ICE6302 — Project II

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1 Digital modulation schemes

In this section, we discuss the main features and implementation of PAM, PSK, QAM and FSK digital modulation schemes. The experiments take M=16 to draw the time-domain and spectrum of the transmitted signals. The performances of the optimum receivers are compared by analyzing the BER_SNR curves of those modulation schemes.

1.1 Pulse Amplitude Modulation(PAM)

Pulse amplitude modulation(PAM) is one of the memory-less modulation methods in digital communication system.In this scheme, the base-band waveform is grouped by a set of narrow pulse signals which differ in amplitude. The siganl waveform can be presented as:

$$\begin{aligned} s_m(t) &= Re[A_m g(t) e^{j2\pi f_c t}] \\ &= A_m g(t) cos 2\pi f_c t, \quad m = 1, 2, ..., M, 0 \leq t \leq T \end{aligned}$$

A_m denotes the set of M possible amplitudes corresponding to $M = 2^k$ possible k-bit symbols, which can be expressed as

$$A_m = (2m - 1 - M)d, \quad m = 1, 2, ..., M$$

If we define ϵ_g as the energy in the pulse g(t), the general form of amplitude in one dimension is

$$s_m = A_m \sqrt{\frac{\epsilon_g}{2}}, \quad m = 1, 2, ..., M$$

To illustrate the modulation scheme, we give the examples where M take 2, 4 and 8 in Figure 1

Hence, the distance between a pair of adjacent signal points is

$$d_{min}^{(e)} = d\sqrt{2\epsilon_g}$$

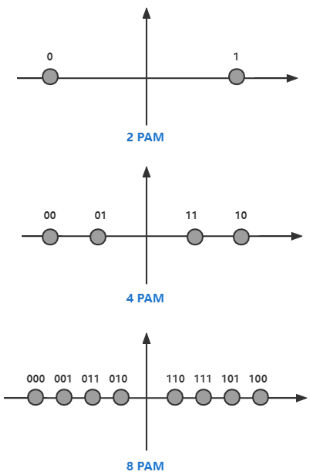
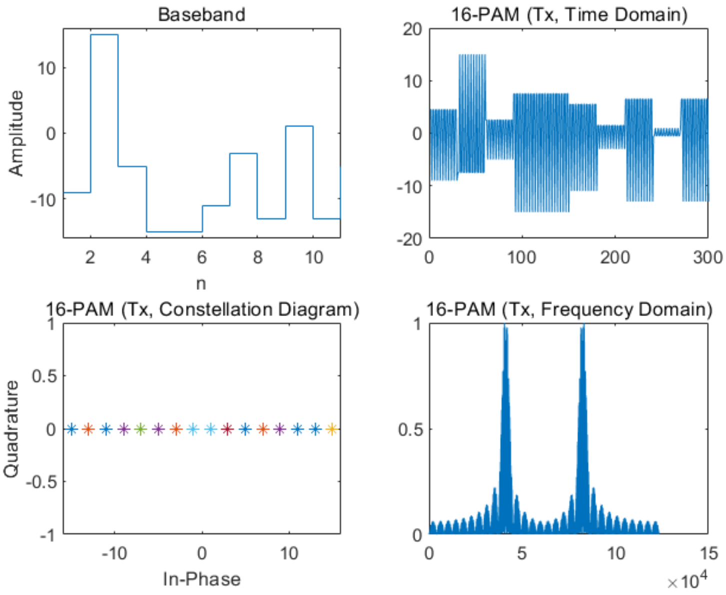
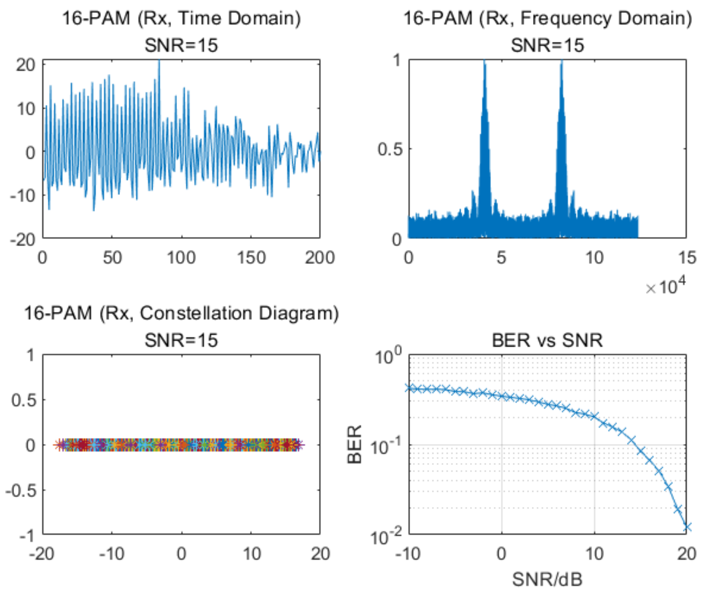


