Construction and Simulation Analysis of a QPSK Modulation and Demodulation Model

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Abstract. Phase shift keying (PSK) modulation is an important modulation method in signal processing, and it has many advantages compared with other modulation methods. QPSK transmits 2 bits per symbol which means the higher spectral efficiency. QPSK is also good trade-off between complexity and performance. In order to better understand the modulation mode of QPSK, this paper establishes a basic QPSK modulation and demodulation model. With the help of MATLAB simulation software, waveform diagram, spectrum diagram, power spectrum diagram, eye diagram and other graphics are used to visualize the changes of signals in each process of QPSK system. And the simulation results are consistent with the theory, which verifies the validity of the model and compare the advantages of QPSK modulation versus other modulation methods. QPSK modulation has wide applicability and can be applied to a variety of information transmission environments, such as cellular network, Wi-Fi, satellite communication and OFDM-based systems. QPSK is very useful for later research on more complex modulation methods.

Keywords: Frequency shift keying, Bit error rate, Signal to noise ratio, visualization, QPSK.

1. Introduction

1.1. Research Background

The transmission modes of digital signals are divided into baseband transmission and band pass transmission. In the process of actual signal transmission, most of the channels have band pass characteristics but cannot directly transmit baseband signals, since digital baseband signals often have rich low-frequency signals. In order to transmit the digital signal normally in the band communication channel, the baseband signal must be carrier to match the channel characteristics [1, 2, 3, 4]. Generally speaking, keying method is the basic method of digital modulation, The most common keying methods are amplitude keying (ASK), Frequency shift keying (FSK) and PSK, Where PSK modulation is more commonly used due to its simple implementation method, BPSK often suffers from inadequate utilization of scarce spectrum resources, Multi-feed frequency shift keying emerged, The QPSK, as the simplest multi-feed frequency-shift keying mode, To understand the use of multi-input frequency shift keying [5]. Therefore, this paper is based on the MATLAB simulation software. This paper established the simulation of the QPSK modulation demodulation system, and analyzed the results of the research experiments. Through the comparative analysis of the waveform, frequency spectrum and constellation diagram in the process of modulation and demodulation, so as to better understand and master the theoretical knowledge of QPSK signal modulation and demodulation system, which also has a certain reference value for practical engineering applications [6].

1.2. Literature Review

The QPSK modulation and demodulation should include how to generate data bit, the Modulator, Pulse Shaping Filter, Matched Filter and Demodulator. Data that be transmitted can be divided into analog signal and digital signal. Analog signal is continuous, such as our voice, sound, temperature, humidity, pressure. These signals can’t change in a certain time point, so they are analog signal. Digital signal is discrete whichever for the time and the amplitude. Analog signal has many short in the data transmitting, like they can’t be encrypted which means they would be transmitted as the same as the original signal. For example, radio station sends the signal by analog signal. It travels through the air as electromagnetic waves. So, anyone can get the information if they set a receiver to accept the signal. That's why it is poor confidentiality. Another disadvantage is that it is easily interfered. The frequency variation of FSK signal makes it more robust to noise and interference. Especially in the context of additive white Gaussian noise (AWGN), FSK is less susceptible to amplitude noise than amplitude modulation (such as ASK). FSK modulation and demodulation circuit is relatively simple, especially suitable for hardware implementation. For example, the demodulation of FSK can be achieved relatively easily with phase-locked loops (PLL), filters, or frequency discriminators. FSK transmits by changing the frequency of the carrier, and the amplitude of the signal does not change. Therefore, it is not sensitive to nonlinear channels (such as amplifier distortion in wireless communication), and its performance is relatively stable. In wireless communication, FSK can cope with multipath effect and signal fading well. This is because frequency-modulated signal features exhibit strong detectability in fading channels. And it also plays an important role in practical application.

1.3. Research objectives and significance

The goal of this paper is to visualize the process of QPSK modulation and demodulation system through MATLAB. The advantages of QPSK modulation and other modulation methods are also analyzed. The significance of this paper is that each step of the modulation system is simulated by MATLAB graphics, and do a detailed analysis.

