GPS L5 Software Receiver Implementation in FGI-GSRx

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Abstract

As a part of GPS modernization project U.S has introduced a third civil signal called L5. The new signal is intended to satisfy the challenging demands for safety-of-life transport and applications requiring higher precision. A software receiver for GPS L5 signal has been implemented and tested with the FGI-GSRx software-defined multi-frequency multi-GNSS receiver. This paper outlines the implementation of GPS L5 signal processing chain and offers a brief description of the L5 signal characteristics. It also demonstrates the comparison between GPS L1 C/A and L5 signals at different phases. Due to its modern signal characteristics and greater processing capacities, GPS L5 is expected to perform better than the legacy GPS L1 C/A signal.

1 Introduction

Locating and guiding is the basic prerequisite for tracing once way. Navigation systems based on satellites have become an important part of such operations where mobility is needed. For an optimized navigation solution, the FGI-GSRx receiver has been used to analyze and validate novel algorithms [1]. With the implementation of GPS L5 signal, the software receiver is now compatible with three GPS signals L1 C/A, L2 CM and L5. Along with that, FGI-GSRx can also process signals from Galileo E1, E5, BeiDou B1, B2 and NAVIC L5. It is also capable of offering a multi-frequency multi-GNSS navigation solution [2].

GPS satellites are broadcasting three types of signals in L1, L2, and L5 bands. This article will concentrate primarily on the GPS L5 signal and its implementation in FGI-GSRx. The L5 signal structure was intended to deliver greater efficiency than other civilian signals in terms of tracking sensitivity, robustness, and measurement accuracy [3]. It also includes enhanced ionospheric corrections, better rejection of interference, and signal redundancy, which makes the L5 signal more reliable. A navigation fix using four GPS L5 satellites is used to validate the overall implementation of the software. Other comparisons in terms of acquisition and positioning accuracy have also been made with the GPS L1 C/A signal. This implementation in FGI-GSRx can offer GPS L5-only solution if there are 4 or more GPS L5 satellites with valid navigation messages.

2 Signal Characteristics of GPS L5

The L5 signal is synchronized and orthogonal in quadrature phase with each other in the data channel (L5I) and pilot channel (L5Q) [3]. Primary Pseudorandom Noise (PRN) code length of both data (I) and pilot (Q) channel is 10,230 chips and channels are transmitted at 10.23 MHz, i.e. (codes) repeats at every 1 ms. The L5 signal also contains secondary Neuman-Hoffman (NH) codes to reduce the cross-correlation effects. On the data channel PRN codes are modulated by 10-bit long NH codes clocked at 1 kHz and on the pilot channel PRN codes are modulated by 20-bit NH codes also clocked at 1 kHz. Due to the Forward Error Correction (FEC) encoding, the data channel (I) transmits the encoded navigation message at 100 Hz rate to maintain effective navigation message rate of 50 Hz. Because of that, 10 ms data symbols and 20 ms data bits are perfectly synchronized with NH10 and NH20 codes respectively. Due to the higher transmission power and lower frequency L5 signals can be successfully received in harsh environments.

Summarized comparison of some fundamental characteristics of the GPS L1 C/A and the GPS L5 signals is shown in Table 1.

Table 1: Comparison of general parameters between GPS L1 C/A and GPS L5 signal.

Characteristics	GPS L1 C/A	GPS L5
Modulation Technique	CDMA	CDMA
Carrier Frequency	1575.42 MHz	1176.45 MHz
Signal Component	Data	Data &Pilot
PRN code Modulation	BPSK (1)	BPSK (10)
Code Frequency	1.023 MHz	10.23 MHz
Primary code length	1 ms	1 ms
Secondary code length (ms)	N/A	10/20(I/Q)
Code Family	Gold Codes	M-Sequence
Data Rate	50bps/50sps	50bps/100sps
Maximum received power (dBW)	-158.5	-157.9/-157.9 (I/Q)
Bandwidth (MHz)	2.046	20.46