Figure 1: PAM Signal Constellation

Take $M = 16$ as an example, figure 2 shows the 16 PAM signal transmitting over an AWGN channel under the $SNR = 15dB$ condition, both in time domain, frequency domain and in signal space. The Bit Error Rate curve with increasing SNR is also depicted in these pictures.



(a) PAM Transmission Signal



(b) PAM Receive Signal

Figure 2: 16 PAM Signal

1.2 Phase Shift Keying(PSK)

Phase shift keying (PSK) uses discrete phases to distinguish digital signals with a constant amplitude. The PSK signal can be denoted as

$$\begin{aligned} s_m(t) &= Re[g(t)e^{j2\pi(m-1)t/M}e^{j2\pi f_c t}], \quad m = 1, 2, ..., M, 0 \leq t \leq T \\ &= g(t)cos\frac{2\pi}{M}(m-1)cos2\pi f_c t - g(t)sin\frac{2\pi}{M}(m-1)sin2\pi f_c t, \end{aligned}$$

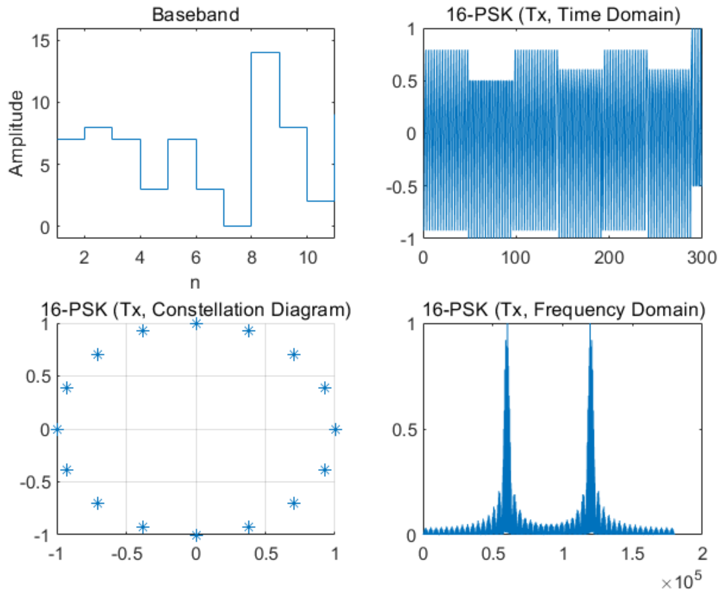
And the two-dimensional vectors s_m which indicates the coordinate on signal space diagram can be given by

$$s_m = [\sqrt{\frac{\epsilon_g}{2}}cos\frac{2\pi}{M}(m-1), \sqrt{\frac{\epsilon_g}{2}}sin\frac{2\pi}{M}(m-1)]$$