2. QPSK modulation and demodulation system model

In the modern communications, generally speaking, signals need to be transmitted over long distances. Digital signal is less easily influenced by noise compared to the analog signal. So, digital signal is more suitable for the long transmission. Because the length of the antenna is inversely proportional to the frequency. In order to achieve the operability of signal transmission, original signal need a high frequency signal to carry itself. This is the process of modulation. After the modulation we need to upsample the signal. By inserting extra sampling point to improve the sampling frequency of the signal. It should be noted that the signal needs to discard part of the sampling point so that the working efficiency would be improved when demodulating the signal. Between the Pulse Shaping Filter and the Matched Filter, channels and noise can be added into the signal. After the all procedure, the received signal will be evaluated used by the curve of the bit error rate. The whole process is shown in figure 1.

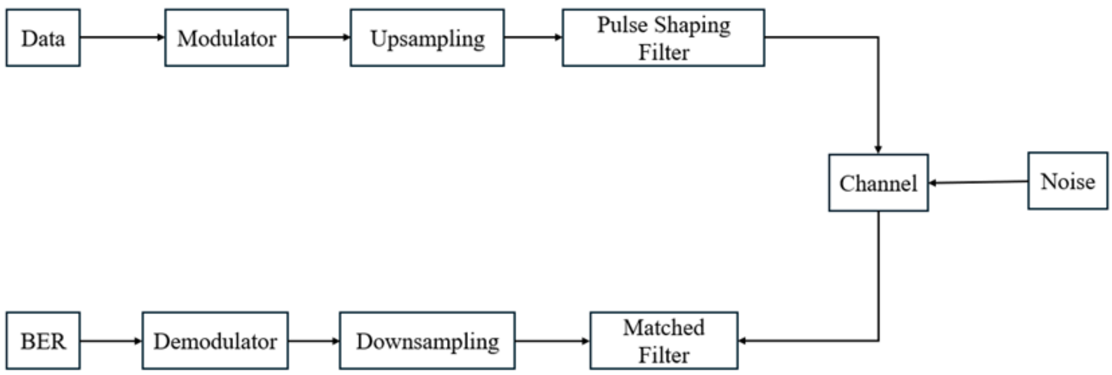

Figure 1. QPSK System Diagram

There are two curves of BER needed to get. One is simulation bit error rate, another is theoretical BER. These two curves need to be closer, for in the paper the channel used is AWGN channel. It is an idealized channel model, so it should be close to the theoretical result. The theoretical BER:

$$P_e(\Gamma) = \int_0^{\infty} p(x)Q(x)dx = \frac{1}{2}\left(1 - \sqrt{\frac{\Gamma}{1+\Gamma}}\right) \quad (1)$$

Where Γ is the average signal to noise ratio (SNR) given as:

$$\boldsymbol{\Gamma = \frac{E_b}{N_0} 2\sigma_h^2} \tag{2}$$

E_b is the bit energy, σ_h^2 is the channel variance. N_0 and σ_ω^2 are the noise energy density and noise variance. The relationship between them is N_0=2σ_ω^2. For the visualization of ever process, many figures are used in this paper. BER is just one metric. There are five kinds of figure. The signal waveform, the signal frequency spectrum, the signal power spectrum, the eye diagram, the constellation. They can present some information about the signal, such as frequency, power and the ability to counter noise. Some types of figures need to be explained. An eye diagram is a powerful visualization tool used in digital communication systems to evaluate signal integrity and system performance [7]. It provides a snapshot of the signal quality, timing, and potential sources of errors by visually overlaying multiple cycles of a digital signal [7]. Eye diagram will be generated when multiple signal waveforms are overlaid on a single time axis. The result of the plot resembles the shape of an eye. It can reflect the information of the signal, such as noise, distortion, jitter, and inter-symbol interference (ISI). In digital communication, a constellation diagram is a graphical representation of a signal modulated by a digital modulation scheme such as PSK, QAM, or ASK [8]. It shows the possible symbols (signal states) in a complex plane, where the x-axis represents the in-phase component (I) and the y-axis represents the quadrature component (Q) [8]. The constellation diagram visualizes the symbols used in a modulation scheme as points in a 2D space. Each point corresponds to a unique combination of amplitude and phase. It provides insight into the modulation technique and helps evaluate signal quality, noise, and distortions in a communication system.

3. Results and Discussion

In this experiment, the original signal should be processed according to the flow of QPSK system diagram. In the process of analysis obtained a variety of results of the graph. Finally, the bit error rate curve is analyzed.

Signals are generated, 0 or 1 are the same probability. The signal consists of discrete zeros or ones. As shown in figure 2.

