UESTC4004
Digital Communications

Instructors: Prof. Muhammad Imran and Sajjad Hussain

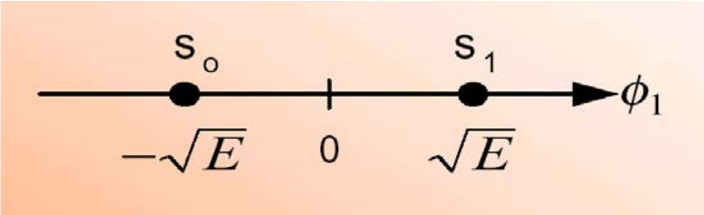
This week: Prof. Muhammad Imran muhammad.imran@glasgow.ac.uk

Lecture Overview

- Constellation diagram
- Pulse shaping
- Eye diagram

Constellation Diagram

- Is a method of representing the symbol states of modulated bandpass signals in terms of their amplitude and phase
- In other words, it is a geometric representation of signals
- There are three types of binary signals:
  - **Antipodal**
    - Two signals are said to be antipodal if one signal is the negative of the other $\Rightarrow s_1(t) = -s_0(t)$
    - The signal have equal energy with signal point on the real line



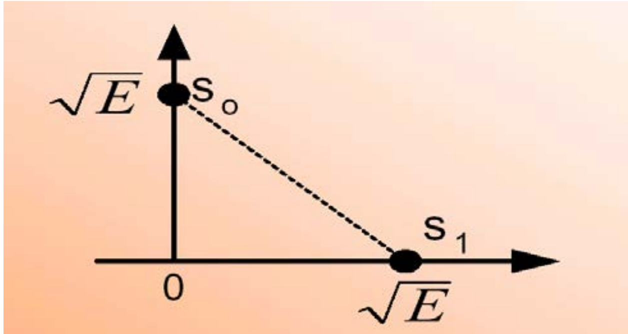
$$E_{avg} = \frac{E+E}{2} = E$$

  - **ON-OFF**
    - Are one dimensional signals either ON or OFF with signaling points falling
    - on the real line

- With OOK, there are just 2 symbol states to map onto the constellation space
  - $a(t) = 0$ (no carrier amplitude, giving a point at the origin)
  - $a(t) = A \cos w_c t$ (giving a point on the positive horizontal axis at a distance A from the origin)

$$E_{avg} = \frac{0+E}{2} = \frac{E}{2}$$

- **Orthogonal**
  - Requires a two dimensional geometric representation since there are two linearly independent functions *s1(t)* and *s0(t)*



$$E_{avg} = \frac{E+E}{2} = E$$

Typically, the horizontal axis is taken as a reference for symbols that are ***Inphase*** with the carrier $\cos w_c t$, and the vertical axis represents the ***Quadrature*** carrier component, $\sin w_c t$

Error Probability of Binary Signals

- Bipolar signals require a factor of 2 increase in energy compared to Unipolar
- Since $10\log_{10}2 = 3\ dB$, we say that bipolar signaling offers a *3 dB* better performance than Unipolar

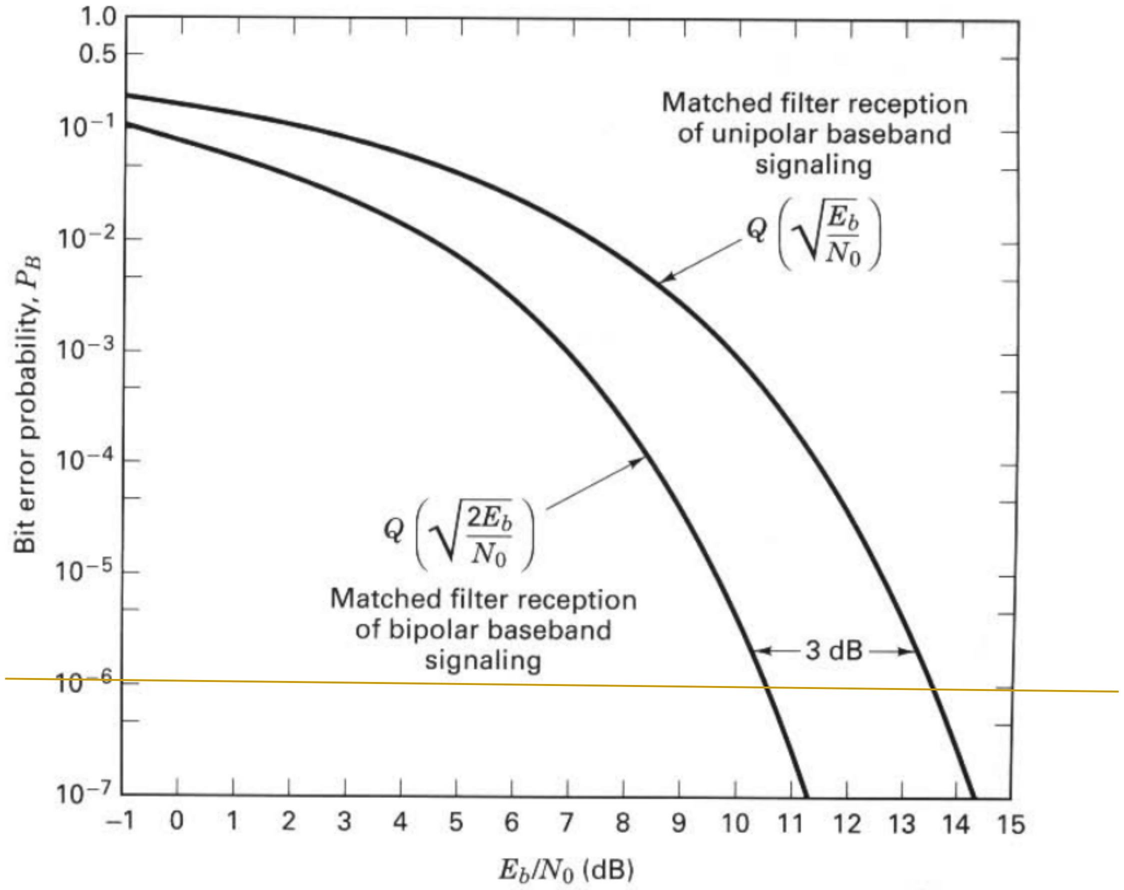


Figure 3.14 Bit error performance of unipolar and bipolar signaling.

