Simulation and Performance Study of Quadrature Amplitude Modulation and Demodulation System

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Abstract. Both traditional frequency modulation and phase modulation digital modulation methods have low spectral utilization, poor multipath fading resistance, slow power spectrum attenuation, and severe out-of-band radiation. Quadrature Amplitude Modulation (QAM) is a digital modulation technique that combines phase and amplitude control. It not only achieves higher spectral efficiency, but also transmits higher rate data in a defined frequency band. In this paper, the basic principle, system structure and performance parameters of QAM modulation and demodulation are studied in depth to realize simulink simulation and performance analysis of QAM modulation and demodulation system. The basic theory and implementation method of analog signal digitization are analyzed in detail to realize simulink of differential pulse code modulation. Based on the above theory, the analog source QAM transmission system is constructed, and simulink is used for modeling and simulation and performance verification. The simulation results show that the constructed QAM digital transmission system can achieve good transmission of analog signals.

1. Introduction

As the variety of satellite payloads increases and the resolution continues to increase, the amount of information that needs to be transmitted is growing. In order to efficiently transmit a large amount of data in a limited bandwidth channel, various modulation methods have been developed to solve the contradiction between limited bandwidth and large amount of data transmission. For example, multi-digit digital modulation, joint modulation, mesh modulation, and the like can be employed. The amplitude and phase combined modulation method, that is, the QAM (Quadrature Amplitude Modulation) modulation method combines the advantages of ASK (Amplitude Shift Keying) and PSK (Phase Shift Keying), and improves the frequency band utilization by using a multi-ary modulation method (increasing information). Transmission rate), so it is superior to the modulation method of a single modulation sine wave in terms of frequency band utilization and receiver error decoding rate, but its equipment complexity is relatively high [1-3].

Quadrature amplitude modulation QAM is a digital modulation technique that combines phase and amplitude control. It has a wide range of applications, not only in the field of mobile communications but also in cable TV transmission, digital video broadcasting, satellite communications and other fields.
QAM plays an important role in today's communications field, so it is of great theoretical and practical significance to conduct an in-depth study of QAM.

2. QAM Modulation

2.1. QAM Modulation Principle
Quadrature amplitude modulation (QAM) is the use of two mutually independent digital baseband signals for double-band modulation of two mutually orthogonal and identical frequency carrier signals. Since the modulated signals are orthogonal in the same bandwidth, they are available. To achieve two-phase parallel digital signal transmission in phase and quadrature.

The general expression of the quadrature amplitude modulation (QAM) signal is [3]:

\[ S_{\text{MQAM}}(t) = \sum_n A_n g(t - nT_S) \cos(\omega_c t + \theta_n) \]

In the formula, \( A_n \) is the amplitude of the baseband signal, \( g(t - nT_S) \) is the waveform of a single baseband signal, the width is \( T_S \). At the same time, the above formula can also be changed to an orthogonal representation:

\[ S_{\text{MQAM}}(t) = \left[ \sum_n A_n g(t - nT_S) \cos\theta_n \right] \cos\omega_c t - \left[ \sum_n A_n g(t - nT_S) \sin\theta_n \right] \sin\omega_c t \]

Make:

\[ \begin{cases} X_n = c_n A \hfill \\
Y_n = d_n A \hfill 
\end{cases} \]

Then:

\[ S_{\text{MQAM}}(t) = X(t) \cos\omega_c t - Y(t) \sin\omega_c t \]

Amplitude in QAM \( Y_n \) can be expressed as:

\[ \begin{cases} X_n = c_n A \\
Y_n = d_n A \hfill 
\end{cases} \]

Where the fixed amplitude is \( A \), \( c_n \), \( d_n \) finally determined by the input signal. The coordinate point of the QAM signal in the signal space is adjusted by \( c_n \), \( d_n \).

2.2. QAM Constellation Diagram
The constellation mapping rules are different, and the constellations present different distribution forms. The 16QAM constellation has a star constellation and a square constellation, respectively. The star constellation is shown on the left side of Figure 1, where the distribution of signal points is star-shaped. Similarly, the distribution of signal points in the square constellation diagram is square, as shown on the right side of Figure 1.
QAM modulation has several important parameters: peak-to-average ratio $\gamma$, minimum Euclidean distance between constellations $d_{\text{min}}$, and minimum phase offset $\theta_{\text{min}}$. Different digital transmission systems have different requirements for these parameters [10].

1. Peak-average value $\gamma$ of QAM signal:

$$\gamma = \frac{P_{\text{peak}}}{P_{\text{ave}}}$$

Among them, $P_{\text{peak}}$ indicates the peak power of the signal, $P_{\text{ave}}$ indicates the average power of the signal.