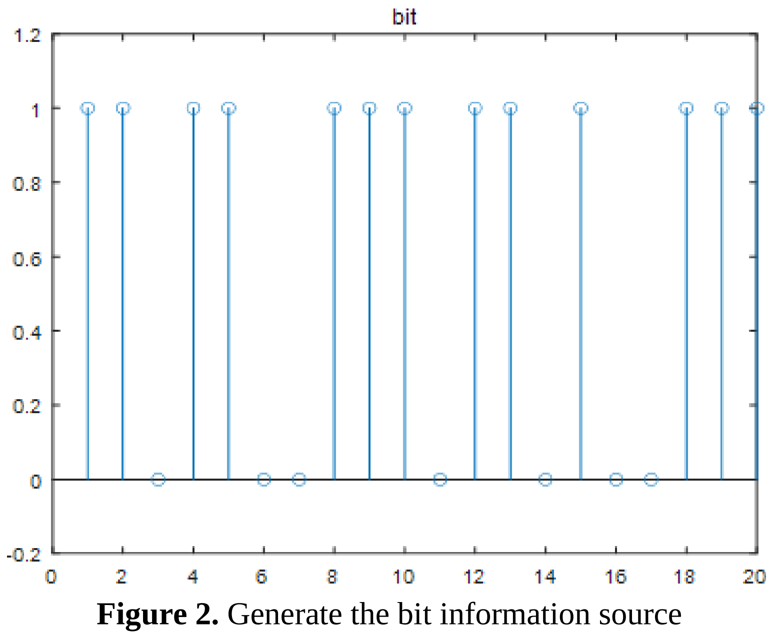

Figure 2. Generate the bit information source

When signals pass the modulator, they will be modulated. The discrete digital signal is modulated onto a high-frequency carrier. The graph also changed from discrete to continuous. It can be observed from the figure3 that the modulated signal waveform is similar to the waveform of the sine function [9]. This is because the carrier function is a high frequency sine wave signal, and because the QPSK modulation mode only changes the phase of the carrier signal, the result is similar to the form of the sine wave function. Besides, the signal waveform is unsmooth, because the up sampling is set to 4. If insert more up-sampling point, the curve will be smoother. The more up sampling points are insert into the waveform, the smoother the curve is. Signal spectrum and signal power spectrum are all the representation of a signal in the frequency domain which is different from time domain [10]. In the frequency domain, the value of the function at each point represents the projection of the cross-section of a waveform. As shown in figure 3, the signals' center frequency is 200mHz. If the simulations after are not wrong, this frequency shouldn't change.

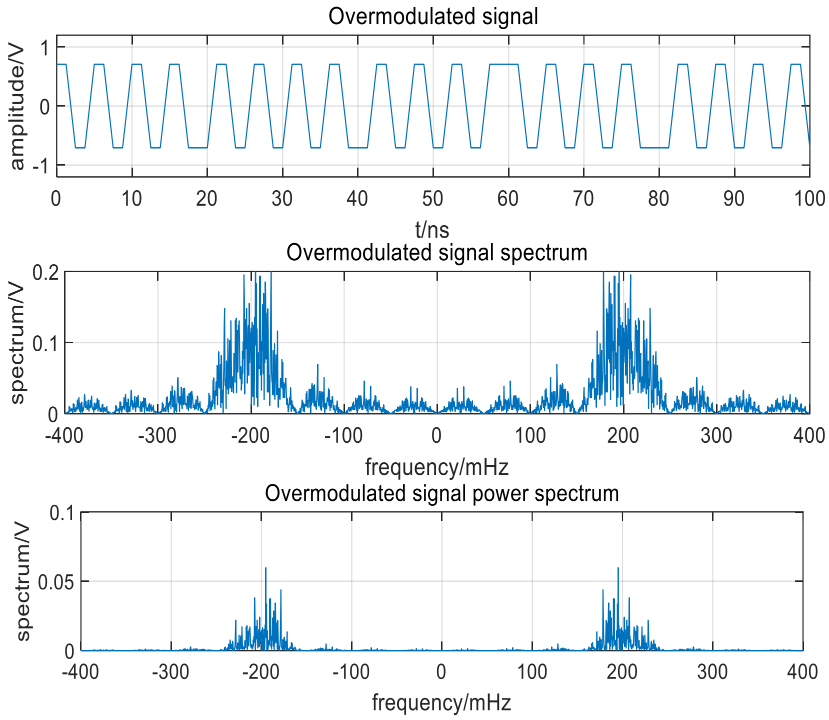

Figure 3. Three kinds of figures after the modulator

As shown in figure 4, the waveform become smoother after the Pulse Shaping Filter, and the center frequency is still 200mHz.

