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Design and implementation of the simulation system for GPS new civil signals

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Abstract: In order to research on the design and implementation of a modernized GPS civil signals simulation system, a brief review of the modernized GPS signals is introduced, including the signal structure and characteristics of L2C, L5 and L1C signals. The design and implementation of the main modules of the simulation system is described in detail. The simulation system is mainly composed of parameter setting, system initialization, signal generator, noise generator, disturbance generator, signal synthesis, low-pass filter, A/D conversion and storage. The simulation results based on Matlab are then presented, and the power spectral density (PSD) of all navigation signals is analyzed. The simulation system completes the physical layer simulation of a modernized GPS new civil signal and can provide a controllable signal source for designing and testing of modernized GPS civil receivers, especially for the signal processing algorithm design of the GPS software receiver.

Key words: modernized GPS; L2 civil signal; L1 civil signal; L5 signal; simulation system
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The modernization of the GPS signal commenced with the launch of next generation satellites (IIR20-M) on 24th March, 2009 by the US. The modernized GPS includes the adding of a new civil code on the L2 frequency (L2C on 1 227.60 MHz), a third civil signal on the L5 frequency (1 176.45 MHz), a new civil code on the L1 frequency (L1C on 1 575.42 MHz) and a military code (M-code) on the L1 and L2. This paper mainly focuses on the civil signals of a modernized GPS including L2C, L5 and L1C signals[1-2]. The new GPS signals affect both the space and user segments significantly. The modernization program aims to improve positioning and timing accuracy, signal availability and integrity monitoring. New GPS signals can provide better immunity to RF interference and multipaths, and better atmospheric corrections.

In order to study the signal processing algorithms of the GPS software receiver, it is necessary to simulate GPS signals for testing their functionality. The simulation system can provide a signal source for designing and testing modernized GPS civil receivers. The key study of this paper is to use the Matlab as a simulation platform to generate digital IF modernized GPS civil signals, to analyze the spread spectrum modulation and to add noise and jamming in the transmission process to make the simulated signals closer to the real ones. A brief review of the modernized GPS signals, including the signal structure and characteristics of L2C, L5 and L1C signals, is first described. Then the architectural design of the simulation system and the simulation results are presented.

1 Modernized L2C, L5 and L1C Signals

1.1 L2C signal structure and characteristics

The L2 civil code denoted by L2C is used on the L2 carrier as a replacement for the C/A code. Currently eight GPS Block IIR-M satellites and two Block IIF satellites transmit the L2C signal. The L2C signal is composed of two codes: L2 CM (a medium length code) and L2 CL (a long code). The L2 CM code is 20 ms long and contains 10 230 chips while the L2 CL code has a period of 1.5 s, containing 767 250 chips[3-4].

The CM code is modulated with data at 25 bit/s using a forward error correction (FEC) technique with a parameters rate of 1/2, to produce 50 symbol/s data. A stronger signal and the FEC permit message recovery with weaker signals or with more radio noise. The improvement will make it possible to obtain messages even with the weakest GPS signals.

The CL code has no data modulation, and the spreading is due to the spreading code. Since there is no data on the CL code, it can be tracked by a phase locked loop (PLL), while a Costas loop is not required. The threshold advantage of a PLL over a Costas loop is 6 dB, considering a 3 dB time share loss. So the improvement is

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about 3 dB when tracking the CL signal. The CM code is modulo-2 added to data and the resultant sequence of chips is time-multiplexed with the CL code. As shown in Fig. 1, the time multiplexed L2C sequence modulates the L2 (1 227.6 MHz) carrier.

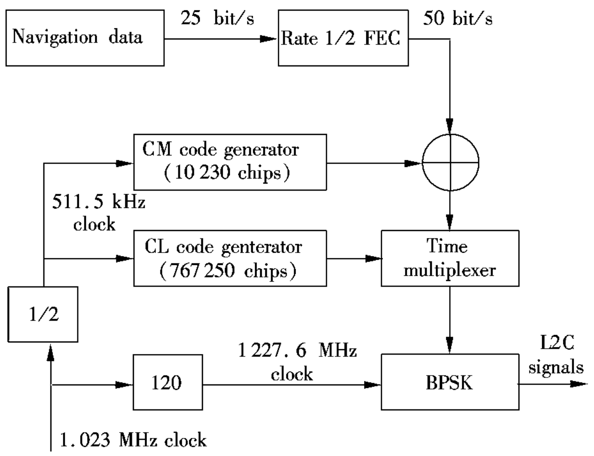

Fig. 1 L2C signal structure

1.2 L5 signal structure and characteristics

The new L5 code QPSK modulates at a frequency of 1 176.45 MHz. The civil code on L5 is similar to the existing P(Y) code. The L5 signal has two phase-orthogonal components, the in-phase code (I code) and the quadrature-phase(Q code). The block diagram of the L5 signal is shown in Fig. 2[5-6].

