Chapter 5

Baseband Transmission of Digital Signals

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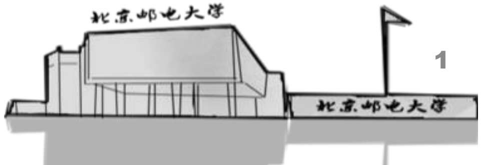
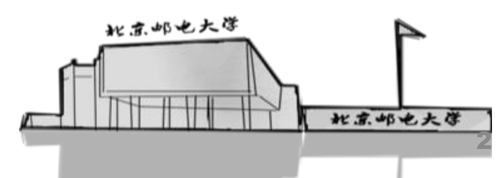
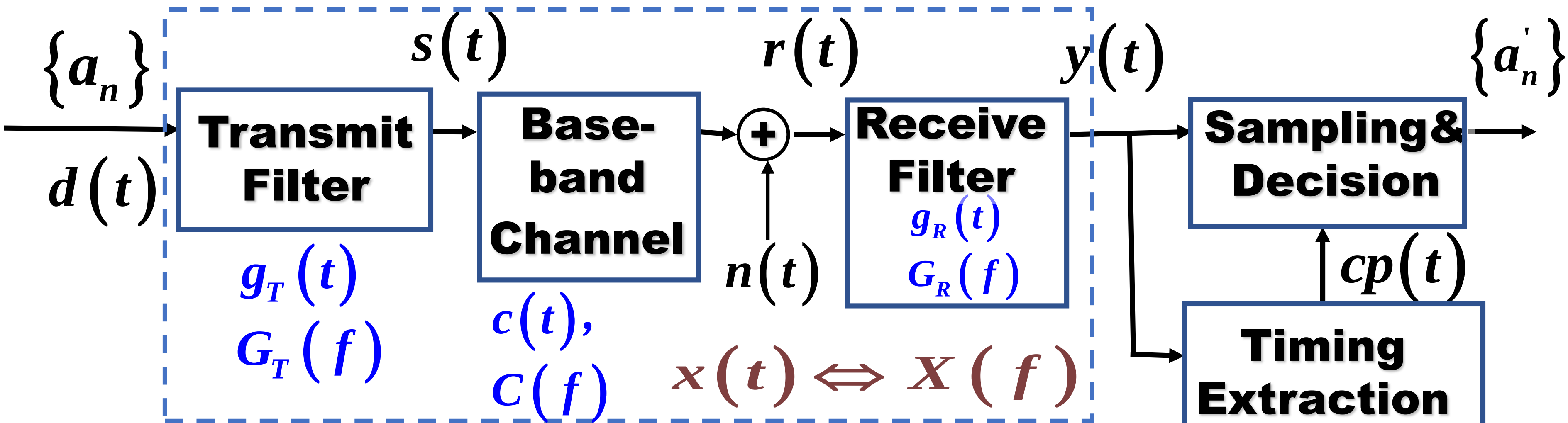


Baseband Transmission of Digital Signals

- Introduction
- Baseband signal and pulse modulation
- Digital PAM signal transmission through AWGN channel
- Digital PAM signal transmission through baseband channel
- Optimal transmission of digital PAM signal through ideal baseband channel and under AWGN condition
- Eye Diagram
- Channel Equalization
- Partial Response System
- Symbol Synchronization
- Summary



Optimal Transmission of Digital PAM Signal through Ideal Baseband Channel and under AWGN Condition



$$G_T(f) \cdot C(f) \cdot G_R(f) = X_{RC}(f)$$

- **If Matched Filter was adopted at the receiver for optimal reception**

$$G_R(f) = G_T^*(f) C^*(f)$$

Optimal Transmission of Digital PAM Signal through Ideal Baseband Channel and under AWGN Condition

