Analyze and Combination of L1, L2 and L5 (Signals) for Dual Frequency of Station GPS

Niaz Mohammad Yaqoobi

Assistant Professor of KPU, Kabul-Afghanistan

Abstract - *Processing of GNSS signals from more than one frequency band enhances the accuracy and integrity of a position solution in both standalone and differential positioning. While there are some advantages in triple-frequency processing in carrier phase applications, in general most of the standalone kinematic receivers get benefit from dual-frequency signals for ionosphere error correction. In implementing a dual-frequency receiver, it is necessary to select a combination of frequencies leading to an optimum performance of the existing civilian signals. In the current research work, we have analyzed the performance of dual-frequency receiver in terms of combined signal observation noise, sensitivity and robustness using analytical models by taking the combination of GPS L1, L2 and L5 signals as an example. Further, we have investigated the benefits of common Doppler estimate-based two-frequency signal tracking to reduce the noise in linear combination of observations. Through analytical and experimental results, it is confirmed that the L1/L5 signal combination in GPS system has low observation noise, which is suitable to use in high accuracy and precise positioning applications using standalone dual-frequency receiver. Further, it is shown that common Doppler estimate-based dual-frequency signal tracking has improved receiver tracking loop performance in terms of observation noise and multipath in linear combination of observations and enhanced receiver sensitivity and robustness. In GPS system, L1/L5 signals processed using common Doppler estimate-aided two-frequency signal tracking architecture, it is possible to effectively mitigate ionosphere delay and other receiver observation errors, to achieve less than 1m position accuracy using unambiguous code phase observations. Proposed analysis is applicable of finding an optimal two-frequency signal combination in multi-frequency GNSS system and suitable signal processing architecture to obtain high accuracy and precise ionosphere-free position solution using code phase observations in standalone dual-frequency receiver.*

Key Words: Multipath, Linear, combination, Dual frequency, Rate aiding

1. INTRODUCTION

An ever growing demand for civilian applications has generated a wide spectrum of performance requirements for GPS receivers, specifically in terms of position accuracy and reliability. To meet the demand for an improved GPS performance for civil use, two new civil signals, namely-L2 civil (L2) signal and the L5 signal are added to the constellation. Currently, GPS satellites transmit civil navigation signals on L1, L2 and L5 at 1575.42, 1227.6 and 1176.45 MHz frequencies. Availability of more signal choices will introduce another challenge to designers in justifying which of the three signals are optimal for a given application. Although each of the three civil GPS signals have one or more key advantages, no one signal will be best suited for every case. For example, L1 has the lowest ionosphere refraction error, L5 has the highest power, code rate and also is transmitted in an Aeronautical Radio Navigation Service (ARNS) band, and L2 has the best cross-correlation performance. As a result, each combination of these signals is suitable to serve one or more segments of the user community. Traditionally, a linear combination of two-frequency signals has been used for different purposes such as ionosphere delay free combination, wide-lane combination in carrier phase ambiguity resolution and narrow-lane combination to generate low noise signal in fixed integer mode. After tracking process, two-frequency signal observations will be linearly combined in the navigation processor of dual-frequency receiver to remove common mode errors in the signal observations. It is well known that the process of forming linear combination of code and carrier phase observations in dual-frequency receiver is limited by the individual signal noise performance and amplification of noise. Hence, the selection of two-frequency signals and signal processing architecture play a key role in defining the performance of dual-frequency receiver. It is necessary to select a combination of two signals and signal processing architecture leading to an optimum performance of a dual-frequency receiver by thorough performance analysis. This requirement of dual-frequency receiver is not well addressed in the literature. Therefore, in the current research work, we are motivated to find an optimal two-frequency signal combination from the existing civil signals and a suitable two-frequency signal tracking architecture to improve the sensitivity and noise performance of a standalone dual-frequency receiver. The basic idea is that the multiple frequency signals transmitted from the same satellite are synchronously generated from the same reference clock, hence, the line-of-sight geometric Doppler shift across the multi-frequency signals is linearly related.

2. Characteristics of L1, L2 and L5 signals

Each of three GPS civil navigation signals have different specifications and key advantages. A brief comparison of L1, L2 and L5 signals with relevant signal specifications is given in Table1.

Out of the three signals, GPS L1 C/A is a legacy signal designed with short codes for fast acquisition and with less ionosphere refraction error. It is broadcast by block-IIR, IIR-M, and IIF satellites.