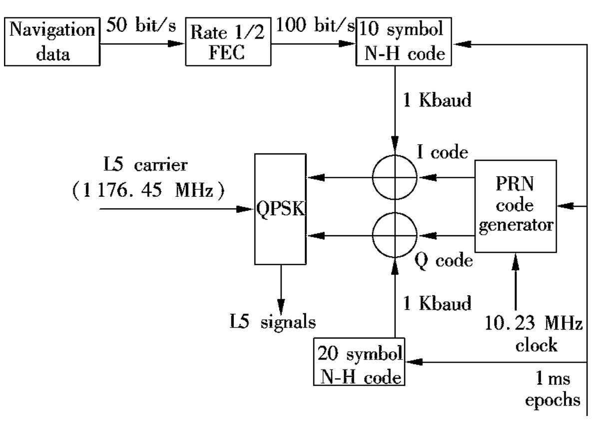

Fig. 2 L5 signal structure

The I code is multiplied by a 10 bit Neuman-Hoffman (N-H) code to extend the code period from 1 to 10 ms. Each N-H symbol runs at a rate of 1 000 N-H symbols per second. The N-H code is modulated with data at 50 bit/s using FEC technique with a parameters rate of 1/2, to produce 100 symbol/s data. In a similar way, the Q code, which has no data, has a ranging code which runs at 10.23 Mchip/s with a period of 1 ms. The Q code is multiplied by a 20 bit N-H code to extend the code period from 1 to 20 ms.

The primary purpose of the N-H code is to reduce the spectral line power of the ranging codes by 10 dB for the I channel and 13 dB for the Q channel.

1.3 TMBOC modulation of L1C signal

TMBOC is the US implementation of MBOC for the GPS L1 civil (L1C) signal. The BOC(1, 1) and BOC (6, 1) spreading symbols are defined as follows[7-8]:

$$\mathrm{TMBOC}(6,1,4/33)(t) = \begin{cases} S_{\mathrm{BOC}}(1,1)(t) & \text{if } t \in S_1 \\ S_{\mathrm{BOC}}(6,1)(t) & \text{if } t \in S_2 \end{cases} \quad (1)$$

where S_1 is the BOC(1, 1) subcarrier's location and S_2 is the BOC(6, 1) subcarrier's location. The BOC(6, 1) spreading symbols are in locations 1, 5, 7, and 30 of each 33 spreading symbol locations. The schematic diagram of the TMBOC (6, 1, 4/33) generation is shown in Fig. 3.

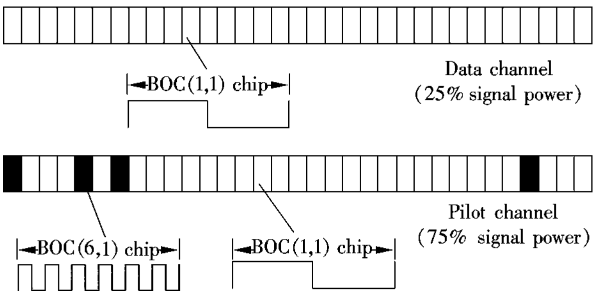

Fig. 3 Schematic diagram of TMBOC(6, 1, 4/33) generation

The total signal power can be divided differently between the pilot and data components. Here 75% of the signal power is assigned to the pilot component and 25% to the data component. Only BOC(1, 1) spreads symbols on the data component and both BOC(1, 1) and BOC(6, 1) spread symbols on the pilot component.