- **For ideal baseband channel, without time delay**

$$G_T(f) = G_R(f) = \sqrt{X_{\mathrm{RC}}(f)}$$

- **For ideal baseband channel, with time delay**

$$G_T(f) = \sqrt{X_{\mathrm{RC}}(f)}e^{-j2\pi f t_T}$$

$$G_R(f) = \sqrt{X_{\mathrm{RC}}(f)}e^{-j2\pi f t_R}$$

Optimal Transmission of Digital PAM Signal through Ideal Baseband Channel and under AWGN Condition

- **BER analysis**

For equal probability transmission of bipolar PAM signal

$$s_1(t) = -s_2(t) \Rightarrow E_b = E_1 = E_2, \quad \rho_{12} = -1$$

For optimal reception with minimum average BER

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

where, N_0 is the single side power spectral density of AWGN, E_b is the average bit energy.

$$E_b = E_1 = E_2 = \int_{-\infty}^{\infty} s_{1or2}^2(t)\,dt = \int_{-\infty}^{\infty} \left|C(f)G_T(f)\right|^2 df = \int_{-\infty}^{\infty} \left|G_T(f)\right|^2 df$$

Optimal Transmission of Digital PAM Signal through Ideal Baseband Channel and under AWGN Condition

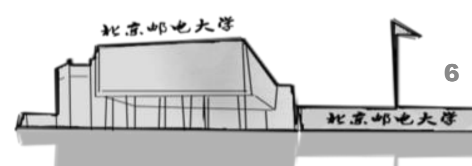
- **The PSD of the transmitted signal**

$$P_T(f) = \frac{1}{T_b}\left|G_T(f)\right|^2 = \frac{1}{T_b} X_{\mathrm{RC}}(f)$$

- **The average bit energy of the transmitted signal**

$$E_b = \int_{-\infty}^{\infty}\left|G_T(f)\right|^2 df = \int_{-\infty}^{\infty} X_{\mathrm{RC}}(f)\,df = 1$$

$$\text{also:}\quad E_b = T_b \int_{-\infty}^{\infty} P_T(f)\,df$$



Optimal Transmission of Digital PAM Signal through Ideal Baseband Channel and under AWGN Condition

- **At the receiver, the equivalent noise bandwidth**

$$B_n = \frac{1}{2\left|G_R(f)\right|_{\max}^2}\int_{-\infty}^{\infty}\left|G_R(f)\right|^2 df = \frac{1}{2X_{\mathrm{RC}}(0)}\int_{-\infty}^{\infty}X_{\mathrm{RC}}(f)\,df = \frac{1}{2T_b} = \frac{R_b}{2}$$

(Note: $B_n = R_s/2$ for MPAM)

- **The output noise of the receive filter *G_R(f)***

Average noise power

$$\sigma_n^2 = \frac{N_0}{2}\int_{-\infty}^{\infty}\left|G_R(f)\right|^2 \mathrm{d}f = \frac{N_0}{2}\int_{-\infty}^{\infty}X_{\mathrm{RC}}(f)\,\mathrm{d}f = \frac{N_0 E_b}{2} = \frac{N_0}{2}$$

Optimal Transmission of Digital PAM Signal through Ideal Baseband Channel and under AWGN Condition

- The PSD of the output signal from the receive filter

$$\boxed{P_s(f)=\frac{\sigma_a^2}{T_s}\left|G_T(f)\right|^2+\frac{m_a^2}{T_s^2}\sum_{m=-\infty}^{\infty}\left|G_T\left(\frac{m}{T_s}\right)\right|^2\delta\left(f-\frac{m}{T_s}\right)}$$

- For equal probability transmission of bipolar sequence $\{a_n\}\in\{A,-A\}$

$$m_a=0,\delta_a^2=A^2,\left|G_T(f)\right|^2=\left|G_R(f)\right|^2=X_{RC}(f)$$

$$P_s(f)=\frac{A^2}{T_s}X_{RC}(f)$$

$$P_b=\frac{1}{2}erfc\left(\sqrt{\frac{E_b}{N_0}}\right)=\frac{1}{2}erfc\left(\sqrt{\frac{A^2}{N_0}}\right),E_b=A^2$$

