

## Design of Spread-Spectrum Communication System Based on FPGA

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**Abstract:** Spread spectrum communication technology, compared with the conventional communication technology, has many characteristics, such as a low interception rate, strong anti-noise performance, noise immunity, information hiding and multiple access communication. Widely used in military communication and civil communication at present, it is the core technology in the third generation mobile communication standards and has become one of the three high-tech communication transmission modes to enter the information age. The communication system of direct sequence spread spectrum (DSSS) is most common in the spread spectrum communication technology, and this type of system was studied in this research. FPGA is one of hot research topics on hardware design. It has been widely used in the algorithm implementation and product prototype verification due to its rich logical unit, high integration, flexible configuration and many other advantages. Design and implementation on digital communication system with a more complex function have become reality on the hardware platform of FPGA with the considerable development of modern microelectronics especially in recent years. The research studied the various parts of key technologies, introduced the various algorithms of the most critical synchronization technologies (including pseudo-code acquisition, pseudo-code tracking, and carrier synchronization) in system in detail and gave their simulation results by establishing a complete simulation system for Direct Sequence Spread Spectrum. Copyright © 2013 IFSA.

**Keywords:** Spread spectrum, PN code, FPGA.

### 1. Introduction

The spread spectrum communication is an important development direction of modern communication technology. Spread spectrum communication uses the pseudo-random code as the basic signal of spread spectrum modulation and thus has many unique advantages, such as strong noise immunity, low interception rate, code division multiple access (CDMA,) hidden signal, security and networking ease. Spread spectrum communication is mainly used in military communication, electronic countermeasure, navigation and measurement in the

past. It begins to be more and more widely used in the field of civil communication now, for example, CDMA, microwave communications, telemetry and telecontrol and so on are all based on the spread-spectrum communication technology [1].

The spread spectrum communication technology is of broad application prospects currently in the fields of both military and civil due to its own many advantages in view of the current analysis. Spread spectrum technology has been advanced for a long time, but there is still a great research value in some key technologies (such as synchronization technology), which is also the research purpose.

## 2. Spread-spectrum Modulation Module

Spread spectrum communication needs spreading code modulation, compared with the conventional communication. Therefore, it is essential to first design a generator of pseudo-random code to produce the required spreading code in the design of transmitter and then conduct spread spectrum modulation to baseband signal [2]. It is because of the pseudo-random code modulation that communications have good features, such as good noise immunity, strong concealment, small interference and easy to implement the multiple access of code division.

### 2.1. Design on Pseudo-random Code

The random code, with white noise characteristic, is best spreading code in spread spectrum communications. This code has extremely good characteristics of autocorrelation and cross-correlation as well as a uniform spectral density of power, but it is difficult to design and achieve in a project. Therefore, spread spectrum modulation is achieved by using a white noise-like pseudo-random code in the application of actual project. The better the properties of autocorrelation and cross-correlation selected by pseudo-random sequence are, the better the noise immunity and security of spread spectrum communications are achieved.

M-sequence is a kind of systematic balance-code sequence with very strong regularity. Only the same m-sequence can be used to despread the original information for the signal after the spread spectrum of m-sequence because m-sequence has good

autocorrelation properties. Correlation peak appears only when the same m sequence is used to despread for the self-correlation of m sequence. M sequence has the characteristics of easy production and replication, so it is ideal for design and implementation on FPGA. The m-sequence is the sequence generated by the n-level shift register with the longest cycle. Easy to be designed and achieved, it is widely used in general spread spectrum communication [3].

The 63-bit m sequence needing to use a 6-level shift register was used as the spreading code in the system (as shown in Fig. 1).

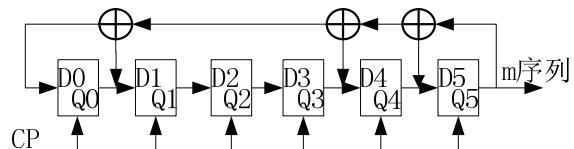


Fig. 1. M sequence structure diagram.