The PSD in data channel and pilot channel is given as

$$G_{\mathrm{P}}(f) = \frac{29}{33}G_{\mathrm{BOC}}(1,1)(f) + \frac{4}{33}G_{\mathrm{BOC}}(6,1)(f) \quad (2)$$

$$G_{\mathrm{D}}(f) = G_{\mathrm{BOC}}(1,1)(f) \quad (3)$$

The total PSD of the TMBOC implementation is given as

$$G_{\mathrm{MBOC}}(f) = \frac{3}{4}G_{\mathrm{P}}(f) + \frac{1}{4}G_{\mathrm{D}}(f) = \frac{10}{11}G_{\mathrm{BOC}}(1,1)(f) + \frac{1}{11}G_{\mathrm{BOC}}(6,1)(f) \quad (4)$$

Better performance can be achieved using spreading modulations that provide more power at high frequencies away from the center frequency. MBOC(6, 1, 1/11) has an increase in higher frequency power compared to that of BOC(1, 1), and the inter-operability and compatibility with the GPS BPSK can be assured. The additional high frequency power is provided by BOC(6, 1) symbols.

2 Architecture Design of the Simulation System

The functional block diagram of digital IF signals generation is shown in Fig. 4. The signal received by the antenna has very low amplitude. This is a result of the combination of a low power transmitter on the satellite and the long distance traveling with noise and disturbance. The preamplifier improves the power of the signal received by the receiver's antenna. The purpose of the down-conversion block is to downconvert the signal provided by the preamplifier. The received signal is down-converted from RF to an intermediate frequency (IF) which is often about a couple of MHz. Bandpass filters are used to perform the primary role of passing selective frequencies and attenuating others. The A/D converter is responsible for sampling the down-converted analog signal and the digital IF signals are obtained[9-11].

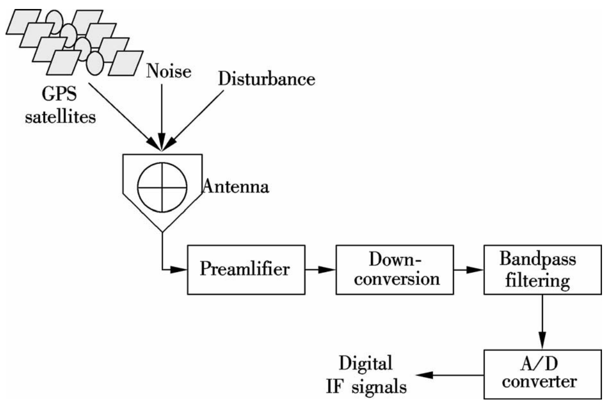

Fig. 4 Functional block diagram of digital IF signals generation

In this paper, Matlab is used as a simulation platform to generate digital IF signals of the modernized GPS system, in order to analyze the spread spectrum modulation and to add noise and jamming in the transmission process to make the simulated signals closer to the real ones. The flowchart of the simulation system is shown in Fig. 5.

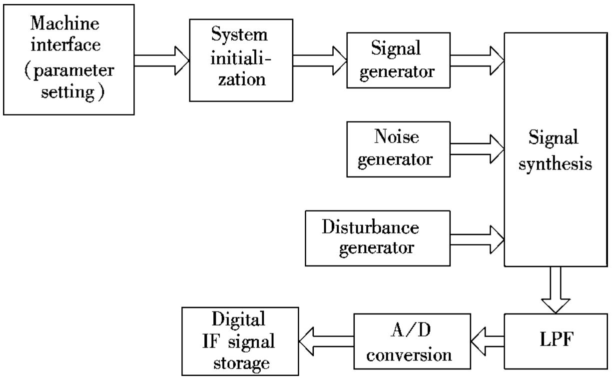

Fig. 5 Flowchart of the simulation system

As shown in Fig. 5, the architecture of the signal generator is constructed as follows:

1) Machine interface (parameter setting)

In the machine interface module, the user is allowed to set a wide range of simulation parameters to guarantee the use versatility and the full control of the simulation conditions, including the number and PRN sequence of the simulated satellite signals, the length of the simulated signals, the type of modulation, the code delay for every satellite, C/N_0 or absence of noise, type of disturbance and characteristics, the front-end filter, the ADC, the intermediate frequency and the sampling frequency etc.

2) System initialization

The system initialization module reads the configuration parameters in the machine interface module and initializes the necessary structures of variables.

3) Signal generator

The signal generator produces the GPS signal samples at the simulated intermediate frequency and sampling frequency, and takes into account possible Doppler effects on the signal.