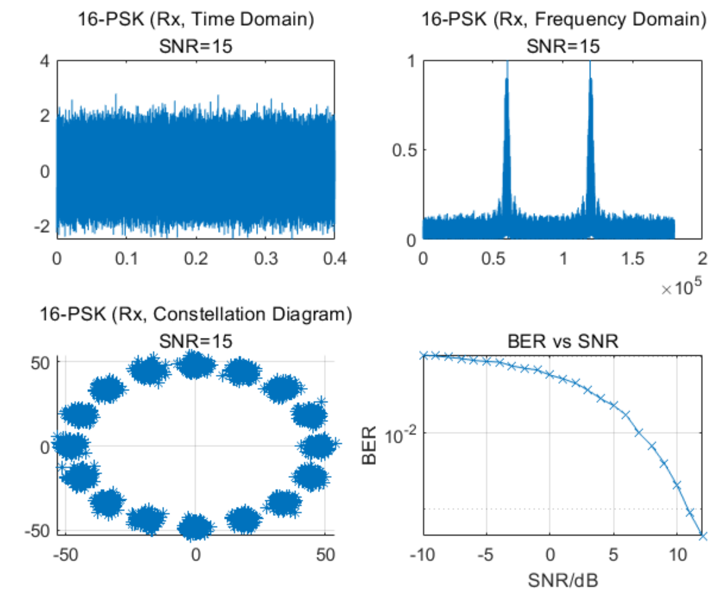
In gray encoding mapping, the minimum Euclidean distance of adjacent signal phases is

$$d_{min}^{(e)} = \sqrt{\epsilon_g(1 - cos\frac{2\pi}{M})}$$

Figure 3 show the 16 PSK signal transmission over an AWGN Channel. We can learn from the constellation diagram that there is no interference between adjacent signals when $SNR = 15dB$.



(a) PSK Transmission Signal



(b) PSK Receive Signal

Figure 3: 16 PSK Signal

1.3 Quadrature Amplitude Modulation(QAM)

Quadrature amplitude modulation(QAM) performs amplitude modulation on two quadrature carriers $\cos 2\pi f_c t$ and $\sin 2\pi f_c t$,the corresponding signal waveforms can be expressed as:

$$\begin{aligned} s_m(t) &= Re[(A_{mc}g(t) + jA_{ms})e^{j2\pi f_c t}], \quad m = 1, 2, ..., M, 0 \le t \le T \\ &= A_{mc}g(t)cos2\pi f_c t - A_{ms}g(t)sin2\pi f_c t \end{aligned}$$

The QAM signal signal waveform may be viewed as combined amplitude and phase modulation from other perspective:

$$s_m(t) = V_m g(t) cos(2\pi f_c t + \theta_m)$$

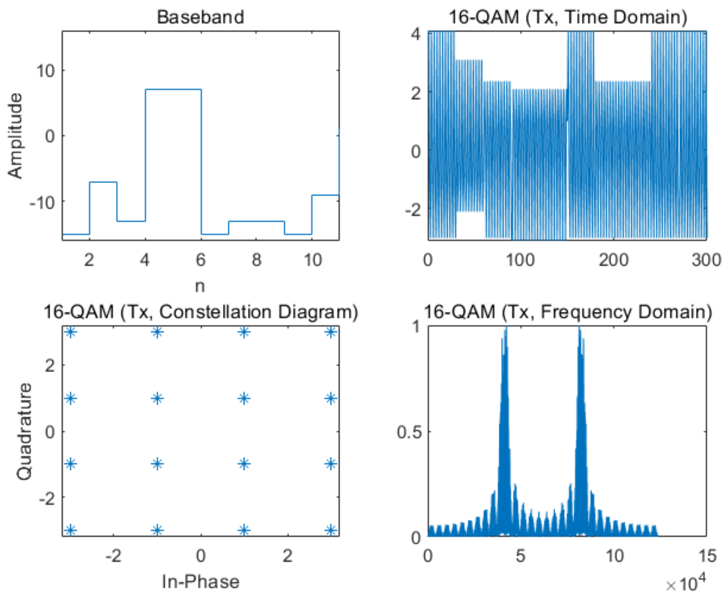
where $V_m = \sqrt{A_{mc}^2 + A_{ms}^2}$ and $\theta_m = tan^{-1}(A_{ms}/A_{mc})$.
The coordinate on the signal space diagram can be expressed as:

$$s_m = [A_{mc}\sqrt{\frac{\epsilon_g}{2}}, A_{ms}\sqrt{\frac{\epsilon_g}{2}}]$$

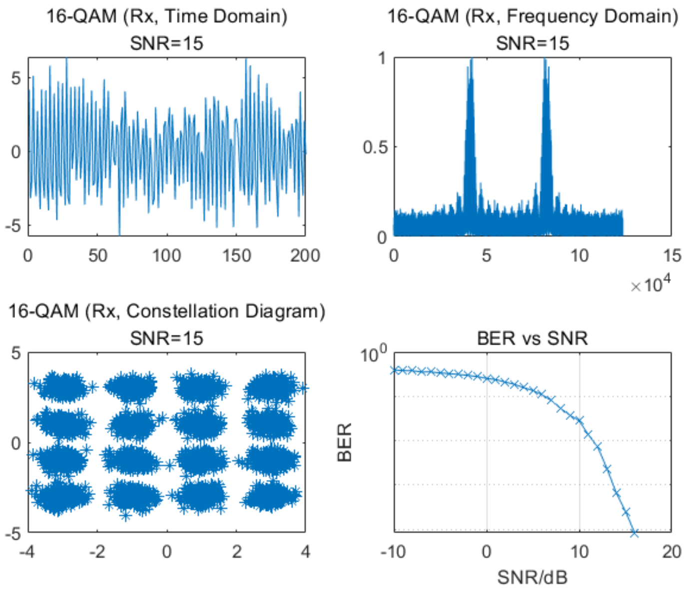
In this case, the minimum Euclidean distance between adjacent points is

$$d_{min}^{(e)} = d\sqrt{2\epsilon_g}$$

which is the same result as for PAM.



(a) QAM Transmission Signal



(b) QAM Receive Signal

Figure 4: 16 QAM Signal

Figure 4 shows the modulation and demodulation process of 16 QAM signal over an AWGN channel. We can learn that QAM modulation has higher bandwidth efficiency for its constellation can accommodate more points than PAM modulation with same minimum Euclidean distance. When the modulation index get larger, the transmission rate increases accordingly. However, it also leads to higher bit error rate under the same noise condition.

Since QAM signal differs both in phase and amplitude, the signal space diagrams also have various forms. The shape of constellation can be square, rectangular and polygon, and Figure 5 gives the example of square constellation($M = 4, 16, 64$).

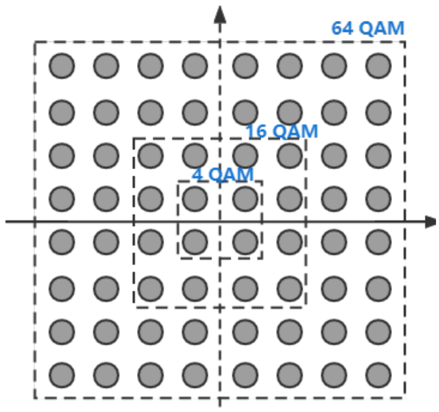


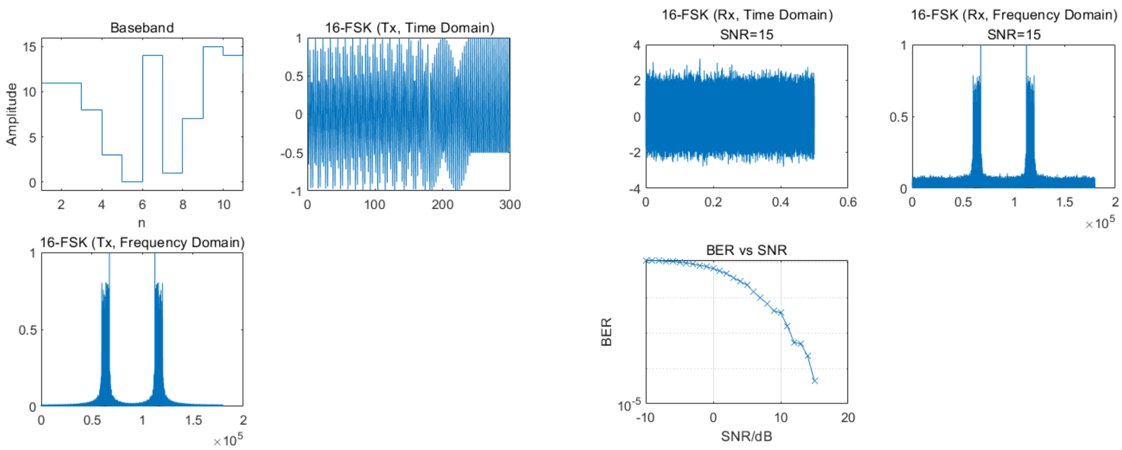
Figure 5: QAM Signal Constellation(Square)