2. Minimum Euclidean distance $d_{\text{min}}$:

Minimum Euclidean distance $d_{\text{min}}$ refers to the minimum distance between constellation points on the QAM signal constellation. This parameter measures the ability of the QAM signal to resist Gaussian noise, the minimum distance. $d_{\text{min}}$ is directly proportional to the performance of anti-Gaussian white noise.

3. Minimum phase shift $\theta_{\text{min}}$:

Minimum phase shift $\theta_{\text{min}}$ is the minimum offset of the phase between the signal points on the standard QAM constellation. This parameter reflects the anti-phase jitter capability of the QAM signal and its sensitivity to clock recovery accuracy. The minimum phase offset $\theta_{\text{min}}$ is the larger the resistance, the stronger the anti-phase jitter capability.

A QAM signal with good performance, its constellation diagram must meet three requirements:

a) The signal peak-to-average ratio is small to ensure that the envelope of the modulated signal is less undulating, thereby enhancing its ability to resist nonlinear distortion.

b) The minimum Euclidean distance between signal points should be as large as possible to ensure the best anti-additive white Gaussian noise performance.

c) The minimum phase offset between constellation points should be as large as possible to enhance the anti-phase jitter performance of the modulated signal, including clock jitter and anti-channel phase jitter performance against timing recovery.

3. QAM System Simulink Simulation

3.1. Simulink Simulation of 16QAM System

The Simulink module library provides the modulator Rectangular QAM Modulator Baseband module, demodulator Rectangular QAM Demodulator Baseband module, bit error rate statistics module,
constellation diagram module, etc., using these modules to construct 16QAM modulation and demodulation system [7], the test model is shown in the Figure 2.

**Figure 2.** 16 QAM modulation and demodulation system test model

Let the transmission symbol rate be 1000 baud, then the symbol time slot width is 1ms. The random integer outputted by the source is sent to the 16QAM baseband modulator, and the modulated output is sent to the corresponding 16QAM baseband demodulator of the receiving end through the Gaussian channel, and the parameter settings of the modulator and the demodulator must be the same. The demodulated symbols (integer) are compared with the sender data to obtain an error symbol rate statistics. When the Gaussian noise variance added to the channel is 0.02, the constellation simulation results of the transmitted and received signals are shown in FIG.

**Figure 3.** 16 QAM modulation and demodulation system constellation diagram

The performance verification of the communication system is through the constellation, eye diagram and bit error rate test tools. It can be intuitive by comparing the constellation and eye diagrams of the sender and receiver, or by the results displayed by the error rate statistics module. Determining the performance of the communication system. Figure 3 shows the constellation diagram of the transmitter and receiver of the system. Here, the roll-off coefficient of the baseband shaping filter is 0, that is, the ideal low-pass characteristic is satisfied, so the constellation diagram of the transmitting end is
completely consistent with the ideal constellation map. Due to the presence of noise on the transmission channel, the constellation at the receiving end has a certain deviation from the ideal constellation point. The size of the deviation can be used to visually judge the performance of the system. Although the eye diagram of the receiving end is larger than the ideal deviation, there is no overlap, so the original waveform can be recovered well by appropriate threshold detection.

Figure 4. 16QAM modulation and demodulation system eye diagram

Figure 4 is an eye diagram of the transmitting end and the receiving end of the 16qam modem system. It is observed that the maximum eye pattern is turned on at the sampling time. Also, due to the noise interference on the transmission channel, the size of the "eye" opening in the eye of the receiving end is much smaller than that of the transmitting end, and its size reflects the excellent performance of the baseband forming. The strength of the inferior, intersymbol interference and the influence of the transmission channel noise.

When the channel noise variance is 0.05, 10s data is transmitted. Through the error rate calculation module error rate calculation and the data display module, the number of error symbols can be observed as 27, and the corresponding error rate is 0.0027.

3.2. Simulink Simulation of 64QAM System
The Simulink module library provides the Rectangular QAM Modulator Baseband module, the demodulator Rectangular QAM Demodulator Baseband module, the bit error rate statistics module, and the constellation diagram module. These modules are used to construct the 64QAM modem system [7]. The test model is shown in Figure 5.

Figure 5. 64 QAM modulation and demodulation system test model
Let the transmission symbol rate be 1000 baud, then the symbol time slot width is 1ms. The random integer outputted by the source is sent to the 64QAM baseband modulator, and the modulated output is sent to the corresponding 64QAM baseband demodulator through the Gaussian channel. The parameters of the modulator and the demodulator must be the same. The demodulated symbols are compared with the sender data to obtain an error symbol rate statistics. When the Gaussian noise variance added to the channel is 0.02, the constellation simulation results of the transmitted and received signals are as shown in Figure 6.