4) Noise generator

The noise generator generates the additive white Gaussian noise (AGWN). The C/N_0 or absence of noise can be set in the parameter setting part.

5) Disturbance generator

The disturbance generator produces four different disturbances, including the intra-system interference (which is from one or more other GNSS signals), the multipath (which is from one or more attenuated and delayed versions of the GPS signal), the narrow-band interference (which is a continuous wave signal), and the wide-band interference (which is a band-limited noise).

6) Signal synthesis

The signal synthesis module is to combine the outputs of the signal generator with the noise generator and the disturbances generator in order to make the simulated signals closer to the real one.

7) Low-pass filter(LPF)

Selective frequencies pass through the low-pass filter and other frequencies are attenuated. It can be activated/deactivated by setting a proper flag in the parameter setting part.

8) A/D conversion

The A/D conversion samples the analog signals at the simulated sampling frequency. Each sample of the sum of all the generated components is optionally quantized and the digital IF signals are obtained.

9) Storage

The digital IF signals are saved in an output file for further processing.

3 Simulation Results

All the development in this signal simulation system is implemented using Matlab. In order to better understand the potentialities of the signal simulation tool, some examples of signal generation are shown.

Fig. 6 and Fig. 7 represent the time and frequency plot of the GPS L2C signal, respectively. The simulation specifications are as follows: the modulation is L2C signal; satellite number is No. 1; the duration of the simulated signal is 10 ms; the sampling frequency is 40.92 MHz; the intermediate frequency (IF) is 10 MHz; the number of the plot samples is 3 000; noise is absent; the front-end filter is absent; there is no ADC quantization. It can be shown that both the code chip samples and the GPS L2C spectrum are clear and reasonable.

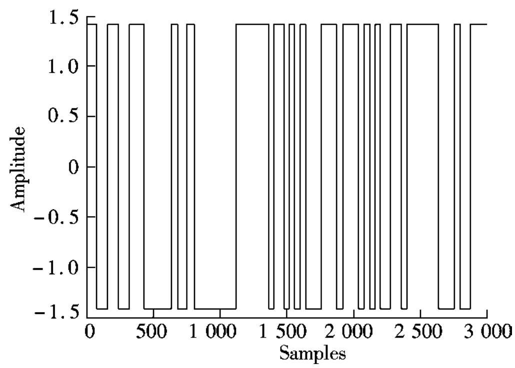

Fig. 6 GPS L2C code chip samples

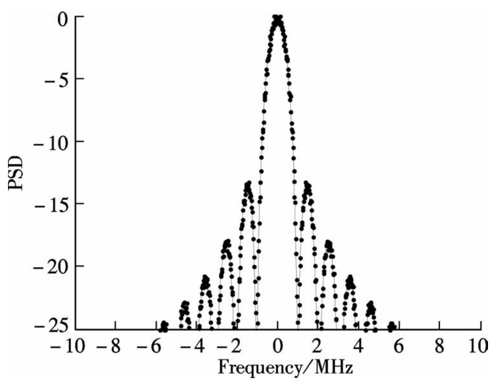

Fig. 7 GPS L2C signal spectrum

Fig. 8 and Fig. 9 represent the frequency plot of the GPS L1C signal and the GPS L5 signal, respectively. It can be shown that the GPS L1C spectrum and the GPS L5 spectrum are clear and reasonable. Due to the space limitation, L2C is chosen as the representative of the modernized GPS signal to analyze the performance.

The signal shown in Fig. 10 is obtained by applying a front-end filter to the configuration of Fig. 7. The