The characteristic polynomial of m sequence used in this study is:

$$f(x) = 1 + x^4 + x^5 + x^6, \quad (1)$$

It is only necessary to instantiate spreading code elements in the design of code when spread spectrum is used to produce module in the design of system with module produced by spreading code being encapsulated into an element [4]. The waveforms on 63-bit m-sequence generator after Modelsim simulation are as shown in Fig. 2.

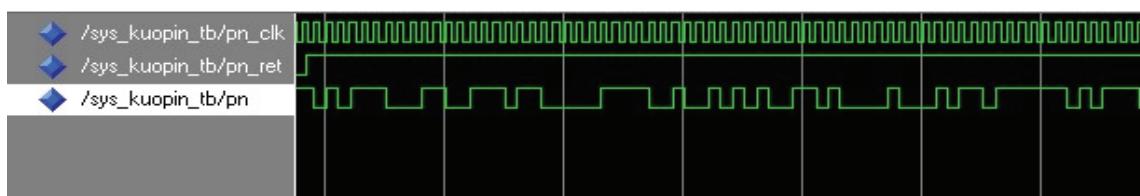


Fig. 2. Waveform chart of 63-bit pseudo-random sequence.

### 2.2. Design on Spread Spectrum Modulation

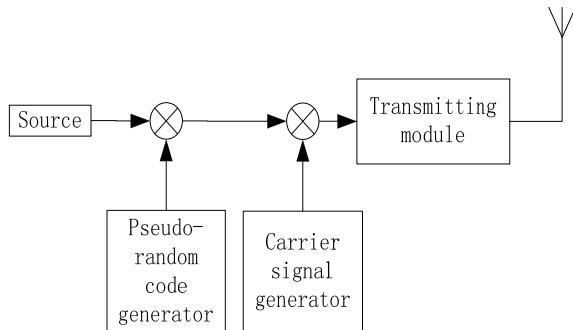
Fig. 3 shows a block diagram of system modulation principles of direct-sequence spread-spectrum communication by taking the modulation system of single-channel PSK as an example.

The priori probabilities of the two symbols contained in the binary digital signals generated by a source are both 1/2. The two symbols are independent to each other, and their waveforms are as shown in Fig. 4. The pseudo-code generator generates the high-speed binary pseudo-random codes, and their waveforms are shown in Fig. 4. The pseudo-random code as a spreading code of the system multiplied by it equals the composite signals

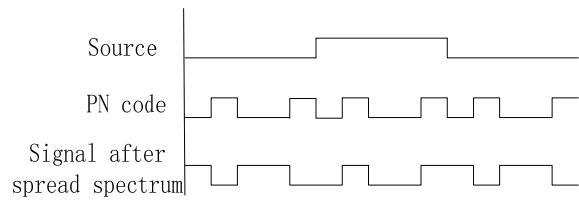
as shown in Fig. 4, which extends the bandwidth of the transmission signal.

The composite signal after spectrum spread makes a BPSK modulation on carrier, and then is fed into the channel for transmission by the transmitter and antenna [5]. The bandwidth of the RF signal equals to 2 times of the rate of pseudo-random code in the case of BPSK modulation, but has nothing to do with the code rate of the digital signal.

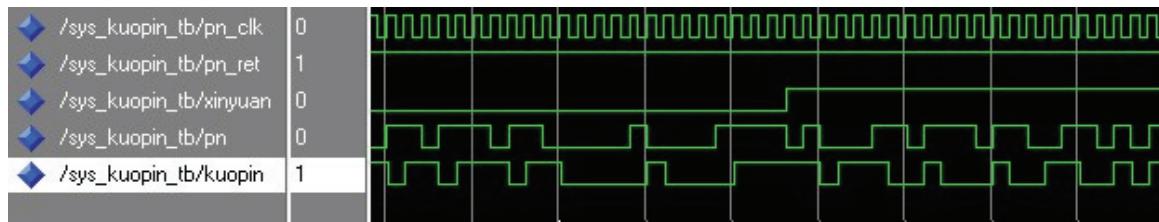
The implementation of the Verilog code modulated by direct sequence spread spectrum is relatively simple and can be completed usually using exclusive or logic. Waveform chart is as shown in Fig. 5 after Modelsim software simulation.



