GPS L5 Acquisition Schemes for Fast Code Detection and Improved Doppler Accuracy

Inone Joo, Cheonsig Sin, Sanguk Lee, and Jaehoon Kim

In this letter, we propose GPS L5 acquisition schemes to detect a fast code phase and improve the accuracy of the Doppler frequency. The proposed approach is based on the code-phase changes which occur during the acquisition processing time originating in the Doppler frequency. The proposed schemes detect a fast code phase within about 1 chip near the estimated code phase and improve the accuracy of the Doppler frequency by up to about 4 times in comparison with the popular Septentrio receiver. The feasibility of the proposed schemes is demonstrated through simulation.

Keywords: GPS L5, acquisition, Doppler, code phase.

I. Introduction

According to GPS modernization, the third civilian GPS signal, L5, will be transmitted for aviation safety services. The L5 signal, in combination with L1 C/A, will improve the position accuracy via ionospheric correction and robustness via signal redundancy. On April 10, 2009, the United States Air Force announced the successful activation of an experimental L5 transmitter on a GPS IIR-20(M) satellite. As the code length of L5 is 10 times longer than that of L1 C/A, the acquisition processing time of L5 takes longer than that of L1 C/A [1], [2]. This feature makes the initial code phase change more than 1 chip during the acquisition processing time and causes the code tracking loop to unlock. Figure 1 shows that the code phase changes during the acquisition processing time (T_{process}). To overcome this problem, a fine acquisition scheme is generally used after a coarse initial acquisition [3]. The popular Septentrio receiver searches the correct code phase again in chips around the initial code phase and at a fixed Doppler frequency [4]. In comparison with Septentrio's receiver, the proposed schemes detect a fast code phase near an estimated code phase and improve the accuracy of the Doppler frequency using the correct number of code phases changed during T_{process}. The proposed approach is based on the code phase changes which occur during T_{process} originating in the Doppler frequency. In this letter, we describe how to estimate the code phase and Doppler frequency.

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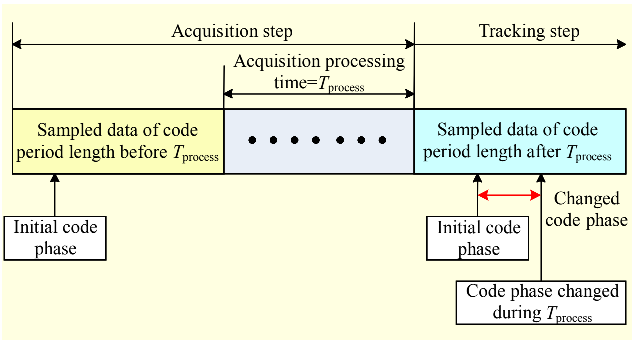

Fig. 1. Code phase changes during acquisition processing time.

II. Proposed GPS L5 Acquisition Schemes

The relation between a Doppler shift in the carrier frequency and a Doppler shift in the chip frequency is given by

$$doppler_{\text{carrier}} : f_{\text{carrier}} = doppler_{\text{chip}} : f_{\text{chip}}, \qquad (1)$$

where f_{carrier} is the carrier frequency (L5=1176.45 MHz), f_{chip} is the chip frequency (10.23 MHz), $doppler_{\text{carrier}}$ is a Doppler shift in the carrier frequency, and $doppler_{\text{chip}}$ is a Doppler shift in the chip frequency.

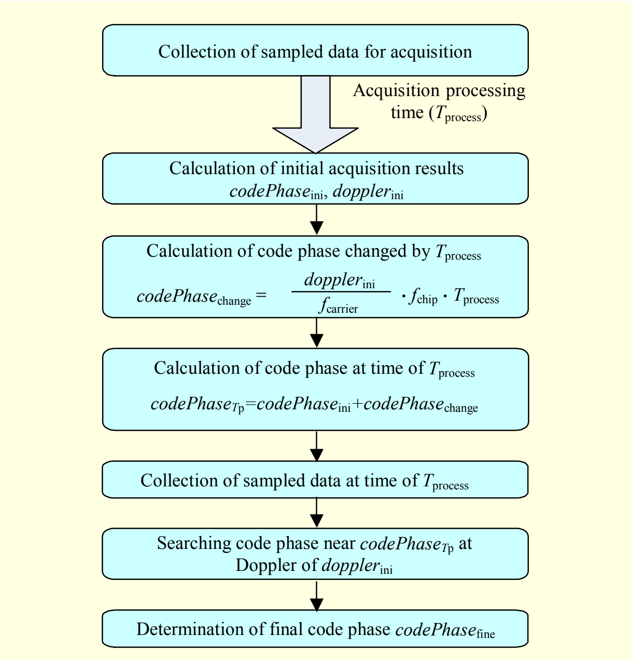

Fig. 2. Proposed scheme for fast code phase detection.

