH AND APPLICATIONS NETWORK TO SUPPORT THE ULTIMATE REAL TIME HIGH ACCURACY EGNSS SOLUTION

OUTLINE

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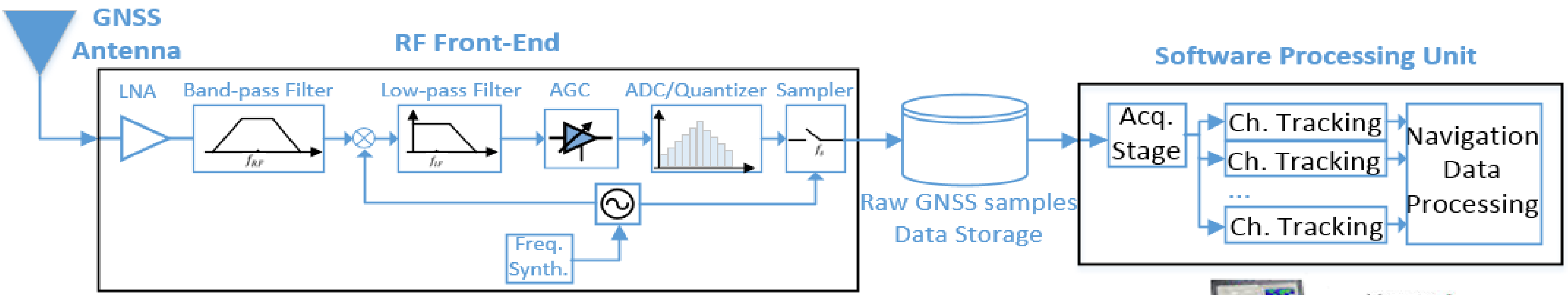
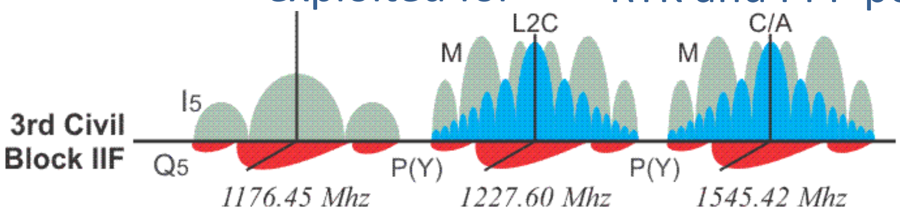
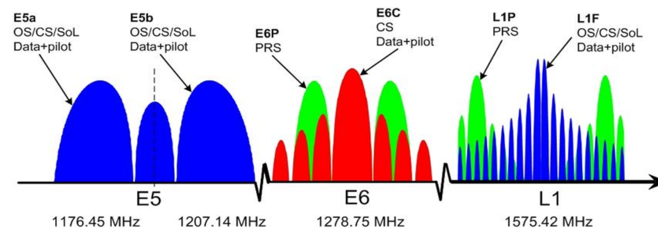
  - Major Accomplishments Expected
- Software Receiver GPS L5 Signal Processing
  - GPS L5 Signal Structure
  - GPS L5 Acquisition Methods
  - Performance Comparison of the Acquisition Methods
- Ionospheric Scintillation – Phase Scintillation
  - Analysis on GPS L5 and L1 Signals
  - Performance Degradation on GPS L5 Acquisition Stage
- Future Works

OBJECTIVES OF ESR-05 PROJECT – MAJOR ACCOMPLISMENTS



- The design of a fully software multi-frequency multi-constellation receiver which is able to provide carrier-based pseudoranges that can be exploited for RTK and PPP positioning





- Interfaces for the external precise orbit and clock corrections
- Research tool to cope with harsh ionospheric scintillation environment

Status:

- GPS L5 signal acquisition methods have been implemented
- Tracking stage work is under progress.