**Fig. 3.** Modulation schematic of spread-spectrum communication system.



**Fig. 4.** Spread-spectrum modulation signal.

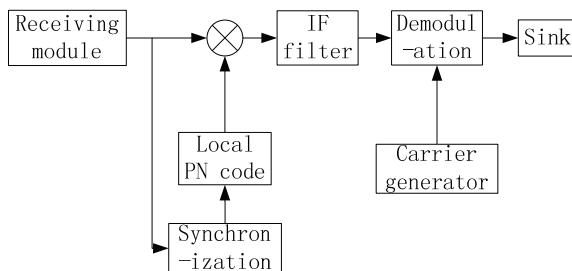


**Fig. 5.** The waveform chart of spread spectrum simulation.

### 3. Despread of Module

The despread of spreading code is multiplying the received signal and the signal of synchronous spreading code and then making the demodulation of the IF filtering and a local carrier through a filter in the DSSS system, shown in Fig. 6 [6-7].

However, the frequency and phase of spreading code of local reference is changed compared with those of the spreading code before emission due to channel interference and the delay of front level circuit, therefore, the premise of despread is finding the synchronous spreading code. The synchronization of spreading code is divided into two parts: acquisition and tracking.



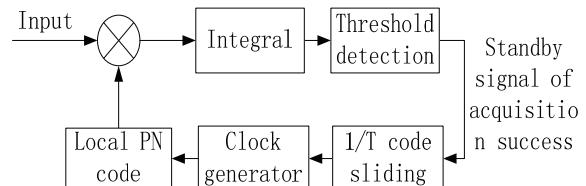
**Fig. 6.** Block diagram of despread principles.

#### 3.1. The Acquisition of Spreading Code

The acquisition of the spreading code means that receiver selects and adjusts the phase of the local reference spreading code when beginning to receive spread spectrum signal (delay) and makes its

difference with the phase of receiving spreading code smaller than the width of one code element (time delay) [8-9]. The pseudo-random sequence of spread spectrum system has good autocorrelation properties, i.e., the correlation function value is maximum when the code sequence is synchronous, otherwise, the correlation function value is very small or close to zero, which provides a basis for the synchronization acquisition of spreading code.

The capturing method of moving correlation was used in the design. Its advantages are that its structure is very simple, and it may be implemented using less hardware [10]. Since the spreading code has good autocorrelation properties, output correlation value is largest when the phases of the two code sequences slide into the substantially same position, i.e., when there is no the relative displacement between two codes, indicating that the synchronization acquisition of system has been reached. The search and acquisition are stopped and then transferred to the tracking state if synchronization acquisition has been completed. Fig. 7 shows the flow chart of capturing method of moving correlation.



**Fig. 7.** Block diagram of capturing method of moving correlation.

The received signal is fed to the integrator after the correlation processing. The integrator integrates within 0-T and outputs the integral value at time T, assuming that T is the rate of data. A signal is outputted to the pseudo-code clock generator to control the work state of clock circuit and change the phase state of the local code if this integral value is below the set threshold compared with the threshold of threshold comparator. The acquisition of the sequence phase of the received spreading code is completed when the spreading code sequence of local reference after the phase state is changed, repeating the above processing again and again until the output of integrator is bigger than the set threshold.

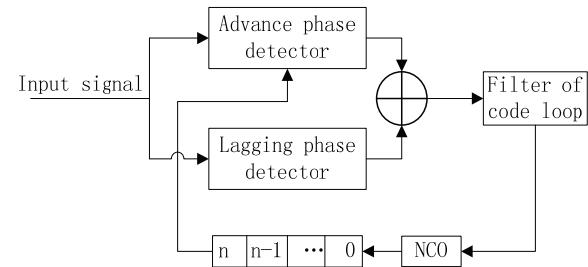
### 3.2. Tracking on Spreading Code

There is a certain difference between the clock frequency of the spreading code and its clock frequency before modulation, so the local reference signal should accurately track the received signal as soon as the spread spectrum receiver captures the received spread-spectrum signal, otherwise, synchronization will be lost [11-12]. The synchronous tracking of spreading code sequence usually uses the delay phase-locked loop. It is very difficult to complete the carrier demodulation, while it is not required to generate correlation carrier in the tracking process if this loop is used because spread-spectrum system working is usually in very low signal-to-noise environment.