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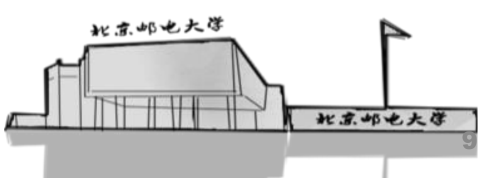
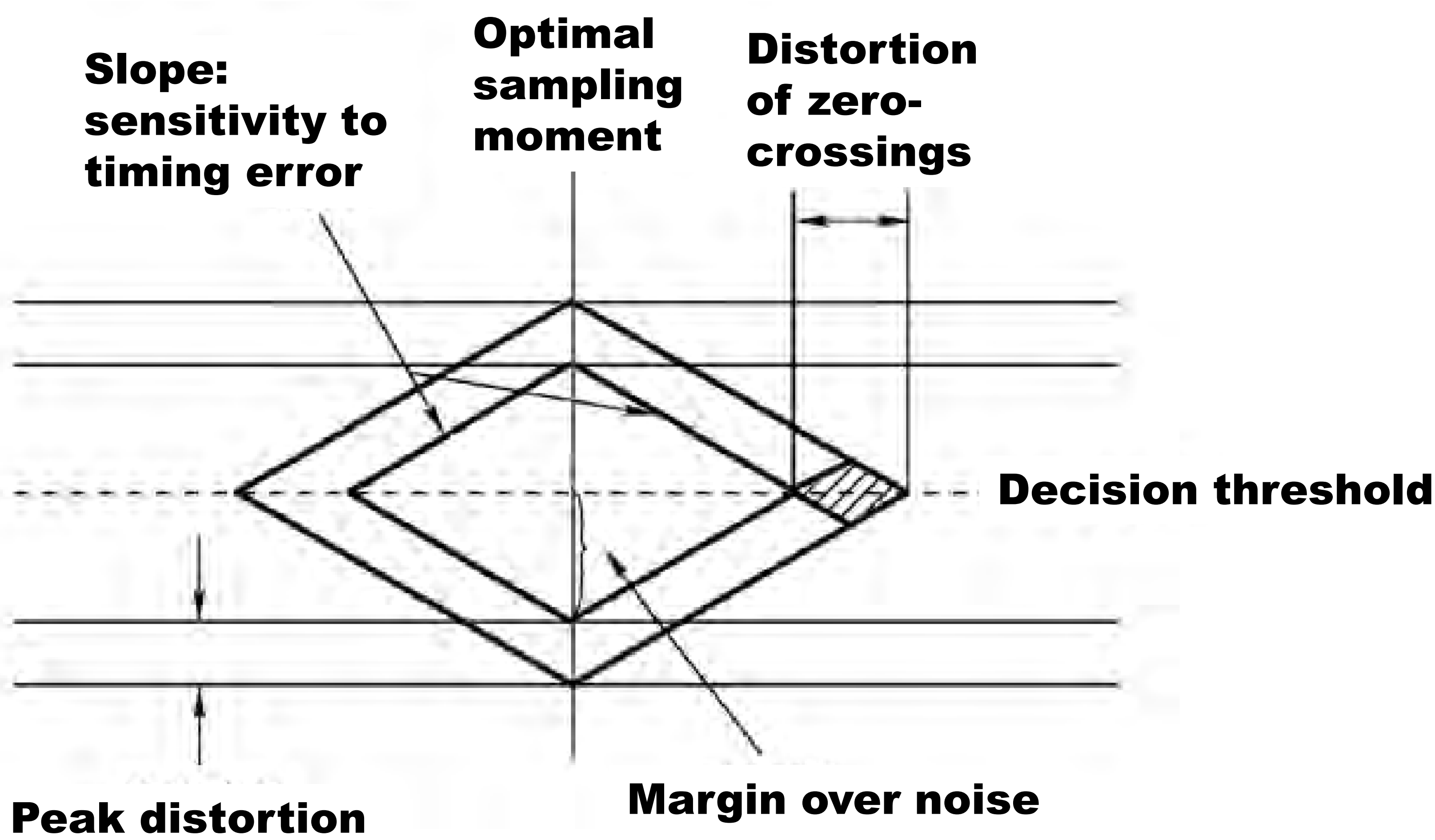