1.4 Frequency Shift Keying(FSK)

Frequency shift keying (FSK) is a modulation scheme which load information on carrier frequencies. FSK can be divided as continuous-phase condition and discrete-phase condition. The discrete-phase condition frequency signal can be expressed as

$$\begin{aligned} s_m(t) &= Re[g(t)e^{j(2\pi(f_ct+m\Delta f)t+\theta_0)}], \quad m = 1, 2, ..., M, 0 \le t \le T \\ &= g(t)cos(2\pi(f_ct + m\Delta f)t + \theta_0) \end{aligned}$$

Since the signal is loaded on discrete frequencies, the coordinate is zero except the chosen frequency, which makes it unable to depicted. The transmission and receiving process of FSK signal(M=16) is given in Figure 6.



(a) FSK Transmission Signal

(b) FSK Receive Signal

Figure 6: FSK Signal

1.5 Optimum Receivers for modulation schemes

To design an optimum receiver, we can easily subdivide the receiver into two parts —— the signal demodulator and the detector. Signal correlators and matched filters are two realizations of the signal demodulator, and Figure 7 shows the implementation of a signal correlator and a detector.

For the signal correlator, since $n^{'}(t)$ can be ignored ,we have the received symbol by calculating the correlation integral of received signal r(t) and base function $f_k(t)$:

$$r_k = \int_0^T r(t) f_k(t) dt$$

The optimum detector can apply ML criterion under the assumption that the M signals are equally probable, and the comparison of posterior probabilities can be simplified to the comparison of C metric, which can be represented as:

$$C(r, s_m) = 2r * s_m - ||s_m||^2$$

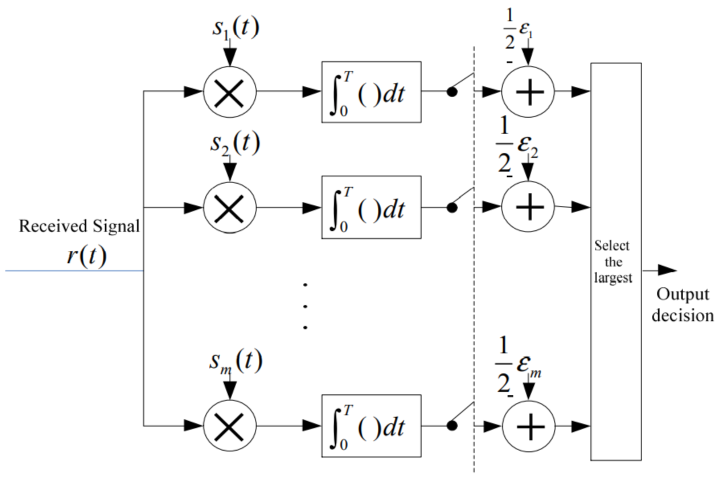


Figure 7: Design of Optimum Receiver

According to the above rules, Figure 8 shows the performance of various receivers when the modulation index M=16. Take SNR=5dB as an example, we can observe that PAM and QAM schemes have high bit error rate over 0.1, while PSK and FSK can keep the number of bit errors relatively low. Among all of them, 16-ary FSK shows the best performance according to our experiments.