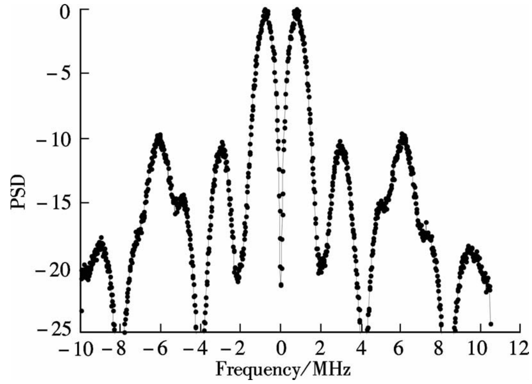

Fig. 8 GPS L1C signal spectrum

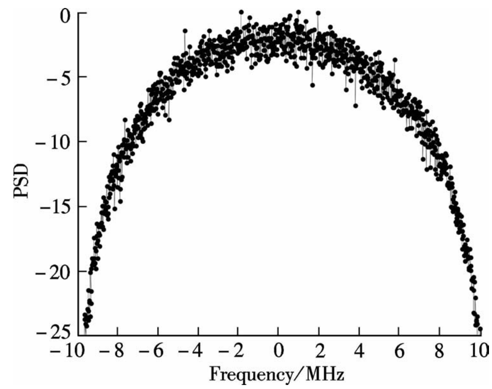

Fig. 9 GPS L5 signal spectrum

sampling frequency is set at 40.92 MHz and the intermediate frequency at 10 MHz. Both the interference and the noise blocks are off. The filter is the Butterworth filter with an order of 4 and the onesided bandwidth is 2.046 MHz. It is easy to observe the effect of the filter on the signal spectrum. It is recognizable that the cut-off frequency is about 2 MHz.

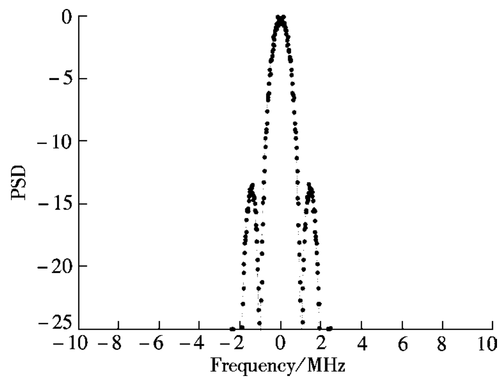

Fig. 10 GPS L2C signal spectrum after filtering

Another example with external interference is shown in Fig. 11. The useful signal is the GPS L2C with CM and CL multiplexed modulation. The sampling frequency is set at 40.92 MHz and the intermediate frequency at 10 MHz. Both the front-end filter and the noise blocks are off. In Fig. 11 an external wide-band interference is added. It is modeled as filtered white Gaussian noise, with a carrier frequency of 2.5 MHz upon the GPS signal, and

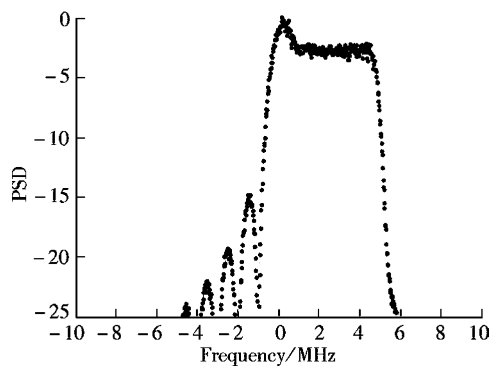

Fig. 11 GPS L2C signal spectrum with wide-band interference

its bandwidth is equal to 5 MHz. The effect of the spectrum distortion is easily observable.

4 Conclusion

In this paper, on the basis of giving a brief review of the modernized GPS signals (L2C, L5 and L1C), a detailed description of the composition of the simulation system is presented, including the principle and implementation method of the main modules of the simulation platform. Simulation results show that the Matlab-based GPS civil signals simulation platform is reasonable and close to the real. It can provide a flexible and configurable platform for testing and validation of new navigation signals.

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GPS 新民用信号仿真系统的设计与实现

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摘要:为了研究现代化的 GPS 新民用信号仿真系统的设计和实现,介绍了现代化的 GPS 信号组成及其结构特点,包括 L2C,L5 和 L1C 信号. 对仿真系统各模块的设计和实施方法进行了详细描述. 该信号仿真系统主要包括:参数设置、系统初始化、信号产生、噪声产生、干扰产生、信号合成、低通滤波、A/D 转换以及信号存储等主要功能模块. 通过 Matlab 对该信号仿真系统进行仿真,并重点分析了所有导航信号的功率谱密度. 结果表明该仿真系统能够完成现代化的 GPS 新民用信号物理层仿真,并可为现代化的 GPS 民用接收机尤其是软件接收机的设计和测试提供可控信号源.

关键词:现代化的 GPS; L2 民用信号; L1 民用信号; L5 信号;仿真系统

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