Comparing BER Performance

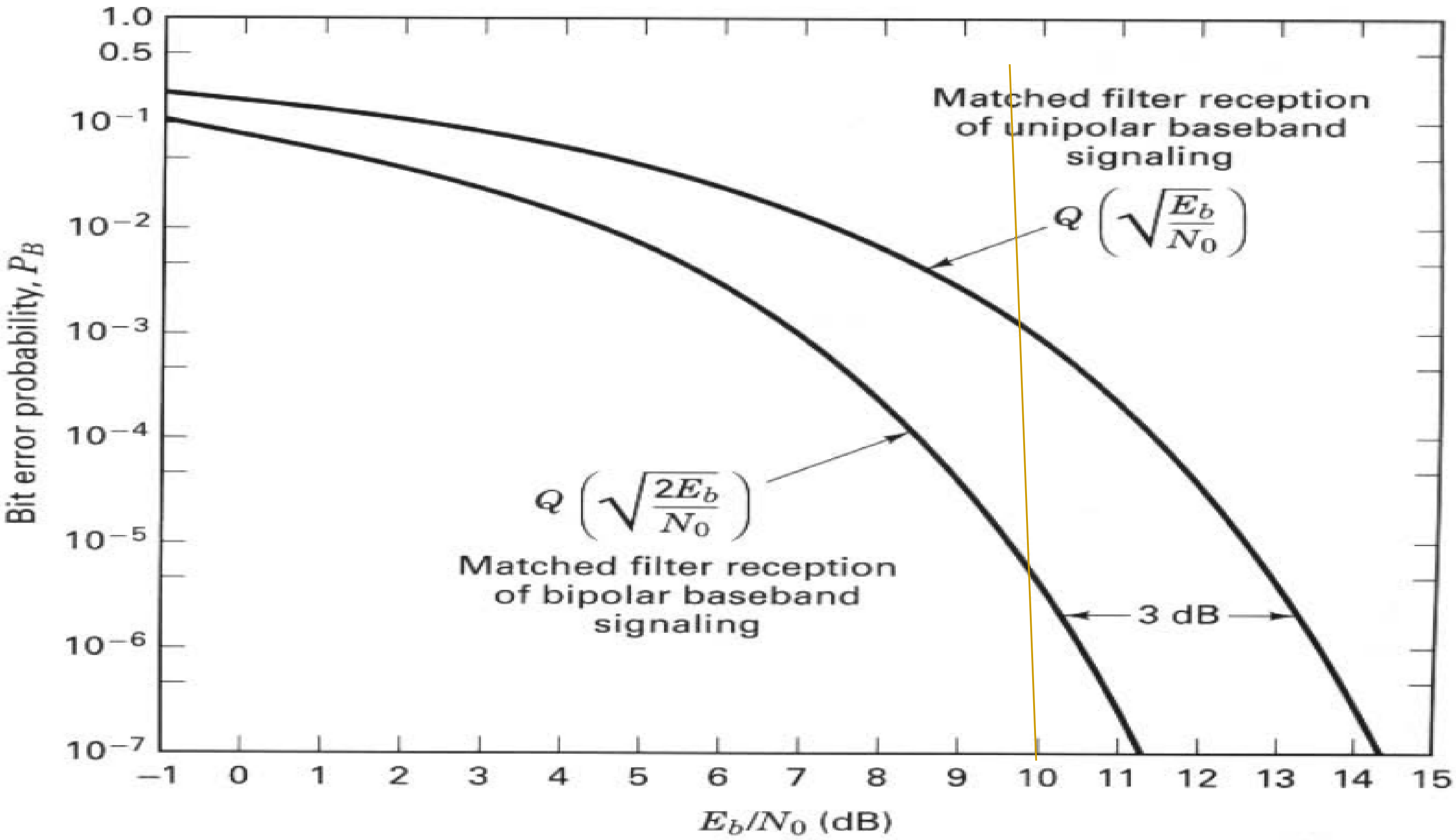
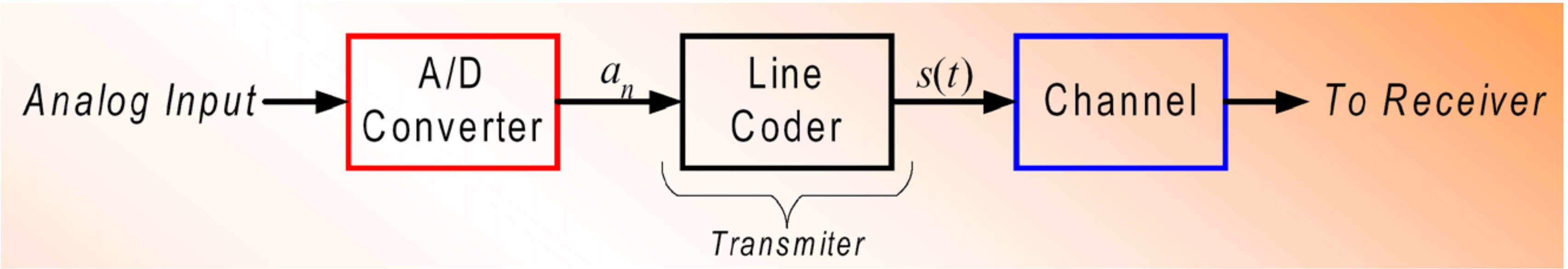


Figure 3.14 Bit error performance of unipolar and bipolar signaling.