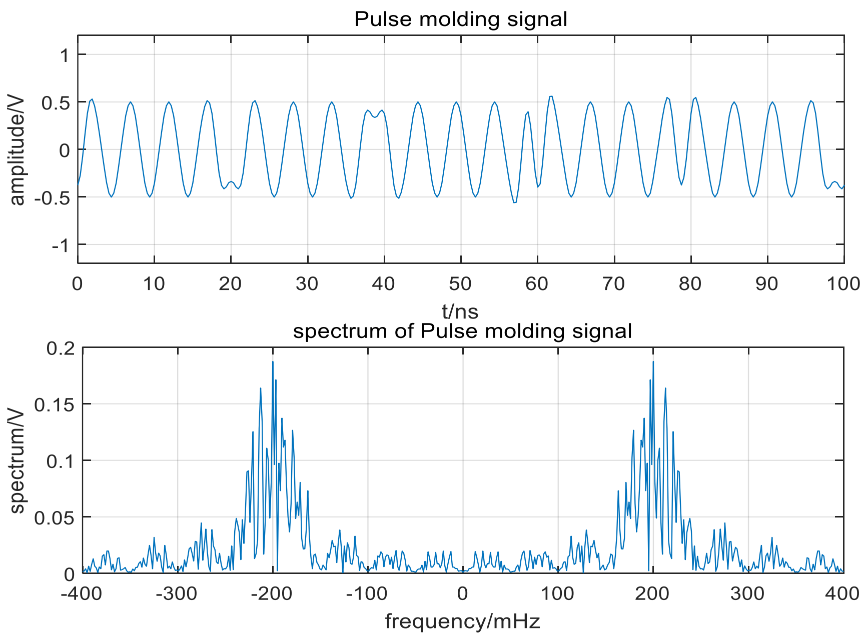

Figure 4. Two kinds of figures after the Pulse Shaping Filter

As shown in figure 5. Compared with the eye diagram before adding noise, the performance of the eye diagram with noise is even worse. Eye diagram is not a single waveform curve, but a phenomenon formed after multiple waves are stacked together. It will mainly appear on the differential signal (such as USB, CAN and other differential signals), it is available to use the dual-channel oscilloscope for observation. It contains a rich amount of information, such as the crosstalk and noise of the signal. So, it is often used to judge the degree of advantages and shortcomings of the system with high-speed signals [11]. There are some definitions needed to explain. Risetime is the time taken for the pulse signal to travel from the low point to the most recent high point, which is generally defined as 10% and 90% of the peak amplitude. Falltime is the opposite of rising time, from high to low, other analogies. Overshoot generally manifested as a tip pulse. It is the rise of the first peak or valley value beyond the set voltage. It is likely to cause the failure of circuit components. Threshold or Crossing Percent is the lowest receiving level that the receiver can reach when the transmission characteristics of the system are lower than a certain bit error rate (error in transmission/total number of transmitted codes). It can also be understood that if it exceeds this level, it will be converted to another state.

Judging the quality of the eye diagram is actually very direct, directly look at the "eye" molding is not obvious. Whether the eye diagram’s eye height is not high enough or the line is both obvious and the eye height is high or not. The signal quality is better when all the factors is good enough. The principle is that the eye diagram contains a large number of signal superposition. The signal can’t be the same waveform every time under the high and low voltage. By a large number of times running, the signal line of the eye diagram gradually superposition thicker. Finally, the vertical axis of the eye diagram represents the voltage noise, and the horizontal axis represents the time domain Jitte. When there is a lot of noise, the trace of the eye map will be blurred and the signal quality will be poor.