Eye Diagram

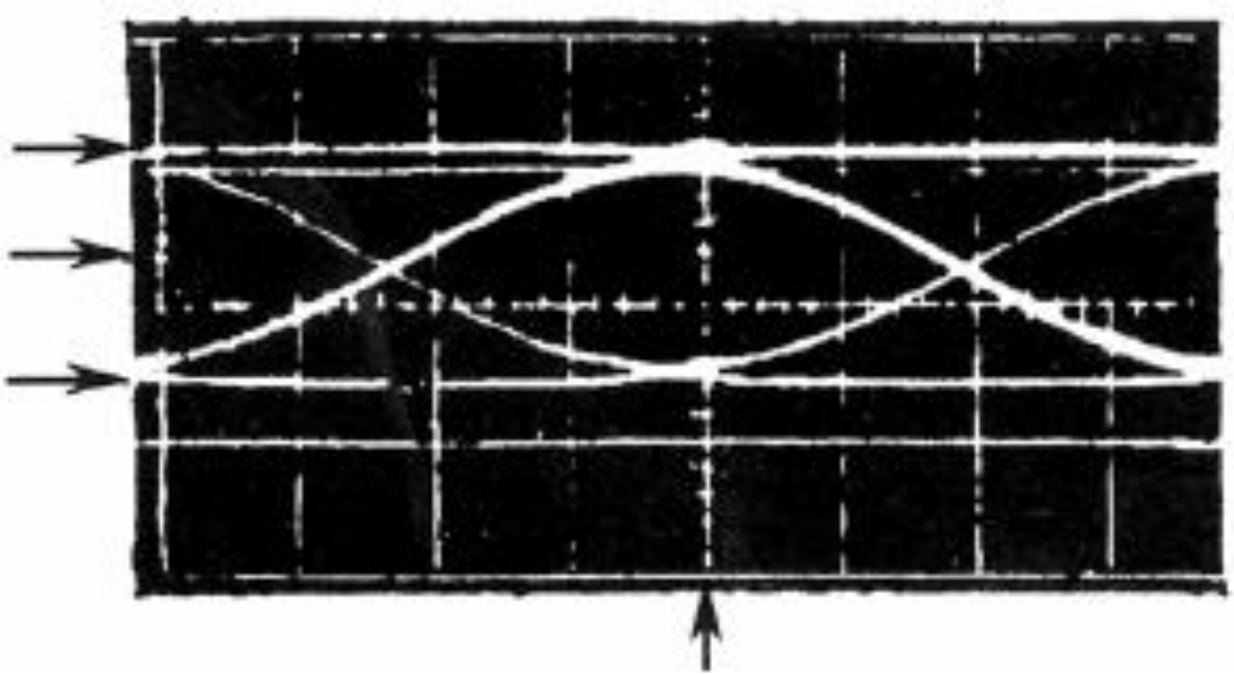
- **Eye diagram is a method of practical observation of the received signal by using an oscilloscope.**
- **It requires that the scanning period of the oscilloscope is times of the symbol period T_s.**
- **It is the overlapping of the output signal waves, which reflects the variations of the signals.**
- **It looks like eyes.**

Eye Diagram


Slope: sensitivity to timing error
Optimal sampling moment
Distortion of zero-crossings
Decision threshold
Peak distortion
Margin over noise

Eye Diagram

- **Eye diagram of 2PAM**



Eye Diagram

- **Eye diagram of 4PAM**