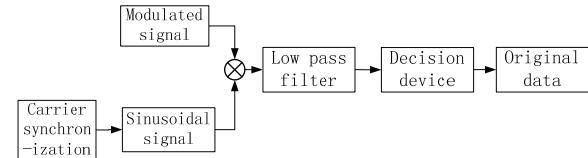
Advance correlator and lagging correlator are the key parts of phase locked tracking of spreading code delay. The peak related to the difference between advance correlator and lagging correlator appears only in the situation of synchronous tracking. The spreading code input of advance and lagging correlators is controlled through the correlation peak in order to achieve synchronous tracking. Common delay phase-locked loop consists of advance and lagging correlators, code phase detector, code loop filter, code numerical controlled oscillator (NCO) and other components [13]. The block diagram of delay phase-locked loop is as shown in Fig. 8.

### 3.3. Signal Demodulation

The BPSK signal is demodulated by coherent demodulation method in this study, and the BPSK demodulation principle is shown in Fig. 9. It is required to use and receive the coherent carrier of BPSK signal with the same frequency and phase in the process of coherent demodulation, which is the simultaneous extraction of carrier.



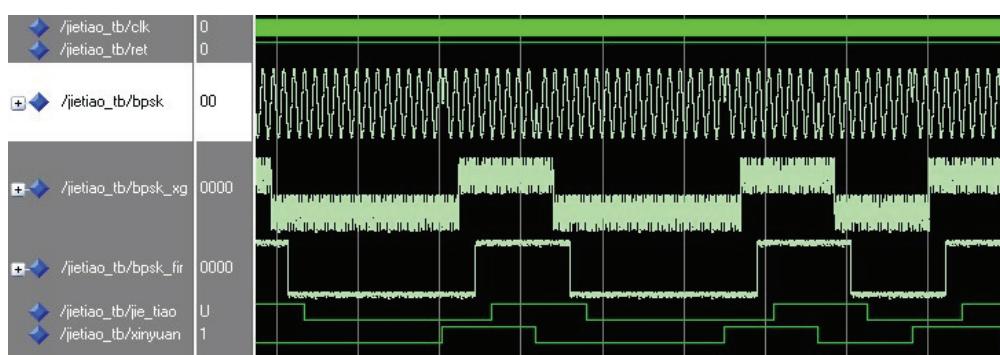
**Fig. 8.** The block diagram of phase-locked tracking loop of spreading code delay.



**Fig. 9.** The block diagram of BPSK demodulation principles.

Synchronization is the key to BPSK demodulation. The sinusoidal signal with the same frequency and phase of modulated signal is produced after the synchronization processing of carrier, then multiplied by the modulated signal and finally processed using a low pass filter. Therefore, the data whose phase shift is  $0^\circ$  multiplied by local sine equals positive value, but the data with the phase shift of  $180^\circ$  multiplied by it equals negative value. The data passes through the decision device to obtain the original data.

Fig. 10 shows demodulation simulation diagram.



**Fig. 10.** Waveform chart of signal demodulation simulation.

The system can demodulate the signal reliably. The delays of circuit line and signal transmission are caused between demodulated signal and original signal, which can meet the system requirements well.

#### 4. Conclusions

The basic principles, features and the block diagram of system constitution of direct-sequence spread-spectrum technology were introduced based on the history, research status and development prospects of the spread spectrum technology. The whole FPGA design and implementation of communication system of direct sequence spread spectrum were constructed according to the system requirements on the basis of the implementation and analysis of moving correlation algorithm.

This study focuses on the FPGA logic processing. Spread spectrum system is realized by FPGA, which is a complete hardware framework. The circuits in it are all implemented by the NAND gate, and its processing speed is faster than that of traditional DSP implementation mode by 1.5 to 2 times.

This study only analyzed and verified the system of 63-bit spreading code taking into account the complexity of the system and the easiness of its verification, description and debugging. The spreading code can be increased and redesigned in the subsequent design, for example, the spreading code is increased to 63 bit, 127 bit.

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