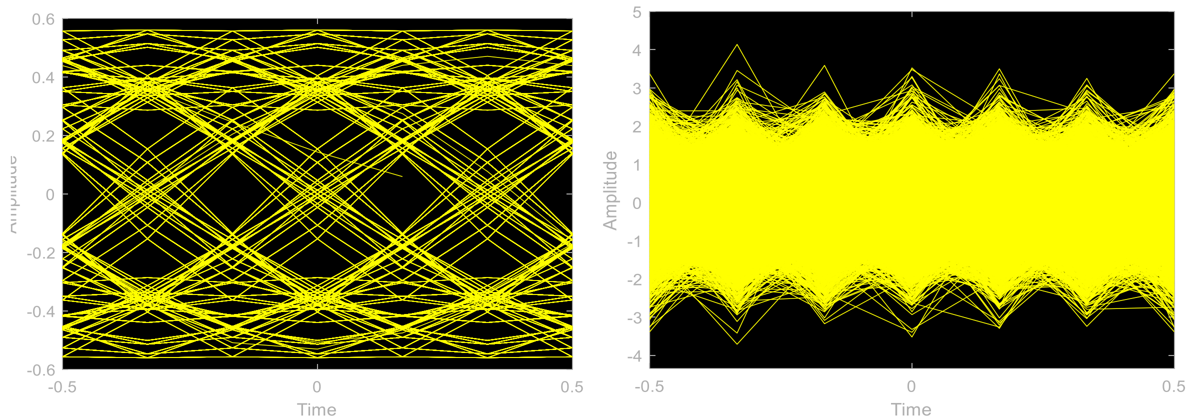

Figure 5. Eye diagram before adding noise and after adding noise

Signal-to-noise ratio is defined as the ratio of signal strength to noise strength, and the bigger the ratio, the stronger the anti-interference ability of the signal. BER means the probability of data transmission errors. Over, when the signal to noise ratio is becoming bigger, the probability of data transmission errors getting lower and lower. The different between simulation bit error rate and theoretical bit error rate is that the simulation BER is obtained by simulating the actual transmission of bits through a modeled communication system. It assumes perfect knowledge of the system parameters and typically does not include real-world imperfections such as hardware limitations or additional noise sources. The simulation BER is obtained by simulating the actual transmission of bits through a modeled communication system [12]. It accounts for practical considerations, such as signal distortion, channel effects, and implementation imperfections. As shown in figure 6, these two curves are almost coincident, so the experiment is right to some extent.

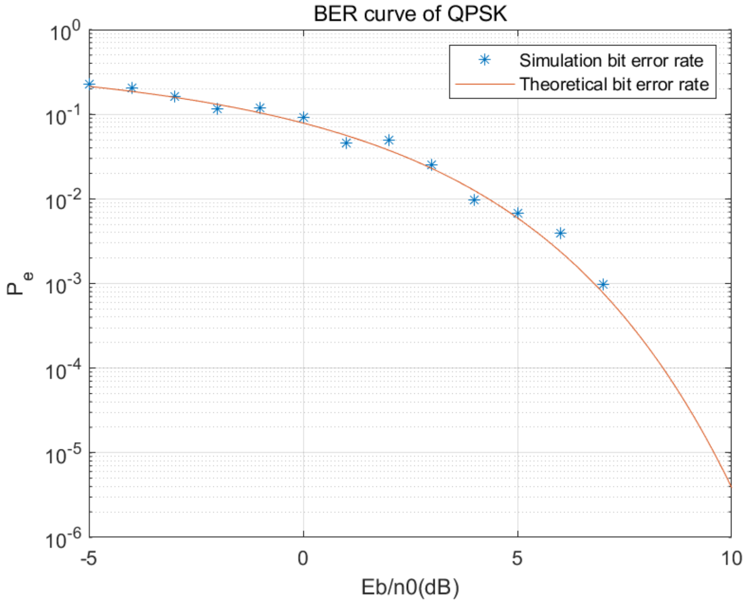

Figure 6. BER curve and theoretical curve

As shown in figure 7, the comparison of QPSK modulation and other modulation methods. Although BPSK encoding method and QPSK, 8PSK, 16PSK these three encoding methods, the signal transmission accuracy is greatly improved. However, it should be noted that BPSK can only carry 1 bit of information per symbol, so the transmission efficiency of the signal will drop very much. 4PSK carries 2 bits of information per symbol, 8PSK carries 3 bits of information per symbol, and 16PSK carries 4 bits of information per symbol [13]. With the increase of the number of bits carried by each symbol, that is, with the increase of information transmission efficiency, the accuracy of information transmission will also be greatly reduced. Therefore, QPSK is a compromise modulation scheme, which can not only meet the transmission efficiency of information, but also ensure the accuracy of information transmission process. This is the advantage of QPSK modulation.

