Model of GPS IF Signal and Its Simulation

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Abstract  A GPS IF signal computer simulation method is proposed in this article. The carrier Doppler frequency and the total propagation and delay time can be modeled or calculated with the input GPS satellite ephemeris file. The simulated GPS IF signal outputs to a text file for post-processing and analysis. The simulation signal spectrum is compared with the received real GPS IF signal spectrum, and the correctness of the simulation result is verified.

Keywords  GPS; intermediate frequency (IF); simulation

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Introduction

Software radio has been a wide concern since Joe Mitola proposed its definition in 1992 in the IEEE Fairfax conference[1]. It was characterized by its unique and free channel configuration. The GPS software receiver is the derivative form of the software radio and the design plane is changed with time[2-5]. It is significant to simulate the GPS IF signal because the validation of the core technique models of acquisition and tracking all depend on it. D.Akos reported that it is impractical to sample the up to 1.5GHz radio frequency signal directly within several years because of the limitation of the chip science. Therefore, radio frequency is currently amplified by the low noise amplifier and then converted to intermediate frequency during the signal processing. Only by this way can the signal be sampled at relatively low frequency. The price of the popular GPS front-end in the market, for example ATR series and GPS10 series, is very high, and the GPS front-end parameters cannot be modified to adapt different environments. Hence, this article presents a new way to simulate sampling GPS L1 frequency intermediate frequency signals by computer, and stores the samples in text format in order to satisfy the validation of the acquisition and tracking models for the GPS software receiver.

1  Mathematic model of GPS intermediate frequency signal

1.1  Down-converted output model

Supposing the received GPS satellite signal above the GPS antenna is $s(t)$ at time $t$ (only L1 frequency is considered), it can be expressed as:

$$s(t) = \sum_{k=1}^{N} \left[ 2P_t d(t+\delta t_k) c(t+\delta t_k) \cos(2\pi f_{c,t} + \delta f_{amp,k}) \right] \cdot$$

$$(t+\delta t'_k) + \phi_k + MP(t) + n(t) \quad (1)$$

where $k, N, \sqrt{2P_t}, \delta t_k, \delta t'_k, \delta f_{amp,k}, \phi_k, MP(t), n(t)$

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represent the received satellite sequence number, the total received satellite number, the $k^{th}$ satellite power, the C/A code time delay, the carrier wave time delay, the $k^{th}$ Doppler frequency, the carrier wave stochastic phase, the multipath delay and the noise, respectively; $d(\bullet), c(\bullet)$ and $\cos(\bullet)$ are the representations of the received ephemeris data, C/A code and carrier wave, respectively. The signal expressed by Eq.(1) is amplified and mixed by the local frequency $f_{L1}$ with the crystal oscillation bias $\delta_{rev}$, the local signal can be written as $s_{rev}(t)$:

$$s_{rev}(t) = \cos(2\pi f_{L1} t - \delta_{rev}) \tag{2}$$

Mixing the signal of Eq.(1) by the signal of Eq.(2) and filtering the high frequency part of the mixed signal, the down-converted intermediate frequency signal $s_p(t)$ can be obtained:

$$s_p(t) = \sum_{k=1}^{N} A_k d(t + \delta_{t_k}) c(t + \delta_{t_k}) \cos(2\pi f_{L1} + \delta f_{dep,k}) t + K + \varphi(t) + MP'(t) + n'(t) \tag{3}$$

Where $f_p = f_{L1} - f_{L1}'$ is the mixed intermediate frequency, $A_k$, $MP'(t)$ and $n'(t)$ are the amplitude of the mixed intermediate frequency, the multipath and noise, respectively; and $K$ is the effective item of mixed intermediate frequency error and in the form of Eq.(4).

$$K = 2\pi((f_{L1} + \delta f_{dep,k}) \delta t_k' - f_{L1}' \delta t_{rev}) \tag{4}$$

Sampling the signal of Eq.(4) according to the sampling theory by an A/D converter and the output is the GPS intermediate frequency digital signal. For convenience, but without losing generality, the two-bit quantification of the GPS intermediate frequency signal is adapted similar with the common GPS front-end.

### 1.2 Time delay model of intermediate frequency signal

According to the characteristics of GPS satellite signal propagation, the time delay $\delta t_k$ and $\delta t_k'$ in Eq.(3) can be written as:

$$\delta t_k = \frac{\rho_s}{C_{light}} + \delta t_{sat,k} + \delta t_{tropo,k} + \delta t_{ion,k} \tag{5}$$

$$\delta t_k' = \frac{\rho_s}{C_{light}} + \delta t_{sat,k} + \delta t_{tropo,k} - \delta t_{ion,k} \tag{6}$$

where $\rho_s$, $\delta t_{sat,k}$, $\delta t_{tropo,k}$, $\delta t_{ion,k}$, $C_{light}$ are the $k^{th}$ satellite to receiver distance, the $k^{th}$ satellite clock error, the $k^{th}$ satellite propagation troposphere delay, the $k^{th}$ satellite propagation ionosphere delay and light speed constant, respectively. During the simulation, supposing the receiver is fixed on earth (known coordinates), the satellite’s positions can be obtained by the ephemeris, and so is the satellite receiver distance. The other time parameters can be estimated by the corresponding general models.