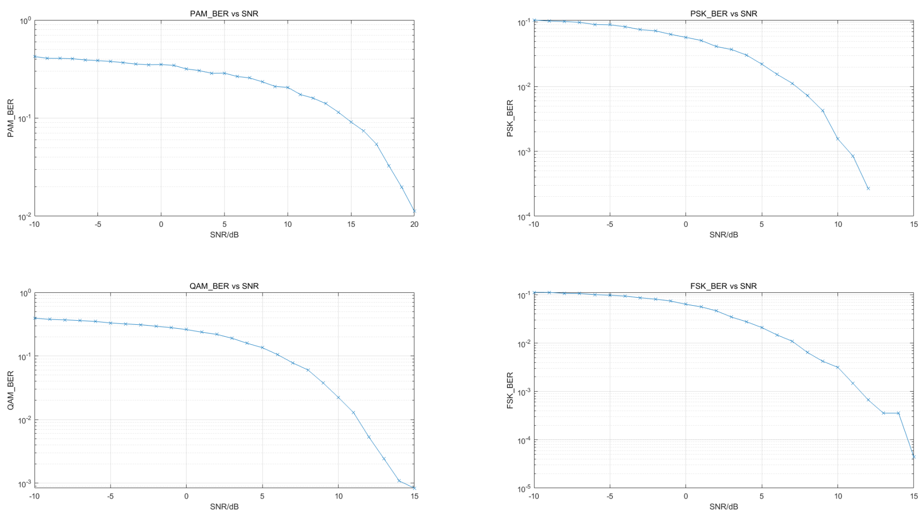


Figure 8: The performance comparison of PAM, PSK, QAM, FSK(M=16)

2 Image file transmission

In this section, we design a digital communication system to transmit a file and analyze it's performance.

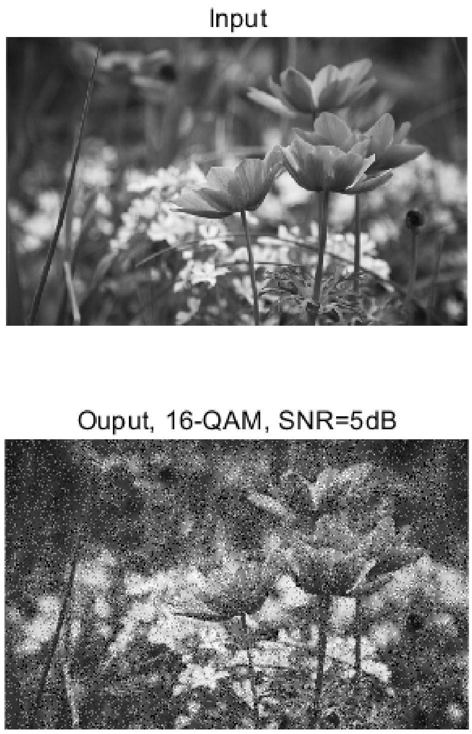


Figure 9: Input and Output

In our experiment, we transmit an image file through an AWGN channel where SNR=5dB using the 16 QAM modulation scheme. And the input and output file of the system is shown as Figure 9 . We get the data that the PSNR(Peak Signal to Noise Ratio) of the output is 18.5606 with the SSIM(Structural SIMilarity) of 0.2554. Although we can distinguish the objects from the picture easily, the result is not quite ideal as we can observe observe obvious noise points from the output file. Transmitting through the channel, the additional Gaussian noise significantly corrupts the image quality. Techniques like different channel coding and modulation schemes can be applied to alleviate this situation.

3 Division of partners

1. Zeyu Sun: PAM,QAM simulation and Part2 simulation.
2. Yining Wang: FSK,PSK simulation and report writing.

4 Reference

[1] John G. Proakis, Digital Communications 4th edition[M].Northeastern University, 2001.

[2] Course material. ICE6302: Chapter5-Optimal Receiver.

[3] Pankaj Anand, Akhil Gupta and Sonam Bhagat, Bit Error Rate Assessment of Digital Modulation Schemes on Additive White Gaussian Noise, Line of Sight and Non Line ofSight Fading Channels. International Journal of Engineering Science Invention, September,2014.