- For the same received signal to noise ratio, antipodal provides lower bit error rate than orthogonal

Baseband Communication System

- We have been considering the following baseband system



- The transmitted signal is created by the *line coder* according to

$$s(t) = \sum_{n=-\infty}^{\infty} a_n g(t - nT_b)$$

where a_n is the ***symbol mapping*** and $g(t)$ is the ***pulse shape***

Problems with Line Codes

- The big problem with the line codes is that they are not ***bandlimited***
  - The absolute bandwidth is infinite
  - The power outside the 1st null bandwidth is not negligible
    - That is, the power in the sidelobes can be quite high

Inter Symbol Interference (ISI)

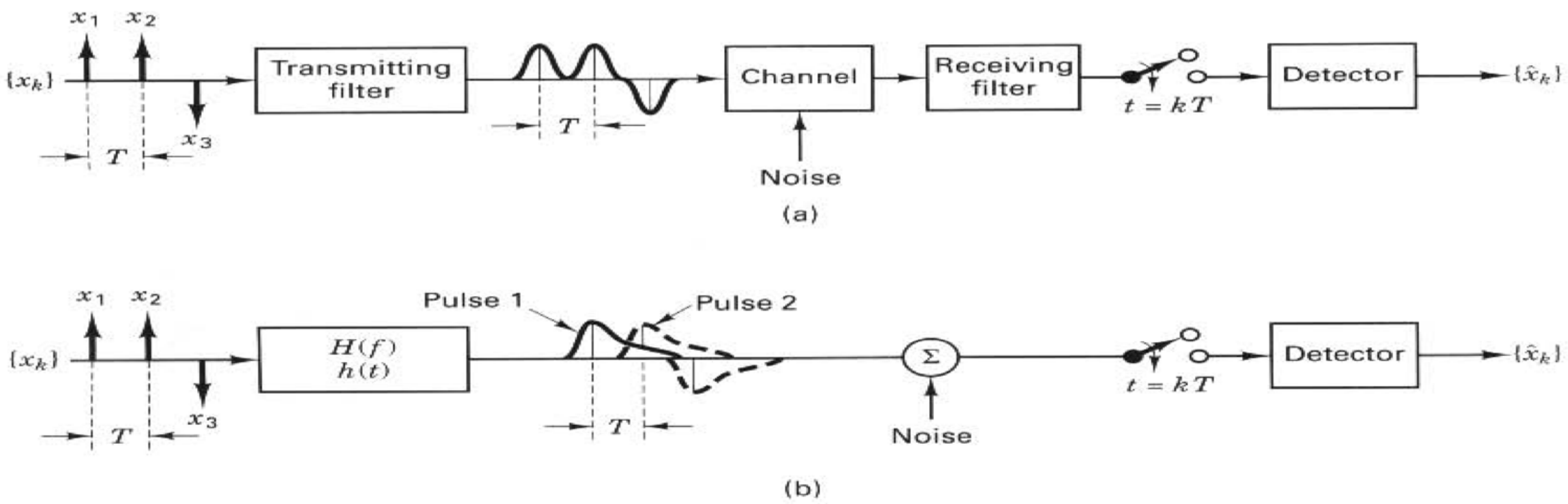


Figure 3.15 Intersymbol interference in the detection process. (a) Typical baseband digital system. (b) Equivalent model.

$$H(f) = H_t(f)\, H_c(f)\, H_r(f)$$

Nyquist to help…

- Theoretical minimum system bandwidth needed to detect R_s symbols/sec without ISI, is $R_s/2$ Hz.
- Sinc and Rect relationship $sinc(\frac{t}{T}) \leftrightarrow T\, rect(\frac{f}{1/T})$

Figure 3.16 Nyquist channels for zero ISI. (a) Rectangular system transfer function $H(f)$. (b) Received pulse shape $h(t) = \text{sinc}(t/T)$.

Trade-off and Goals

Shrink the pulse to obtain better spectrum efficiency at the cost of increased ISI and vice versa.

- **Problems with Sinc(.) function**
  - But there are problems with Sinc(.) pulse shape function
    - It is not possible to create Sinc pulses due to
      - Infinite time duration
      - Sharp transition band in the frequency domain

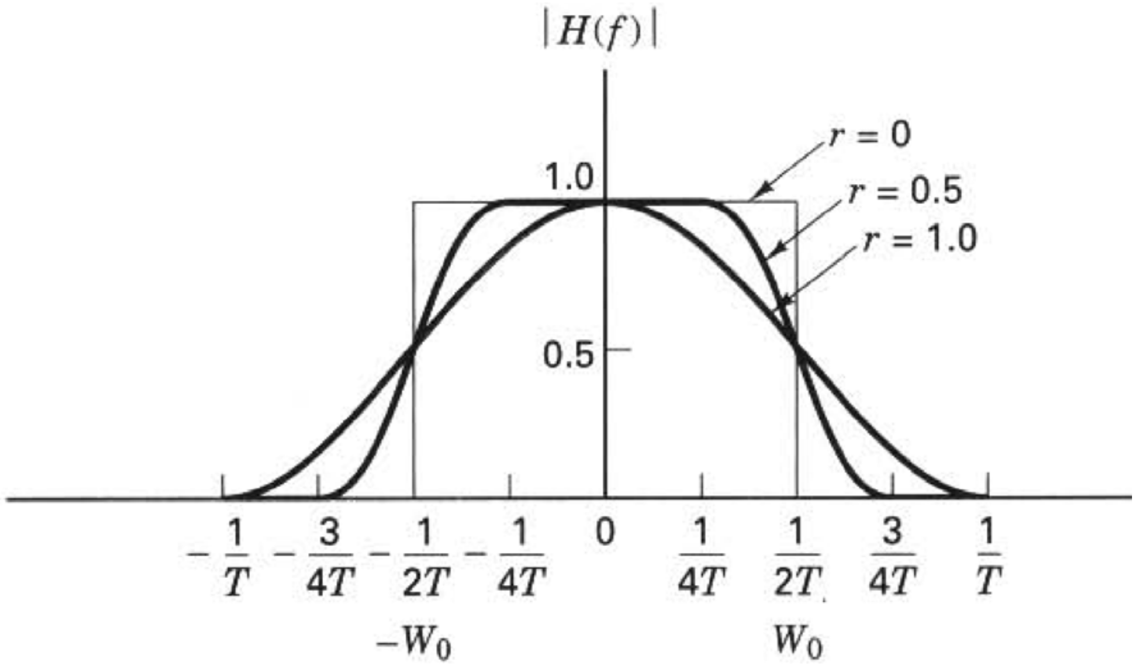
  - Sinc(.) pulse shape can cause ISI in the presence of timing errors
    - If the received signal is not sampled at exactly the bit instant, then ISI will occur