As $doppler_{chip}$ indicates the number of the code phases ($codePhase_{change}$) changed during $T_{process}$, (1) is modified by

$$codePhase_{change} = \frac{doppler_{carrier}}{f_{carrier}} \cdot f_{chip} \cdot T_{process}. \qquad (2)$$

Figure 2 shows a flow chart of the fast code phase detection scheme. The sampled GPS L5 data is collected for signal acquisition. After $T_{process}$, $codePhase_{ini}$ and $doppler_{ini}$ of the acquisition results are detected. Then, we estimate the number of code phases changed during $T_{process}$ by using (1) and calculate $codePhase_{Tp}$ at the time of $T_{process}$. After the sampled data is collected again at the time of synchronization with 1 ms, the L5 code period, we search the interval of a few chips near $codePhase_{Tp}$ at the initial Doppler frequency ($doppler_{ini}$) and detect the final code phase ($codePhase_{fine}$). Table 1 shows the estimated code phase error of the proposed schemes when the Doppler frequency error is 250 Hz. Considering that $T_{process}$ of L5 is about 480 ms for a Septentrio receiver [4], the estimated code phase error of the proposed scheme is about 1 chip. Thus, the proposed scheme can quickly detect a correct code phase in comparison with a Septentrio receiver, which discovers it at around $codePhase_{ini}$.

Figure 3 shows the proposed scheme. We could obtain $codePhase_{change\_fine}$, the correct number of code phases changed during $T_{process}$, by using ($codePhase_{fine}$–$codePhase_{ini}$). We could then estimate the final Doppler frequency ($doppler_{fine}$) by using $codePhase_{change\_fine}$ instead of $codePhase_{change}$ in (2). Table 2 shows the estimated Doppler frequency error of the proposed schemes when the code phase error is 0.25 chips. We were able

Table 1. Code phase error in the proposed schemes (assuming a Doppler frequency error of 250 Hz).

$T_{process}$ (ms)	240	480	900
Code phase error (chip)	0.52	1.04	1.95

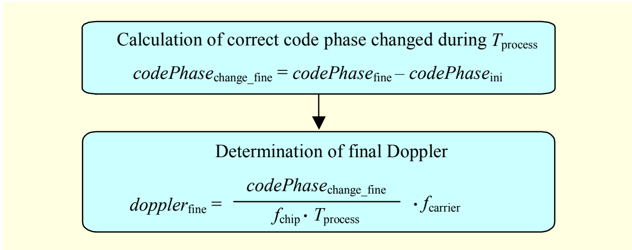

Fig. 3. Proposed scheme for improved Doppler accuracy.

Table 2. Doppler frequency error in the proposed schemes (assuming a code phase error of 0.25 chips).

$T_{process}$ (ms)	240	480	900
Doppler frequency error (Hz)	119.7	59.8	31.9

to confirm that the accuracy of the Doppler frequency improves as the acquisition processing time increases. Considering that $T_{process}$ of L5 is about 480 ms for a Septentrio receiver, the estimated Doppler frequency error is less than 60 Hz. This means that the proposed scheme improves the accuracy of the Doppler frequency by up to about 4 times in comparison with a Septentrio receiver, which uses $doppler_{ini}$ and includes a Doppler frequency error of 250 Hz.

III. Simulation Results

Figure 4 shows the environment used to collect a GPS L5 signal. Considering only the effect of a Doppler shift created due to satellite motion, we generated an L5 signal under a fixed position scenario in a Spirent simulator and used a Rubidium clock to exclude the effect of the receiver clock offset.

Acquisition is processed using a Doppler frequency bin size of 500 Hz and 0.5 chip code phase search step in accordance with the error analyses of Tables 1 and 2. The $T_{process}$ of L5 is assumed to be 480 ms for the Septentrio receiver used for comparison. Figure 5 shows the initial acquisition results detected in the sampled data before $T_{process}$. We were able to then estimate the number of code phase changes during $T_{process}$ by using $doppler_{ini}$ and calculate $codePhase_{Tp}$ at $T_{process}$ as

$$codePhase_{Tp} = codePhase_{ini} + \frac{-4500}{1176.45e^6} \cdot 10.23e^6 \cdot 0.48$$
$$= 2656 - 18.8 = 2637.2 \text{ chips}.$$

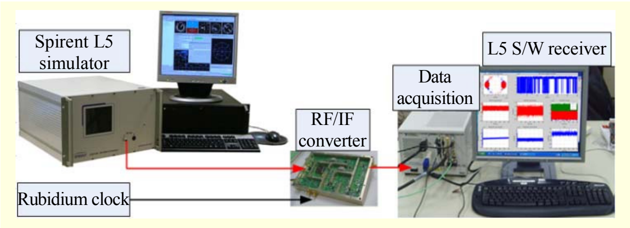

Fig. 4. GPS L5 signal collection environment.