GPS-L5 SIGNAL STRUCTURE

- The GPS L5 signal is ***QPSK modulated signal*** with in-phase and quadrature carrier components.
- Both carrier components are BPSK modulated by ***different sequences of bits***.
- Both the in-phase and the quadrature channels have ***different spreading codes***, and also include ***different Neuman-Hoffman codes***.
- GPS-L5 signal has ***longer spreading codes*** for both I and Q channels and ***higher transmitted power*** compared to GPS-L1

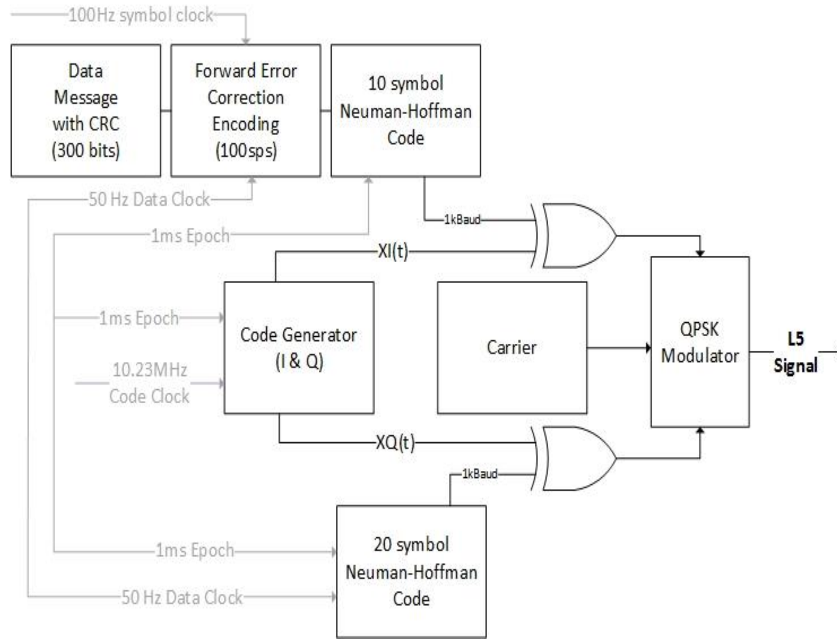


Fig. Generation of GPS L5 Signal and Modulation of Signals

$$S_{L5}^{k}(t) = \sqrt{2C}\left(d^{k}(t)\oplus NH_{10}(t)\oplus X_{I}^{k}(t)\right)cos(2\pi f_{L5}t)$$
$$+\sqrt{2C}\left(NH_{20}(t)\oplus X_{Q}^{k}(t)\right)sin(2\pi f_{L5}t)$$

GPS-L5 SIGNAL ACQUISITION METHODS

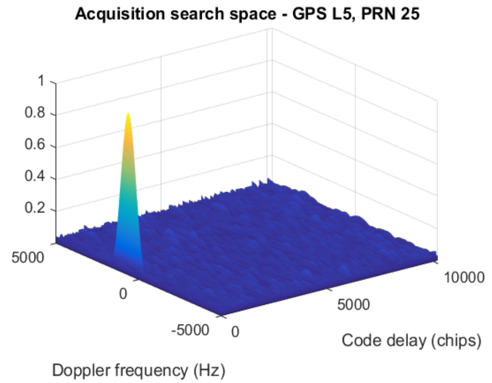
In our analysis, four L5 acquisition methods were implemented and compared.

In our tests, we process only the ***quadrature channel of the L5*** signal by taking the advantage of the ***absence of data*** and ***less computational burden***.

Implemented Methods:

- **Method-A:** Short Coherent Integration with Non-Coherent Accumulations
- **Method-B:** Zero-Padding Algorithm
- **Method-C:** Long Coherent Integration with Non-Coherent Accumulations
- **Method-D:** Differentially coherent channel combining with sign recovery

- Performance are assessed at the level of the Cross Ambiguity Function (CAF) and in terms of acquisition statistics



Method-A: Short Coherent Integration with Non-Coherent Accumulations

- A parallel code search algorithm is employed.
- The coherent integration time is limited to 1ms
  - One NH bit is 1ms long
  - A potential bit transition could lead to a degradation in the peak or false peaks.