Two new civil navigation signals L2 and L5 are designed with promising features to provide improved cross-correlation protection, tracking loop performance, and multipath mitigation. The second GPS civil signal L2 is broadcast by block-IIR-M and block-IIF satellites and is designed to be interoperable with the Quasi-Zenith Satellite System (QZSS) under development by Japan. A third GPS civil signal L5 is broadcast by block-IIF satellites in the ARNS band and is designed for safety-of-life applications. It is designed to be compatible and interoperable with Galileo, GLONASS, and QZSS. Table.1

In a conventional dual-frequency receiver, two-frequency signals are tracked independently and then signal observations are combined in a linear way to reduce the common performance is influenced by an individual signal noise performance mode observation errors. The dual-frequency receiver performance in weak signal environment. The individual signal tracking loop performance can be evaluated using 1- sigma code and carrier phase noise as discussed in the following section. Fig. 1

Table-1 GPS civil signal specifications

Civil signal	Carrier frequency (MHz)	Code length (chips)	Code frequency (MHz)	Relative power difference (dB)
L1 C/A	1575.42	1023	1.023	0
L2	1227.6	10,230 (CM) 767,250 (CL)	1.023	− 1.5
L5	1176.45	10,230 (I5) 10,230 (5)	10.23	+ 1.5

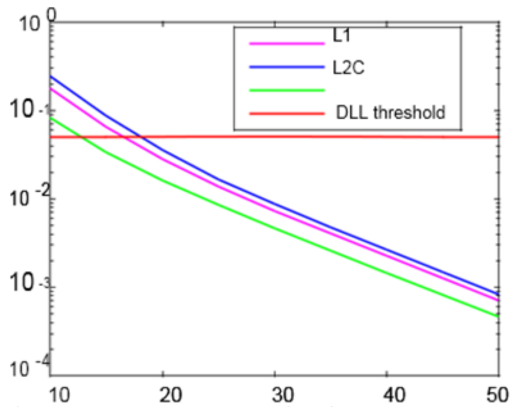

Fig. 1 Comparison of 1-sigma code phase error variation with C/N 0 in GPS L1, L2, and L5 signal code tracking loops

3. Receiver tracking loop performance

A typical tracking channel comprises of Delay Lock Loop (DLL) for tracking delay of the pseudorandom (PR) code and Frequency Lock Loop (FLL)/Phase Locked Loop (PLL) for tracking the frequency and phase of the received carrier signal. Relative power level differences in the three GPS civil signals are given in Table 1, which are considered during the evaluation.

4. Experimental results

In this section, dual-frequency receiver performance is evaluated through experiments using live satellite data collected over GPS L1, L2 and L5 signal frequencies from block-IIF and block-IIR-M satellite constellation. The major benefit of Doppler-aided tracking to reduce observation noise in linear combination of dual-frequency observations is evaluated in comparison to standard tracking loop architecture. Table. 2.

A commercial off-the-shelf (COTS) wideband RF front-end SDRNav40 with 20.46 MHz pre-correlation bandwidth and 27.456 MHz sampling rate is used to collect L1 C/A, L2 and L5 signal data. Digitized IF data from the RF front-end is processed in the dual-frequency software receiver, which has been tailored just for this project with a set of parameters as given in Table 3. As of now, navigation data (CNAV) is not available for all L5 and L2 satellite signals, so we have used navigation data from L1 signal to compute satellite position. Fig. 2

In this section, we have presented two set of experimental results. First, we have evaluated the GPS L1, L2-CM (Civil Medium code) and L5 signal tracking loop noise performance through error statistics. Fig. 3

Table-2 Tracking loop parameters in GPS L1 C/A, L2, and L5 signals

Tracking loop parameters	L1 C/A	Aided tracking loop	L5 (Q5)	L2 (CM)
Pre-correlator BW (MHz)	20.46	20.46	20.46	20.46
DLL correlator spacing (chips)	0.1	0.1	0.1	0.1
Integration time (ms)	20	20	20	20
DLL loop BW (Hz)	1	0.1	1	1
PLL loop BW (Hz)	10	5	10	10
FLL loop BW (Hz)	50	25	50	50