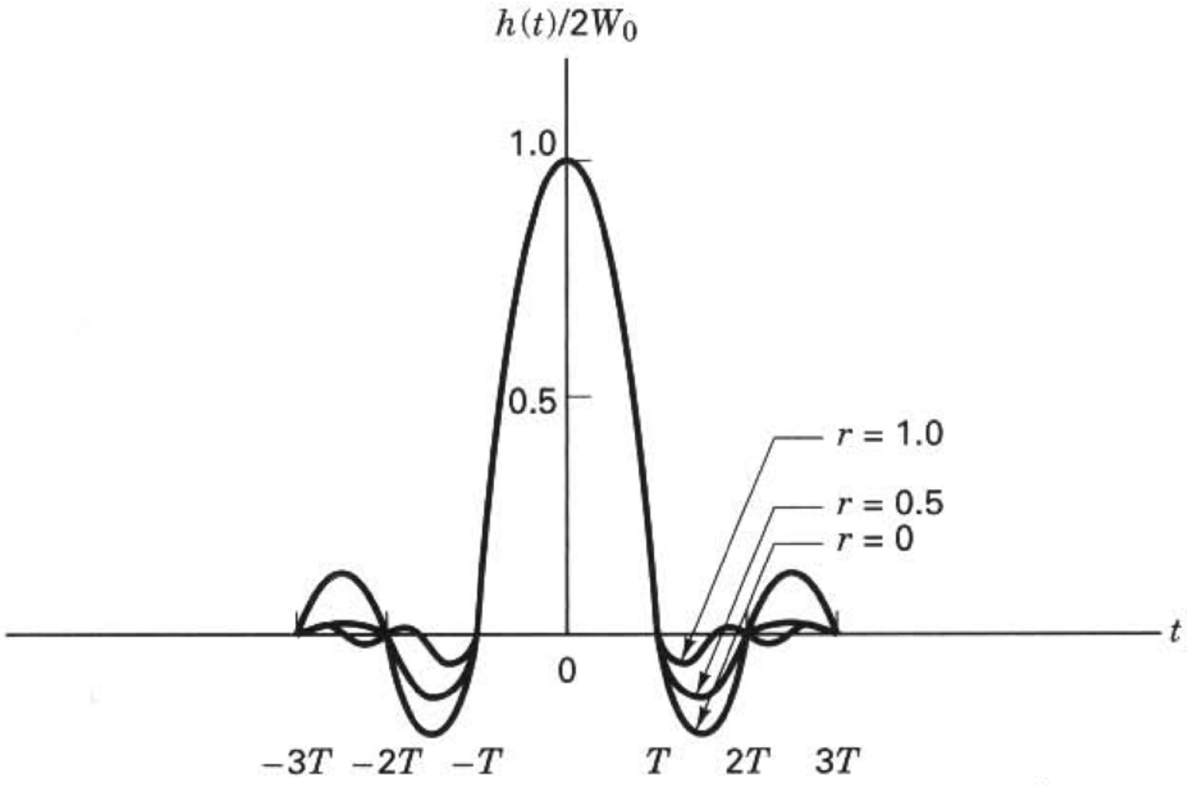
Raised Cosine Filter

- Belongs to Nyquist class (zero ISI at sampling instants)

$$H(f) = \begin{cases} 1 & \text{for } |f| < 2W_0 - W \\ \cos^2\left(\dfrac{\pi}{4}\dfrac{|f| + W - 2W_0}{W - W_0}\right) & \text{for } 2W_0 - W < |f| < W \\ 0 & \text{for } |f| > W \end{cases}$$

$$h(t) = 2W_0(\operatorname{sinc} 2W_0 t)\frac{\cos[2\pi(W - W_0)t]}{1 - [4(W - W_0)t]^2}$$