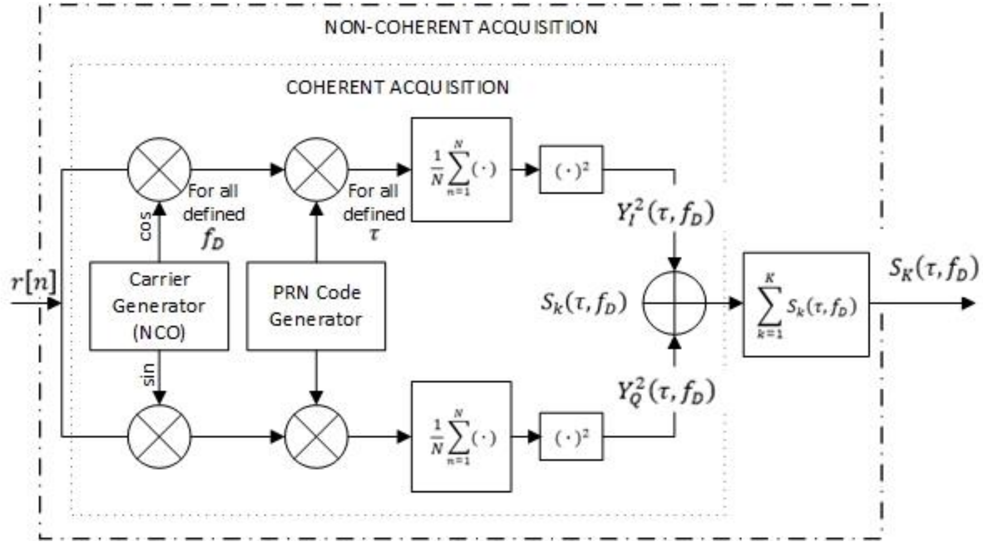


Fig. GPS General Signal Acquisition Scheme for Coherent & Non-Coherent Cases

$$Y_I(f_D, \tau) = \sqrt{C/4}\; R(\Delta T)\frac{\sin(\pi N \Delta F)}{\pi N \Delta F}\cos(\Delta\theta) + \eta_{I,Pilot}$$

$$Y_Q(f_D, \tau) = \sqrt{C/4}\; R(\Delta T)\frac{\sin(\pi N \Delta F)}{\pi N \Delta F}\sin(\Delta\theta) + \eta_{Q,Pilot}$$

$$S(\tau, f_D) = Y_I^2(\tau, f_D) + Y_Q^2(\tau, f_D)$$

$$S_K(\tau, f_D) = \sum_{k=1}^{K} S_k(\tau, f_D)$$

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Method-B: Zero-Padding Algorithm

- Zero padding acquisition is implemented by circularly correlating 2ms of the incoming signal with 1ms of the generated local + 1ms of zeros.

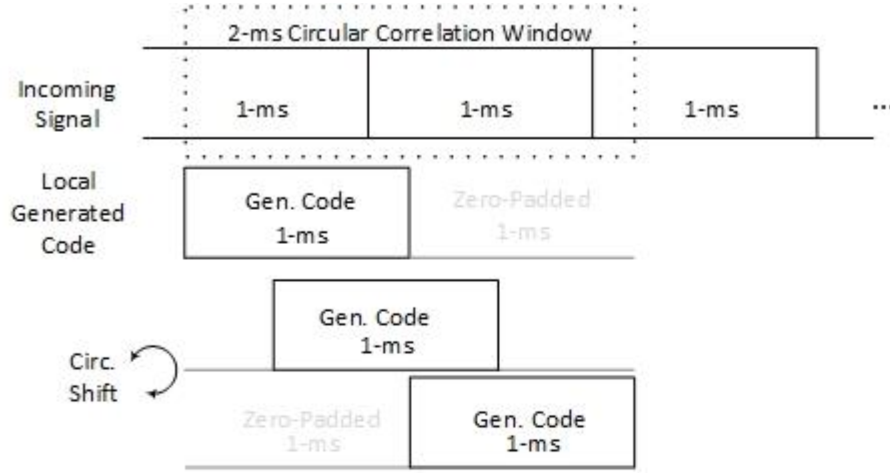

Fig. Zero-padding Method

- Since we use an expanded time-domain of 2ms data, this method produces two peaks.

- The peak in the second millisecond is degraded due to the NH bit transition.