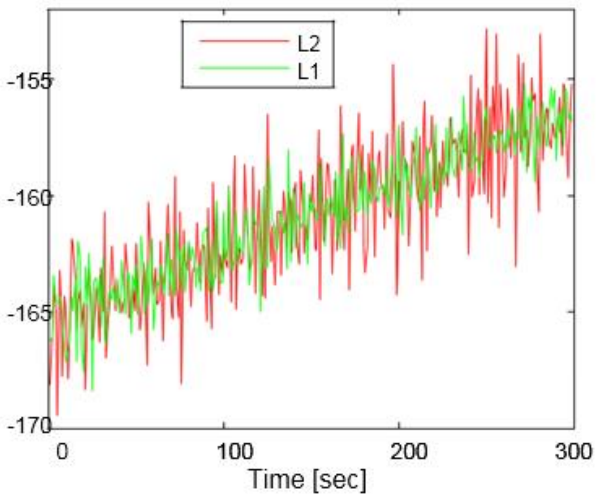

Fig. 2 Comparison of GPS L1 and L2 code pseudorange rate

Table-3 Pseudo range errors in GPS L1, L2 and L5 signals

1-Sigma	L1 C/A	L2–CM	L5–Q5
Range error (m)	1.5	1.9	0.2

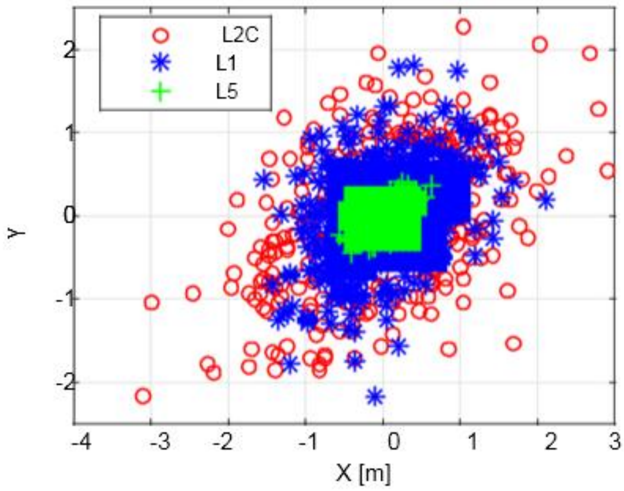

Fig. 3 Position coordinate variation computed based on L1, L2 and L5 observations

5. Conclusion

We have analyzed the noise performance of three GPS civil signals, L1 C/A, L2 and L5 and dual-frequency signal combination of L1, L2 and L5 signals using analytical error models and experimental data. Both analytical and experimental results have shown that the GPS L5 civil signal with higher chip rate and received power relative to L1 and L2 signals has substantially low pseudo range observation noise, which is more suitable for precise positioning applications. However, ionosphere delay bias still retains in L5 single-frequency observations, which is required to be eliminated for high accuracy positioning. In dual-frequency signal combination, L1/L5 signal pair has benefits of L5 signal and also low amplification of noise compared to other signal combinations. However, spread in the ionosphere-free position solution using L1/L5 linear combination of observations is more than that of L5 single-frequency observation. Hence, to reduce noise in linear combination of observations, we have investigated the benefits of using common Doppler estimate two-frequency signal tracking. Theoretical and experimental results have shown that the common Doppler-aided two-frequency signal tracking has number benefits, to reduce noise in linear combination of observations and improve receiver sensitivity and robustness to RF interference. The spectrum allocation for L1 and L5 signals in primary ARNS band qualifies L1/L5 dual-frequency receiver as an optimal choice for high accuracy safety-of-life applications. One limitation in L1/L5 dual-frequency receiver is its wider bandwidth to use in a battery powered applications such as mobile phones. On the other hand, L1/L2 dual-frequency receiver has slower chip rate of 1.023 MHz and proportional lower power consumption is suitable for ionosphere-free position solution in battery powered and miniaturized applications, with some compromise in performance. However, the bandwidth limitation of L5 signal can be overcome with advanced chip technology. This work can be extended to analyze dual-frequency receiver performance with code-carrier phase observation combination to achieve centimeter accuracy, which will be a great substitute for expensive geodetic receiver.

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BIOGRAPHY:

I was born in 1963 in Kabul – Afghanistan. I received my B.S. and MSc. degree in applied Geodesy from Uzbekistan during 1987-1992. During 1993-1998 I worked with deferent personal governmental organizations in Geomatics fields. Now I work as a lecturer at Geomatics and Cadastre faculty of Kabul Polytechnic University.