![Figure 6. Constellation diagram of 64 QAM modulation and demodulation system](image)

Figure 6 shows the constellation diagram of the transmitter and receiver of the system. Similarly, the constellation diagram at the transmitting end is identical to the ideal constellation map. Due to the presence of noise on the transmission channel, the constellation at the receiving end has a certain deviation from the ideal constellation point. The size of the deviation can be used to visually judge the performance of the system.

When the channel noise variance is 0.05, 10s data is transmitted. Through the error rate calculation module error rate calculation and the data display module Display display, it can be observed that the number of 64QAM modulation and demodulation system error symbols is 29, and the corresponding error symbol rate is 0.0029. The number of error symbols in the 16QAM modem system is 27, and the corresponding error symbol rate is 0.0027.

Further simulation, under the condition that the channel noise variance is 0.05 when transmitting 10s data, the error rate of the M-QAM modulation and demodulation system is shown in Table 1. It can be seen from Table 1 that the larger the M, the higher the system error symbol rate.

| M-QAM    | 16QAM | 64QAM | 256QAM | 1024QAM | 2056QAM |
|----------|-------|-------|--------|---------|---------|
| Wrong symbol rate | 0.0027 | 0.0029 | 0.0031 | 0.0035 | 0.0037 |

3.3. Application Example Simulation
In modern digital communication, the most closely related to people's lives is the transmission of sound signals and image signals. Here we use the voice signal as an example to verify the performance of this transmission system. The audio input and output module of the DSP module library in Simulink can process the real audio signal, and construct a QAM digital transmission test model of the speech signal based on the DPCM codec module and the QAM modem module, as shown in Figure 7.
Figure 7. QAM transmission model when the original signal is a sound signal

At the transmitting end, an audio signal is first subjected to PCM encoding to complete analog-to-digital conversion, then QAM digital modulation is performed, and then transmitted via channel transmission. The simulation time is required to be 20s and the step is 1/32000s. The Gain module is used to adjust the amplitude of the input sound signal. At the receiving end, the received modulated signal is first demodulated, and then DPCM decoding is performed to complete digital-to-analog conversion.

When the AWGN channel noise variance is reset to 0.01, 0.001 or less, respectively, the simulation can be started, and the DCPM decoded speech signal transmitted at a specific bit error rate can be heard. Despite the obvious "giggle" decoding noise, the speech is basically understandable. At the same time, the original input signal of the transmitting end and the signal recovered by the receiving end are observed by an oscilloscope, as shown in Figure 8.

Figure 8. Oscilloscope output waveform

It can be seen from the above verification that in this simulation, whether the speaker is used to listen to the voice signal or the oscilloscope observes the recovered speech signal at the receiving end, the results of the two methods indicate that the channel is constructed under certain channel errors. The QAM transmission system can achieve the correct transmission of voice signals.

4. Conclusion
The QAM modulation technique is widely used not only for obtaining higher spectral efficiency but also for transmitting higher rate data in a limited frequency band. Especially in the mobile communication and satellite communication where bandwidth resources are not very rich, the superiority of the modulation technology is more apparent. Based on the basic research of QAM modulation and demodulation and the theory of digital transmission of analog signals, this paper constructs a QAM digital transmission system with analog source, and realizes system establishment and performance
verification through Simulink simulation platform. The simulation results show that the analog signal can be transmitted well in this system while allowing certain distortion.

References
[1] Wang Fuchang. Principles of Communication [M]. Beijing: Tsinghua University Press, 2006
[2] Liu Lianqing. Digital Communication Technology [M]. Beijing: Mechanical Industry Press, 2006
[3] Fan Changxin Cao Lina. Principles of Communication [M]. Beijing: National Defense Industry Press, 2006
[4] Li Li. Research on high-speed 16qam transmission technology [D]. Xi'an University of Electronic Science and Technology. 2010
[5] Wei Tao. Analysis of qam modulation and its application. Communication and Radio and Television [J]. 2002 (1)
[6] Han Lizhu Wang Hua. Matlab Electronic Simulation and Application [M]. Beijing: National Defense Industry Press, 2003
[7] Shao Yubin. Modeling and Simulation of Matlab/Simulink Communication System [M]. Beijing: Tsinghua University Press, 2008
[8] Deng Hua. Matlab communication simulation and application examples explain [M]. Beijing: People's Posts and Telecommunications Press, 2003
[9] Li Hebing. Simulink Communication Simulation Course [M]. Beijing: National Defense Industry Press, 2006
[10] Yu Fengyun Zhang Ping. All-digital implementation of QAM modulation and demodulation [J] Modern Electronic Technology, 2005 (3)