$r = \frac{W - W_0}{W_0}$ where $0 \le r \le 1$

Effect on bandwidth requirements

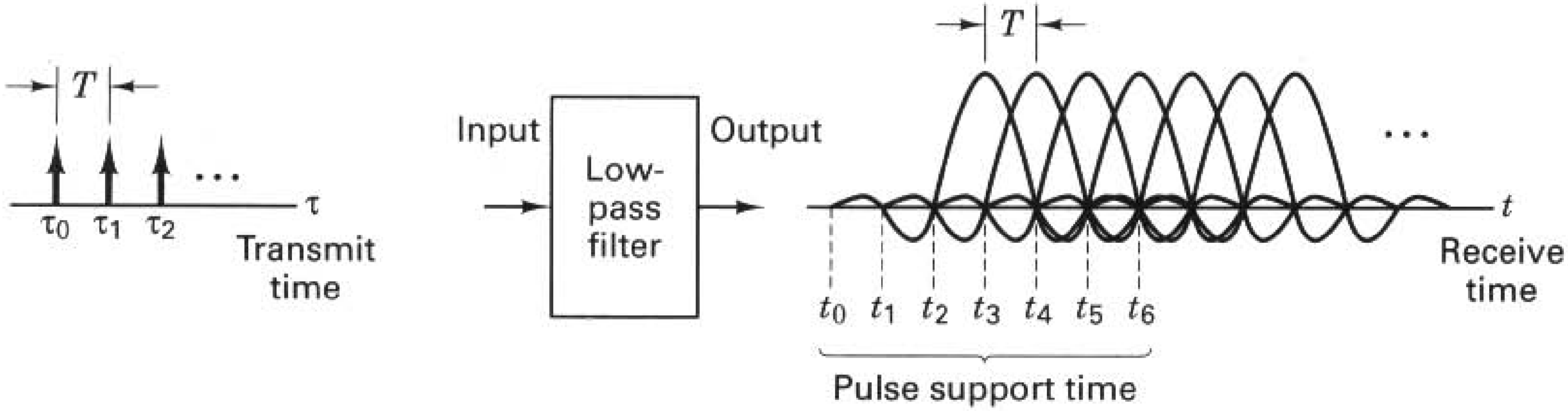
$$W = \frac{1}{2}(1 + r)R_s$$

Find the minimum required bandwidth for the baseband transmission of a four-level PAM pulse sequence having a data rate of $R = 2400$ bits/s if the system transfer characteristic consists of a raised-cosine spectrum with 100% excess bandwidth ($r = 1$).

Practical Issues with Pulse Shaping

- Like the sinc(.) pulse, RC rolloff pulses extend infinitely in time
  - However, a very good approximation can be obtained by truncating the pulse
    - Can make *h(t)* extend from *-3T* to *+3T*
- RC rolloff pulses are *less sensitive to timing* errors than sinc(.) pulses
  - Larger values of r are more robust against timing errors
- US Digital Cellular (IS-54/136) uses root RC roll off pulse shaping with r=*0.35*
- IS-95 uses pulse shape that is slightly different from RC roll off shape
- European GSM uses Gaussian shaped pulses

Overall effect with pulse shape filtering



Root RC rolloff Pulse Shaping

- We saw earlier that the noise is minimized at the receiver by using a ***matched filter***
  - If the transmit filter is *H(f)*, then the receive filter should be *H*(f)*
- The combination of transmit and receive filters must satisfy Nyquist's first method for zero ISI

$$H_e(f) = H(f)H^*(f) \Rightarrow H(f) = \sqrt{H_e(f)}$$

- Transmit filter with the above response is called the ***root raised cosine-rolloff filter***
- Root RC rolloff pulse shapes are used in many applications such as IS- 54 and IS-136

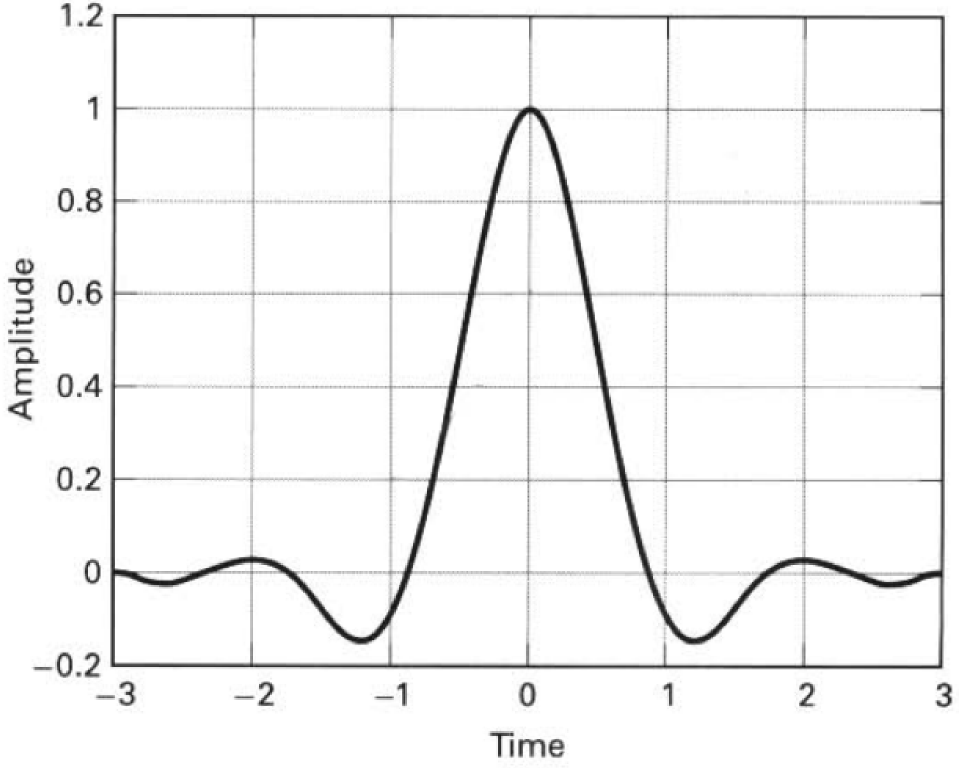


Figure 3.22a Square-root Nyquist pulse.