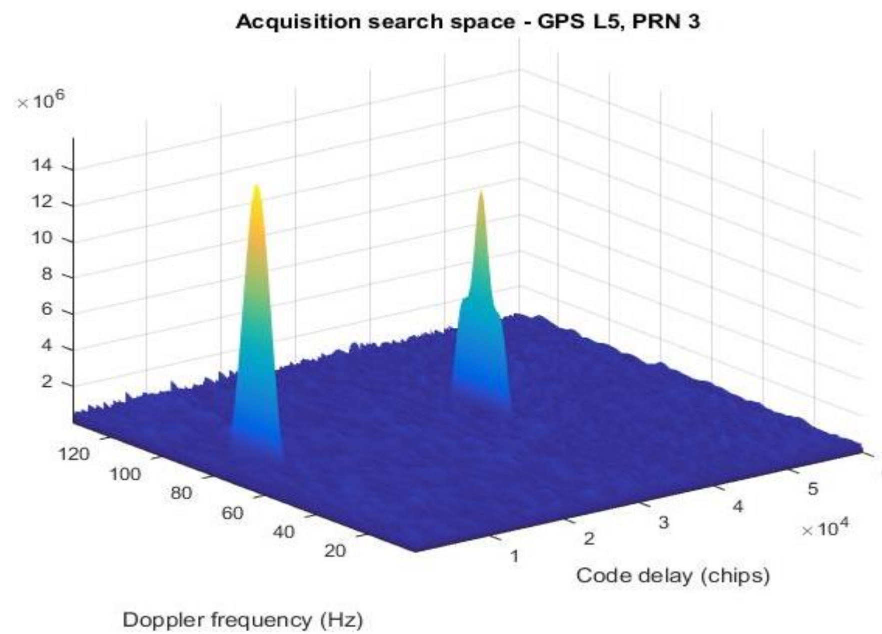

Fig. Acquisition Search Space

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Method-C: Long Coherent Integration with Non-Coherent Accumulations

- We are able to acquire the L5 signal in **low signal-to-noise conditions** by using the data-less channel and by **increasing the coherent integration time**.

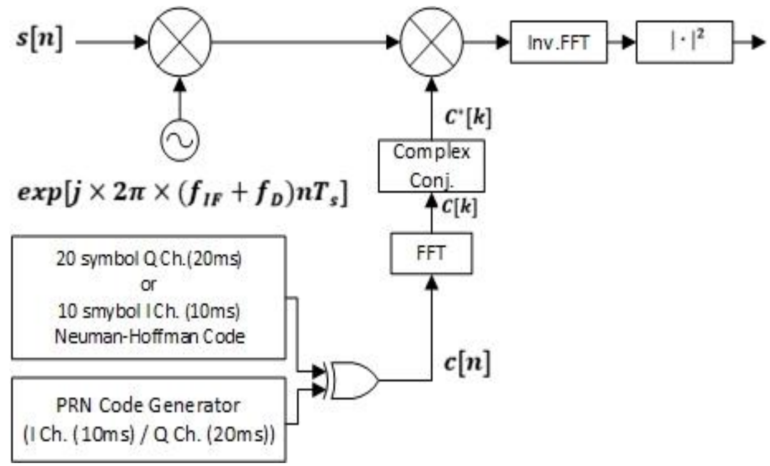


Fig. GPS Signal Acquisition Scheme for Coherent & Non-Coherent Cases

- The misalignment of the NH code causes false peaks at integer multiples of 1ms.