### 1.3 Doppler frequency simulation of intermediate frequency signal

It is proved that the change domain of Doppler frequency $\delta f_{dep,carrier}$ of GPS L1 frequency carrier wave is $[-5 \ kHz, 5 \ kHz]$ especially for the low speed motion GPS receiver\[6\]. However, the C/A code Doppler frequency $\delta f_{dep,c/a}$ is far less than the carrier wave counterpoint and it can be neglected during the simulation. The relationship of the two different Doppler frequencies satisfies Eq.(7).

$$\delta f_{dep,c/a} = \frac{f_{L1}'}{f_{L1}} \delta f_{dep,carrier} = \frac{1}{1540} \delta f_{dep,carrier} \tag{7}$$

Assuming the earth is a sphere and the satellite orbit is a circle, the carrier Doppler frequency in Eq.(3) can be expressed as:

$$\delta f_{dep,k} = \frac{v_k \cos(\alpha_k + \theta_k)}{C_{light}} f_{L1} \tag{8}$$

where $v_k$, $\alpha_k$ and $\theta_k$ are the $k^{th}$ satellite speed, the $k^{th}$ satellite elevation angle, and the circle angle decided by the $k^{th}$ satellite-receiver-earth core, respectively. In another word, the carrier Doppler frequency can be estimated by the satellite and receiver coordinates.

### 1.4 Multipath and noise simulation of intermediate frequency signal

The multipath of the signal can be of the following form:

$$MP'(t) = \sum_{j=1} A_j' (t + \delta t_{MP}) \tag{9}$$

Here, $A_j'$ is the ratio of reflected signal amplitude to the direct signal one, and its value relates to the reflecting characteristic of the object and satisfies $A' < 1$; $\delta t_{MP,j}$ is the reflected signal time delay and can be depicted $\delta t_{MP,j} < 1 + d/2C_{chip} \ [7]$, where $C_{chip}$ is the C/A code chip width and $d$ is the correlation space.
during the signal tracking; $s'_p(t)$ is similar to Eq.(3) but expresses only one satellite intermediate frequency signal.

The noise is considered to be Gaussian white noise and generated by the method of Marsaglia-Bray.

2 The software realization of GPS intermediate frequency signal

The program flow chart and the simulation software are designed according to the previously mentioned GPS intermediate frequency signal simulation model. The parameters are calculated and estimated by reading the ephemeris file and receiver coordinates. The discrete C/A code is generated by the instruction of ICD-GPS-200, and the signal-to-noise ratio (SNR) value is controlled by manual input. The simulated signal is sampled by two-bit quantification and denoted as 3, 1, −1 and −3. The simulation clock is controlled by the input sampling frequency and the period of C/A count. The simulation principle chart of GPS intermediate frequency signal is shown in Fig.1 where a bold cross means joint.

In order to calibrate the simulation results, a set of real GPS intermediate frequency digital signal was sampled by using NewStar 210A GPS IF digitizer, and the software simulation was also started by using the same parameters as NewStar 210A did. The parameters are listed in Table 1; the collected signal spectrum and the simulated signal spectrum are illustrated in Fig.2, Fig. 3 and Fig.4.

By contrasting Fig.2 and Fig.3, a conclusion can be drawn that they are so similar, but they are much more different from Fig.4. The side lobes of Fig.2 and Fig.3 are smoothed, while the side lobes of Fig.4 are projected. The possible reason for this phenomenon is that noise was not added in Fig.4 during the simulation; however, Fig.2 and Fig.3 considered the noise effect. No matter how different the figures are, they keep the characteristic of main lobes that contain the useful 2MHz bandwidth intermediate frequency sig-

| Item                | Value                      |
|---------------------|----------------------------|
| GPS Time            | 2007 03 30 11:33:00        |
| PRN No              | 22                        |
| Intermediate frequency | 20 491 635 Hz             |
| Sampling frequency  | 16 367 667 Hz             |
nal and can be used for data source for GPS software receiver study.

3 Conclusion

A method of using a navigation file and coordinates to estimate carrier Doppler frequency is proposed in this article, and the model of generating GPS intermediate frequency digital signal is also analyzed. The simulation software is programmed based on the analysis. By contrasting the spectrum of simulated and collected GPS intermediate frequency signal, a conclusion is drawn that the simulated GPS intermediate frequency digital signal is feasible and valid, which can be used to provide cheap source data for GPS software receiver core technique studies, such as signal acquisition and tracking.

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