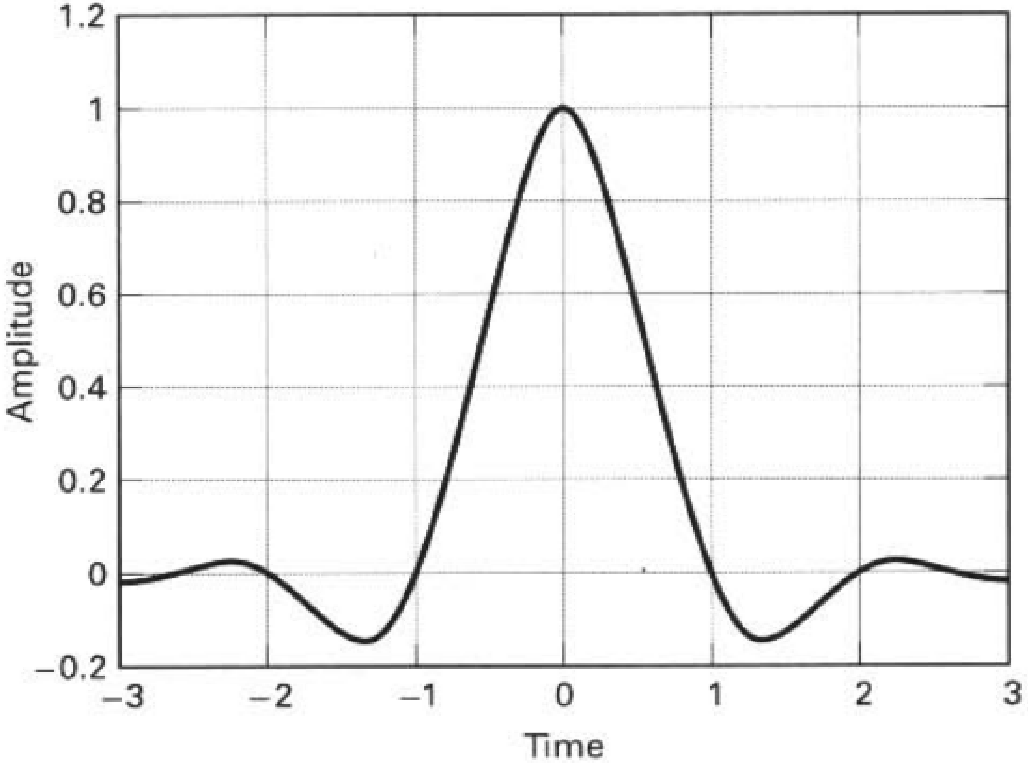


Figure 3.22b Nyquist pulse.

Notice the zero crossings!!!

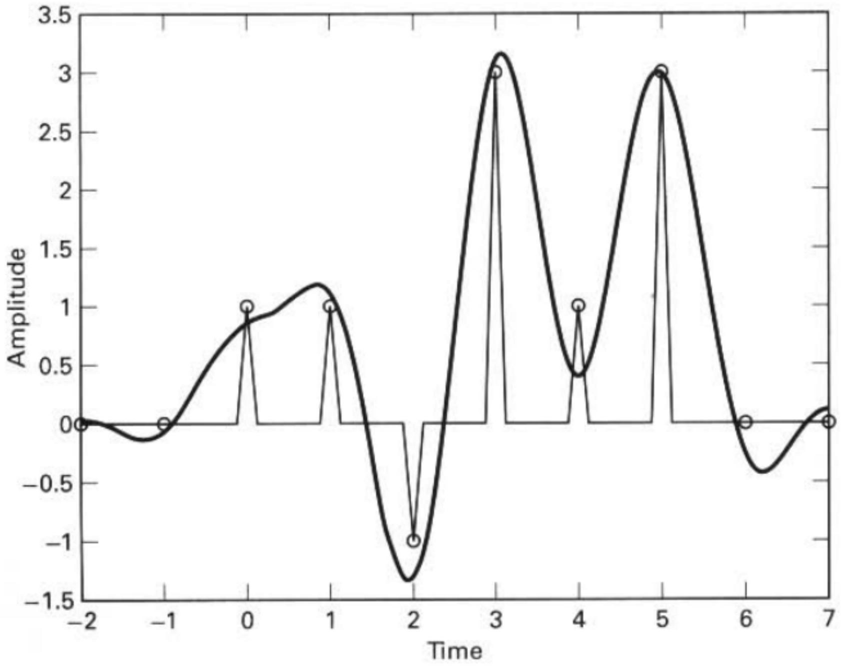


Figure 3.23a Square-root Nyquist-shaped *M*-ary waveform and delayed-input sample values.

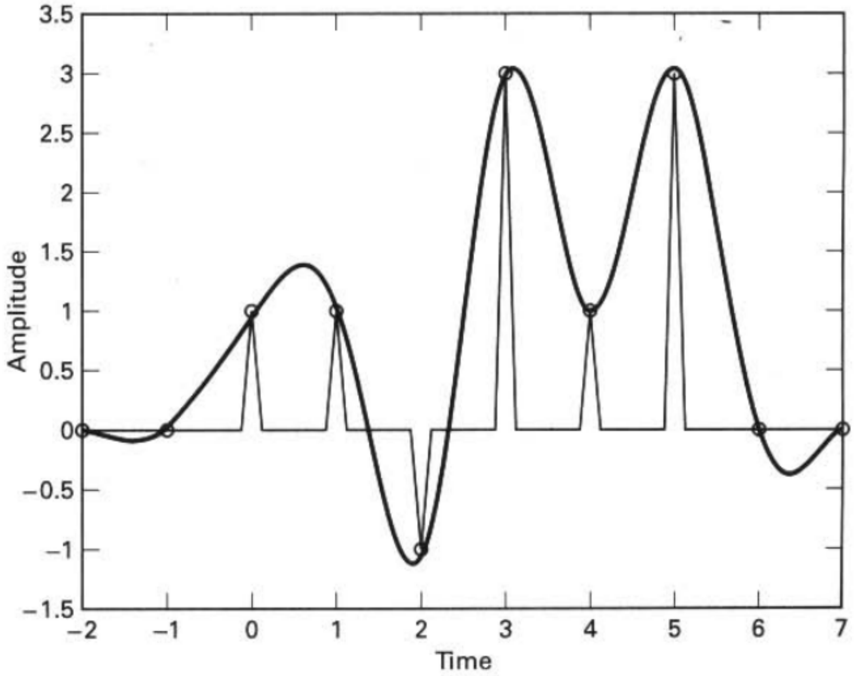
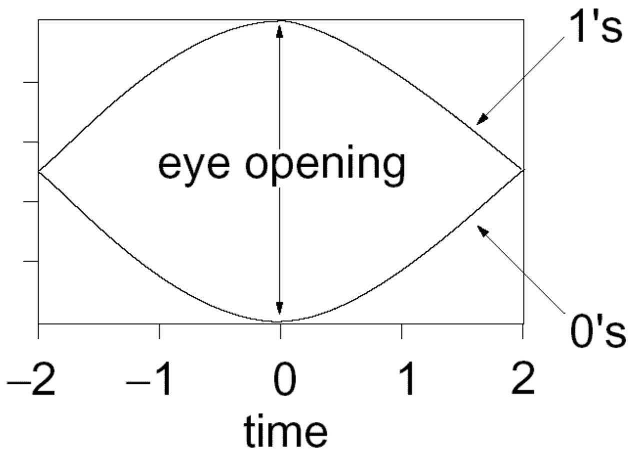