3 Signal Acquisition for GPS L5

In the acquisition stage, the received signal is correlated with a local replica code using certain assumed values of the frequency doppler shift and this process is commonly applied to all GNSS signals. Acquisition is described as the estimation of the carrier frequency and code delay of the received signals, here local codes regarded as the NH modulated PRN codes. In L5 mainly two types of acquisition can happen: single channel acquisition, dual channel acquisition. Dual channel acquisition is beneficial where both data and pilot channels are used and overall 3 dB power gain with respect to single channel. There are several parameters that affect the acquisition type such as integration time, acquisition time and signal power. Coherent integration time is a flexible parameter to process the signals based on their reception strengths. The coherent integration time per code period should be as short as possible for the strong received signals and for the weak signals it may be the longer duration to enhance the sensitivity of the receiver. Dual-channel acquisition, however, suffers from the existence of unknown data bit transitions primarily on the data channel. Due to the existence of NH codes in both data (I) and pilot (Q) components the L5 acquisition performance is also lower than that of the L1 C/A. After all, these NH codes are considered as the data modulation during the acquisition process, where bit synchronization has not yet been accomplished [4].

4 Signal Tracking for GPS L5

Once the rough estimation of propagation delay and frequency shift of detected visible satellites is achieved, then these outcomes from acquisition can be used in the tracking stages. The tracking process is performed based on the carrier and code using a closed-loop Delay Lock Loop (DLL) and a Phase Lock Loop (PLL) respectively. Once the NH code synchronization has been achieved, it is possible to obtain a more reliable and precise tracking. It is also possible to implement a combined data & pilot tracking to improve the overall tracking performance [5]. Figure 1 shows the results of GPS L5 PRN1 tracking, obtained post processing the dataset collected on September 10, 2019 using NSL-Stereo_v2 dual chain GNSS front end and FGI-GSRx software receiver. From the figure 1, it can be seen that the signal is correctly placed on the real part of the correlator output and there is only noise contribution in the imaginary part. The noise also remains in the correlation results plot, where the greatest amount of energy lies in the prompt correlator and relatively less power lies on either side (early and late) of the prompt correlator. The upper right figure shows that the receiver tracking loop is capable of tracking the incoming signal phase with the local replica signal within a very short time.

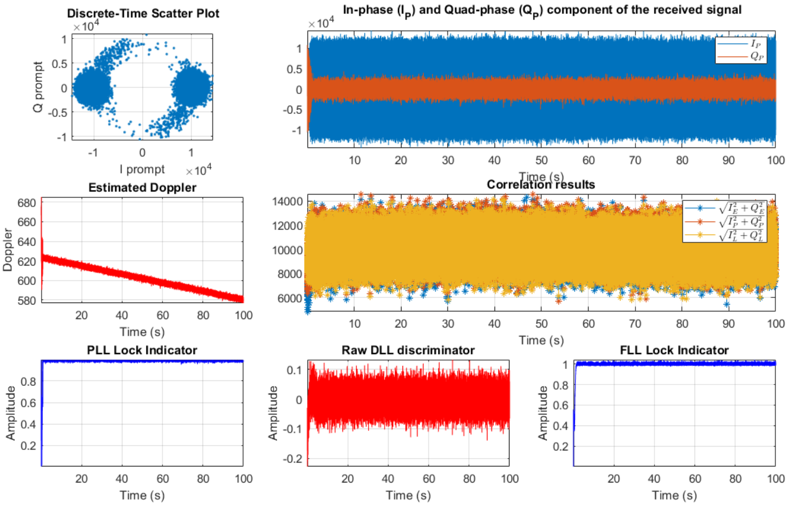

Fig. 1: Tracking results of GPS L5I

5 Position Computation and Result Analysis for GPS L5

New CNAV message format raises the need for a new algorithm for subframe synchronization. The characteristics of interest for the synchronization are the preamble, PRN number, z-count, and the CRC check. After the conversion from symbols to bits via FEC mechanism, the synchronization algorithm attempts to find the subframe beginning by correlating with 8-bit preambles. The z-count increases subframe to subframe by one, and the parity of subframes is also checked. Navigation messages can be read once the synchronization of the subframe has been validated. The most important types of messages are 10, 11 and 30 in terms of ephemeris, clock, ionospheric correction and group delay.

The receiver attempts to estimate position, time and velocity after decoding the navigation messages from at least 4 satellites. The Least Square Error estimation (LSE) algorithm is used to compute the position solution. Pseudorange measurements can be affected by noise and multipath that can be mitigated by using different carrier smoothing algorithms.