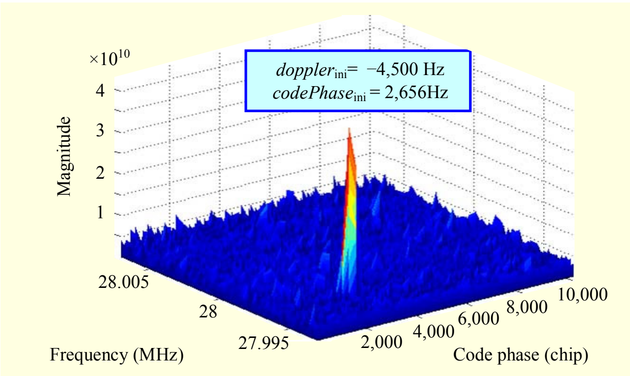

Fig. 5. Initial acquisition results.

Figure 6 shows the code phase results detected in the sampled data after $T_{process}$. The $codePhase_{fine}$ in the sampled data after $T_{process}$ is detected in 2,636 chips, which is only 1.2 chips different from the code phase ($codePhase_{Tp}$) estimated by the proposed scheme. However, a Septentrio receiver has to search 20 chips to detect $codePhase_{fine}$ because it starts to search from $codePhase_{ini}$. Thus, the proposed scheme could detect the code phase faster than the Septentrio receiver.

Now, by using ($codePhase_{fine}$–$codePhase_{ini}$), we could obtain the correct number of code phase changes during $T_{process}$ and estimate the Doppler frequency as

$$doppler_{fine} = \frac{-20}{10.23e^{6} \cdot 0.48} \cdot 1176.45e^{6} = -4791.6 \text{ Hz} .$$

Figure 7 shows the NCO results of the carrier tracking loop by using $doppler_{fine}$= −4791.6 Hz, estimated by the proposed scheme. Because the real Doppler frequency is −4741.6 Hz, the Doppler frequency error of the proposed scheme is about 50 Hz, and that of a Septentrio receiver using $doppler_{ini}$= −4500 Hz is 241.6Hz. These results show that the proposed scheme improves the accuracy of the Doppler frequency by up to about 4 times in comparison with the popular Septentrio receiver.

IV. Conclusion

A GPS L5 acquisition scheme for fast code detection and a scheme for improved Doppler accuracy were investigated to overcome the challenges in developing a real GPS L5 H/W

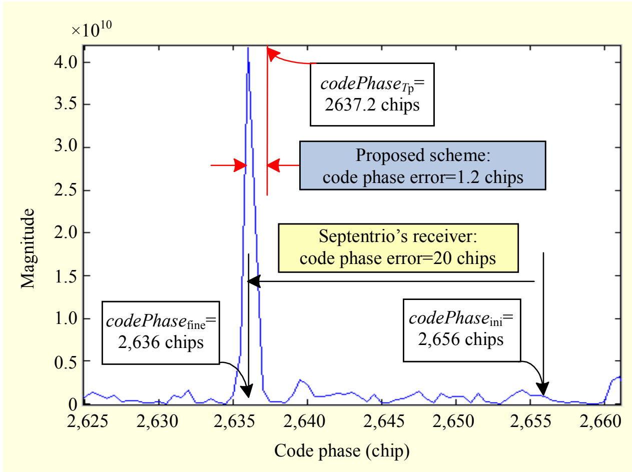

Fig. 6. Code phase results changed during $T_{process}$.

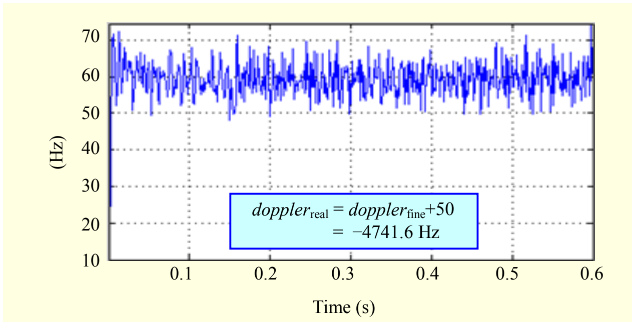

Fig. 7. Carrier NCO results of the proposed scheme.

receiver. We proposed a method to estimate the code phase and Doppler frequency by using the code phase changes which occur during the acquisition processing time originating in the Doppler frequency. The feasibility of the proposed schemes was demonstrated through simulation, which showed good performance in comparison with the Septentrio receiver. In the future, we will further investigate the performance of the proposed schemes after applying them in a GPS L5 H/W receiver.

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