Figure 3.23b Output of raised-cosine matched filter and delayed-input sample values.

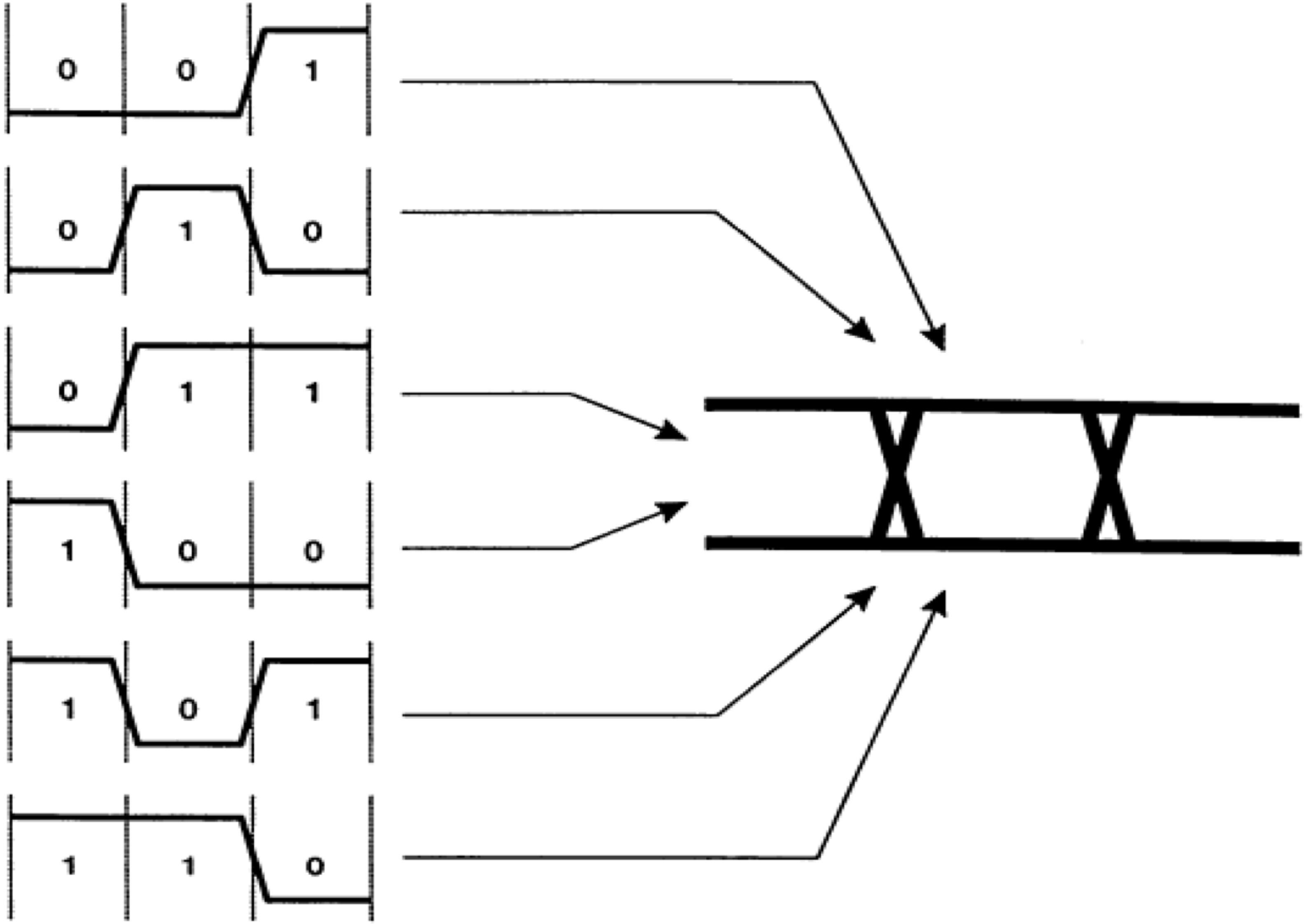
For data sequence of {1 1 -1 3 1 3}

Eye Patterns

- An **eye pattern** is obtained by superimposing the actual waveforms for large numbers of transmitted or received symbols
  - Perfect eye pattern for noise-free, bandwidth-limited transmission of an alphabet of two digital waveforms encoding a binary signal (1’s and 0’s)