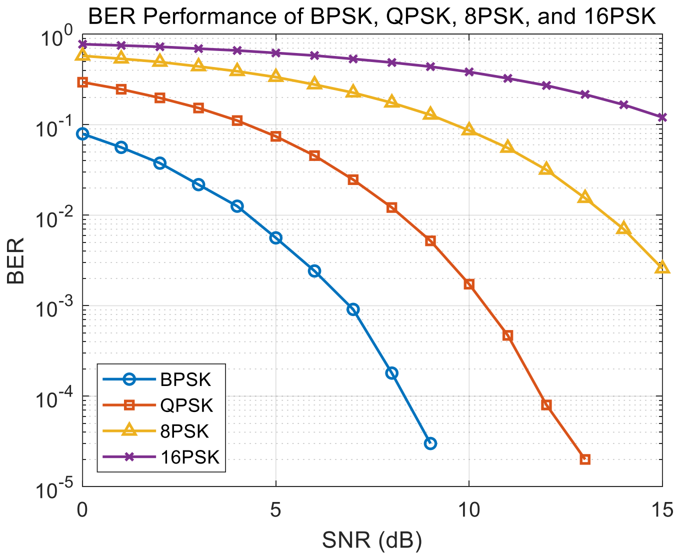

Figure 7. Comparison of QPSK modulation and other modulation methods

4. Limitations and Future Outlooks

Besides the ways of modulation and demodulation, there are many other factors can influence the performance of the system, for example, in the process of signal propagation, multi-path signals will be formed due to reflection, refraction, diffraction, etc., which may lead to mutual interference. That will lead to fading, such as Rayleigh fading and Rician fading. One another factors are the Adjacent

Channel Interference (ACI) is a phenomenon in communication systems where signals from neighboring channels "leak" or "spill over," causing interference. It usually occurs in systems with tight spectrum resources, such as cellular networks, Wi-Fi, and broadcast communication systems. Co-channel interference refers to the phenomenon that when multiple signals are transmitted with the same frequency (co-channel) in a communication system, the communication quality deteriorates due to the mutual interference between the signals. Such interference is common in cellular communications, satellite communications and wireless networks, and is a key problem that must be faced in frequency multiplexing systems. To enhance overall system performance, various coding techniques can be applied in the experiment, including Hamming codes, Bose–Chaudhuri–Hocquenghem (BCH) codes, and Reed-Solomon codes. All these codes can improve the accuracy of signal transmission. In QPSK system, synchronization is very important, including carrier synchronization, symbol synchronization and frame synchronization. Carrier synchronization is used to ensure that the receiver can accurately recover the frequency and phase of the carrier, so as to demodulate the signal correctly. Symbol synchronization is used to ensure that the receiver can sample the signal correctly in each symbol period. Frame synchronization is used to identify the start and end of a data frame so that the data can be properly parsed.

5. Conclusion

On the basis of mastering the 4PSK modulation and demodulation, MATLAB is used to model and simulate the 4PSK modulation and demodulation system. Through the data and pictures, the changes of waveform diagram, spectrum diagram, power spectrum diagram, eye diagram can be clearly and intuitively observed, which has a positive effect on the deeper understanding of the 4PSK modulation and demodulation. The simulation results are in agreement with the theoretical results, which means the correctness of 4PSK modulation and demodulation system. Further discussion is needed to improve the QPSK model, such as adding coding methods. The paper also compares the performance of 4PSK, BPSK, 8PSK, and 16PSK under the same conditions. The conclusion of which modulation method is better under different conditions is obtained. In the process of obtaining the curve of 4PSK theoretical bit error rate and actual bit error rate, waveform diagram, spectrum diagram, power spectrum diagram, eye diagram analyzed the influence of the original signal through a series of processing, such as Modulator, Up sampling, waveform diagram, spectrum diagram, and eye diagram. Pulse Shaping Filter, Matched Filter, Down sampling, Demodulator, and subsequent changes. Analyze the signal's center frequency, shape, and anti-noise performance.

This paper designs and implements the modeling and simulation analysis of QPSK modulation and demodulation system. The QPSK modulator and demodulator modules are built through the simulation platform (MATLAB), and the key performance indicators of the system are deeply analyzed and verified. First is the construction and verification of the model. By designing the system block diagram of QPSK modulator and demodulator, the process of modulation and demodulation of input binary data stream is realized successfully. The simulation results show that the model can effectively transmit and restore QPSK signals both in theory and in practice, and the system works stably and the results are accurate. Second is the system performance analysis. The BER performance of QPSK system is evaluated in simulation. Simulation results show that QPSK modulation has good anti-noise performance in AWGN channel. Consistent with the theoretical analysis results, the higher SNR is, the bit error rate of the system decreases significantly.

The last is the simulation results are consistent with the theory. This paper further verifies the characteristics of QPSK modulation with high bandwidth utilization and low bit error rate, especially in the condition of medium and low signal-to-noise ratio, its performance is better than that of traditional two-phase modulation (such as BPSK).

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