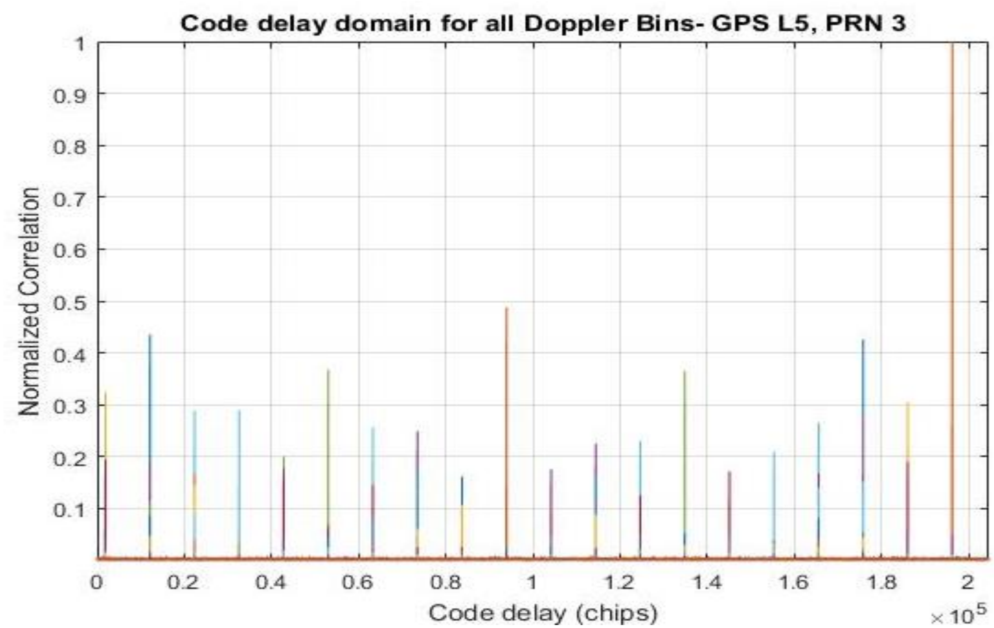


Fig. Code Delay Domain for All Doppler Bins

Method-D: Differentially coherent channel combining with sign recovery

- CAF in output is characterized by **one or two consecutive peaks**.
  - The presence of two peaks is the key to understand whether a data sign-transition has occurred or not.
- The motivation of this algorithm is to be **less affected by the NH bit sign-transition**.

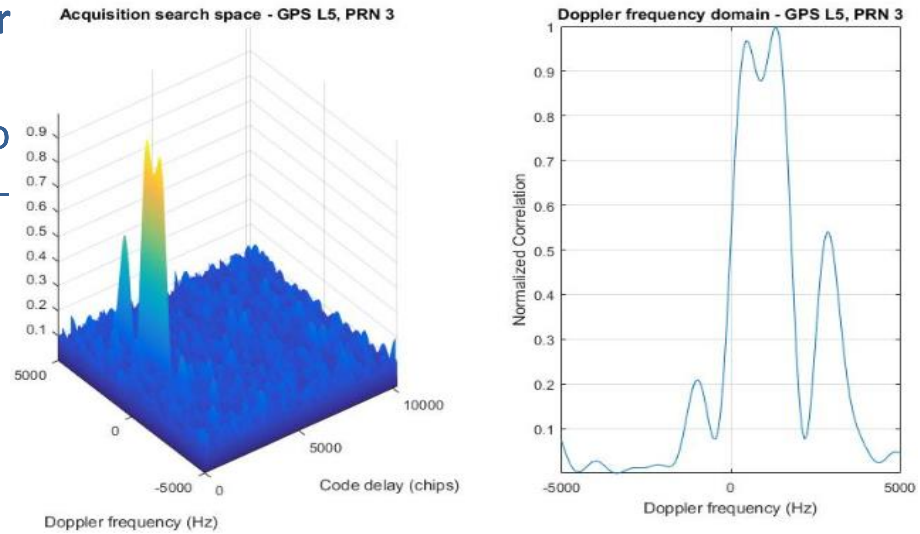
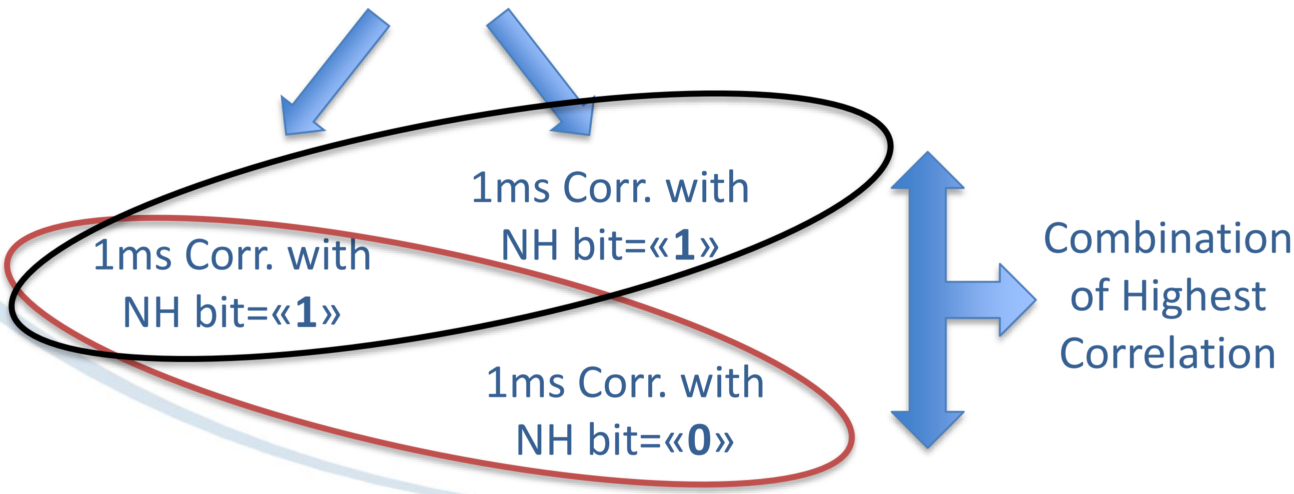


Fig. Double Correlation Peak – Sign Transition

It combines the information of both cases where the **NH bits are 1 and 0** for the consecutive 1ms length of data.