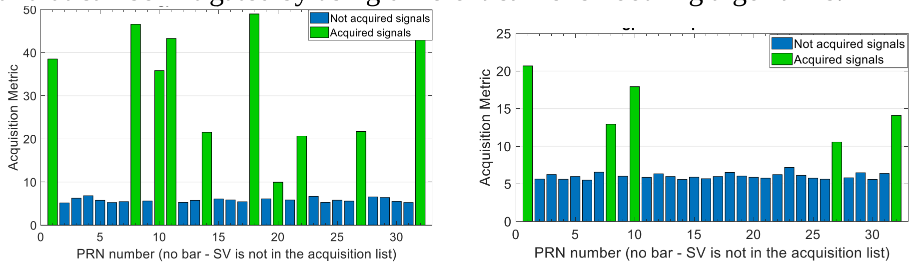

Figure 2: Acquisition results of GPS L1 C/A (Left) and GPS L5 (Right)

The FGI-GSRx software receiver was able to acquire and track 10 satellite for L1 and 5 satellites for L5 signal (as shown in Figure 2). It is observed that not all GPS satellites are currently broadcasting L5 signals. In order to make a comparison between L1 C/A and L5, the same sub set of satellites (PRN 1 10 27 32) was used for positioning computation. Table 2 indicates the position error comparison statistics of both GPS L1 C/A and GPS L5 signals with respect to true position. From Table 2 and the Figure 3 it can be seen that with the same amount of satellites, GPS L5 performs better than GPS L1 C/A in terms of positioning error and coordinate variations.

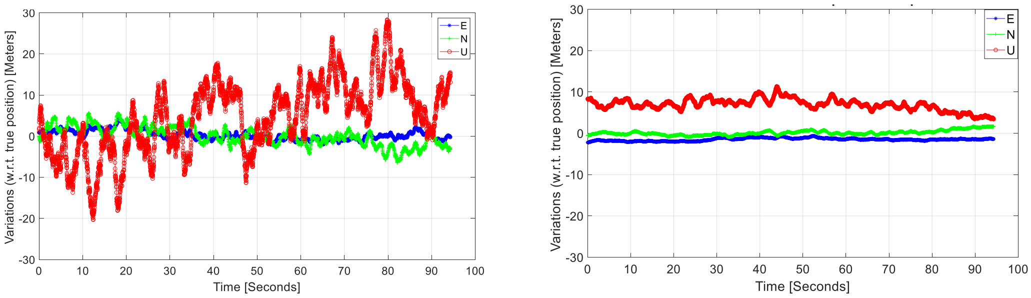

Figure 3: Coordinate variation with respect to true position of L1 C/A (Left) and L5 (Right)

Table 2 Statistics of position error concerning the true position.

	Horizontal				Vertical					
GNSS Signal	Max [m]	RMS [m]	Mean [m]	HDOP	Max [m]	RMS [m]	Mean [m]	VDOP	3D RMS [m]	No of Satellites
GPS L1 C/A	6.90	6.57	2.22	4.15	28.32	7.92	8.21	4.02	10.22	4
GPS L5	2.32	3.83	1.59	4.15	11.37	6.17	6.94	4.02	7.27	4
GPS L1 C/A	4.40	3.49	1.69	1.35	12.58	3.97	4.24	1.41	5.29	10

6 Conclusion

Under the FGI-GSRx architecture, a software-defined receiver for GPS L5 signal has been implemented and tested. The presence of NH code imposes an extra challenge at the acquisition and tracking stage. The pseudoranges measurements and navigation solution accuracy analysis proved to be very satisfactory compared to GPS L1 C/A due to the increased code rate and the required received bandwidth. The results here validate the overall implementation of the GPS L5 software receiver and open the way to further inquiry. In particular, the synchronization phase of the subframes requires the determination of the exact beginning of the subframe. Some algorithms are implemented here to determine the exact start of the subframes. In future, the impact of different error sources on code and carrier tracking will be investigated in order to optimize the implementation of both tracking loops.

Acknowledgements

This work has been conducted within the project '5G-assisted Ground-based Galileo-GPS receiver Group with Inertial and Visual Enhancement (5GIVE)', which is funded by European Space Agency.

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