PERFORMANCE COMPARISON of THE ACQUISITION METHODS

- The setting parameters of the implemented methods for the first analysis which is under non-scintillated conditions

Table-I - Specifications Of The Methods

Parameters	Method A[A]	Method B[B]	Method C[C]	Method D[D]
Coherent Integration Time	1ms	2ms	20ms	2ms
Number of Non-Coh. Acc.	3	3	3	1

[A] Short Coherent Integration Acquisition without NH Code
[B] Zero Padding Method with Non-Coh. Acc.
[C] Long Coh. Integration Acq. with NH Code Included
[D] Acquisition with NH Bit Sign Recovery Method

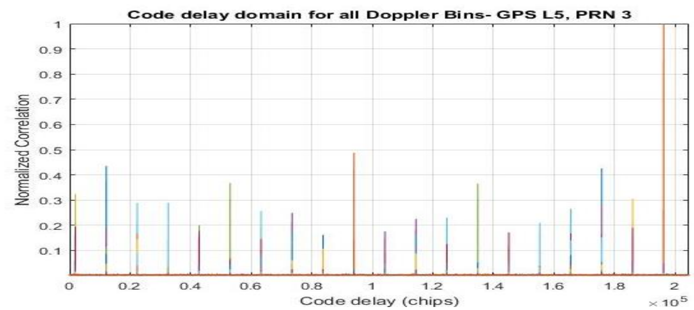
PERFORMANCE COMPARISON of THE ACQUISITION METHODS

Table-II - Performance Metrics Of The Methods

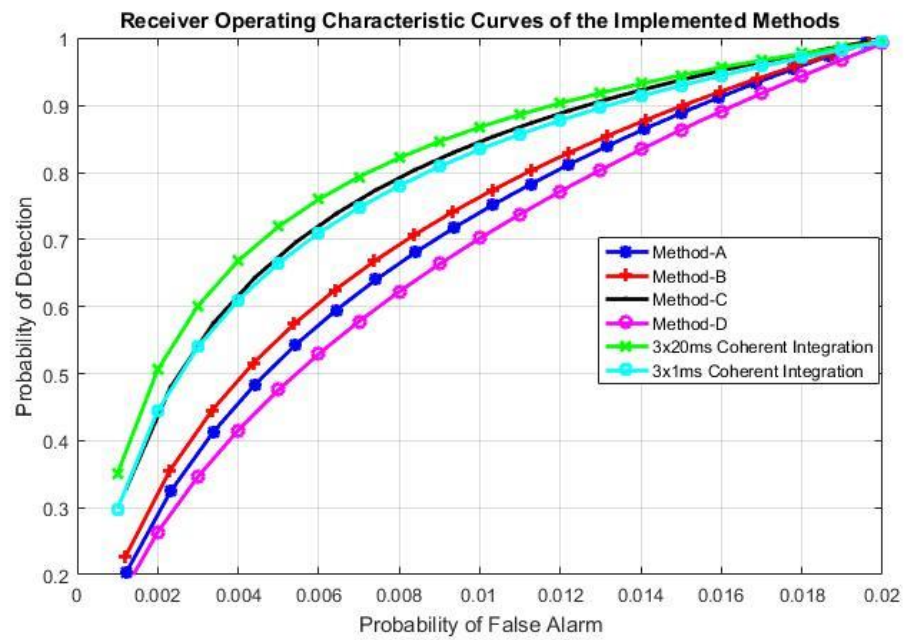
Metrics	Method-A	Method-B	Method-C	Method-D
Peak-to-Floor Ratios	26.57dB	26.89dB	6.2dB ~ 39.5dB	14.25dB ~ 20.84dB
*Acquisition Time per SV ~ Comput.Load**	t	2.5t	14t	1.6t

*Time values are expressed in proportion to each other.

$$NH_{20} = 0\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ 1\ 1\ 0\ 1\ 0\ 1\ 0\ 0\ 1\ 1\ 1\ 0$$



- ROC curves of 4 methods
- Benchmark: Ideal **1-ms and 20-ms coherent acquisition methods** are plotted as bounds **bounds for Method-A and Method-C**, respectively.



Receiver Operating Characteristics (ROC) Curves of the Implemented Methods

THE EFFECT of THE PHASE SCINTILLATION on GPS L5 & GPS L1 SIGNALS

- DATA:
  - ✓ SANAE IV Antarctic Station
  - ✓ 8 May 2016
  - ✓ Block IIF Satellite Signal
  - ✓ Phase Scintillation Event

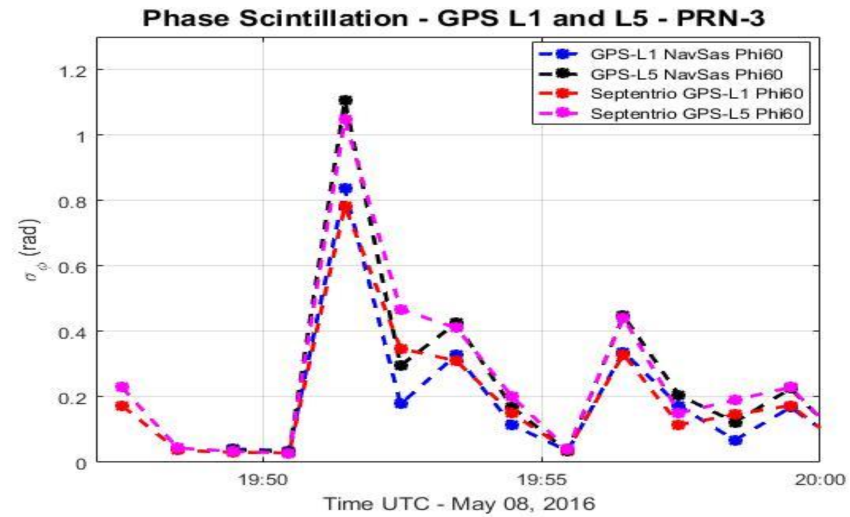


Fig. Phase Scintillation Index Values at GPS L1 and L5 Signals

- It is observed that in low P_{FA} values there is a **decrease in P_D around 0.002**.
- However, in increasing P_{FA} values, the effect of phase scintillation in P_D decreased.

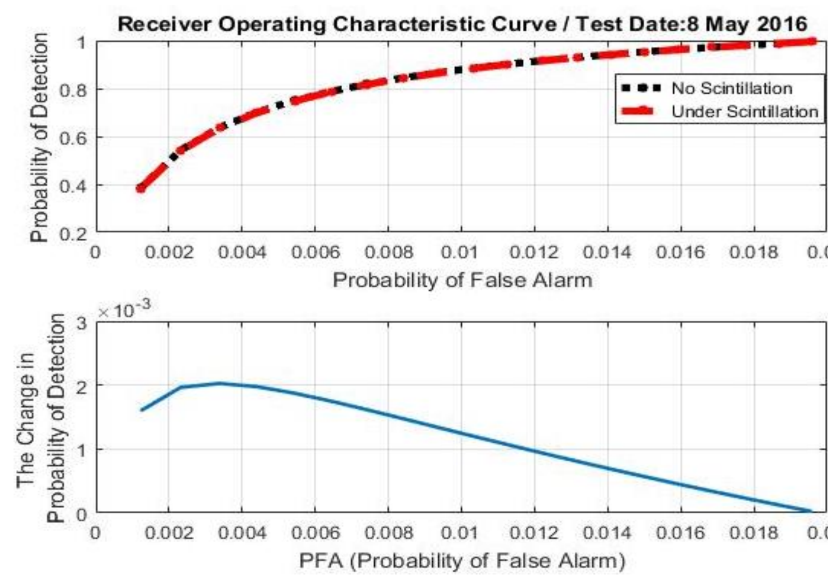


Fig. ROC Curves under Phase Scintillation

FUTURE WORKS

- The comparison of the implemented GPS-L5 signal acquisition methods under amplitude scintillation

- Implementation of Kalman filter based tracking algorithms for both L1 and L5 signal processing and analyze the performance of the structures with the amplitude & phase scintillated data

- Research on the cycle slip detection, open loop estimators, FLL/PLL/DLL structures and implementation of carrier-phase measurement algorithms on MATLAB for multi-frequency (L1 and L5) GPS receiver to reach accurate carrier-based pseudo-range measurements.

Thank you for your attention!

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