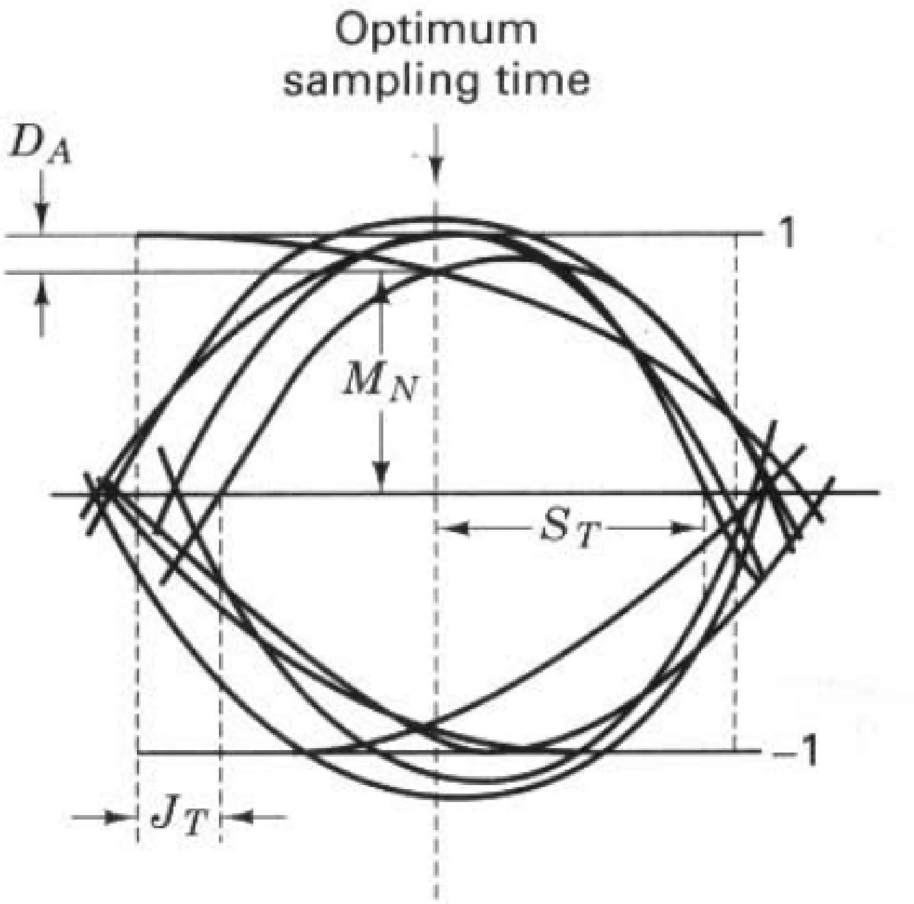


  - Actual eye patterns are used to estimate the bit error rate and the signal to- noise ratio

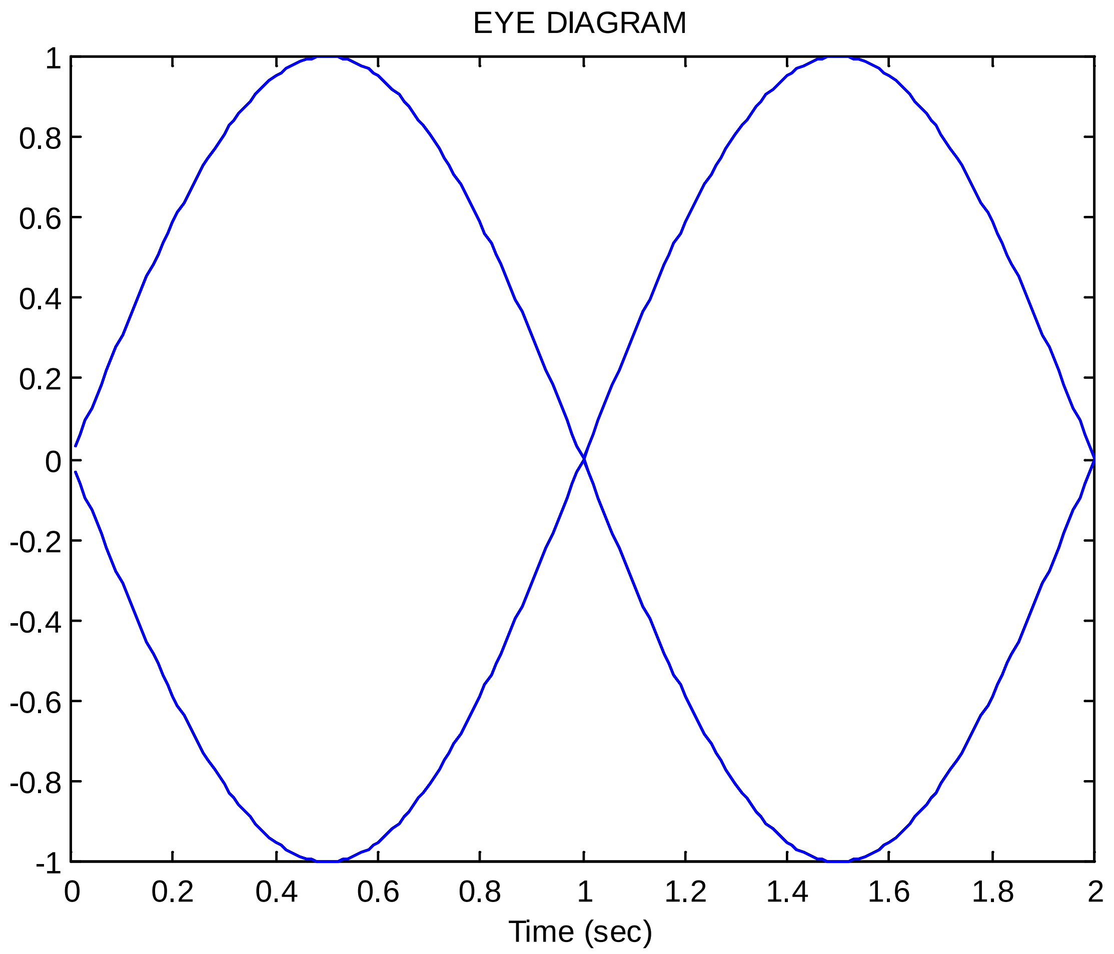


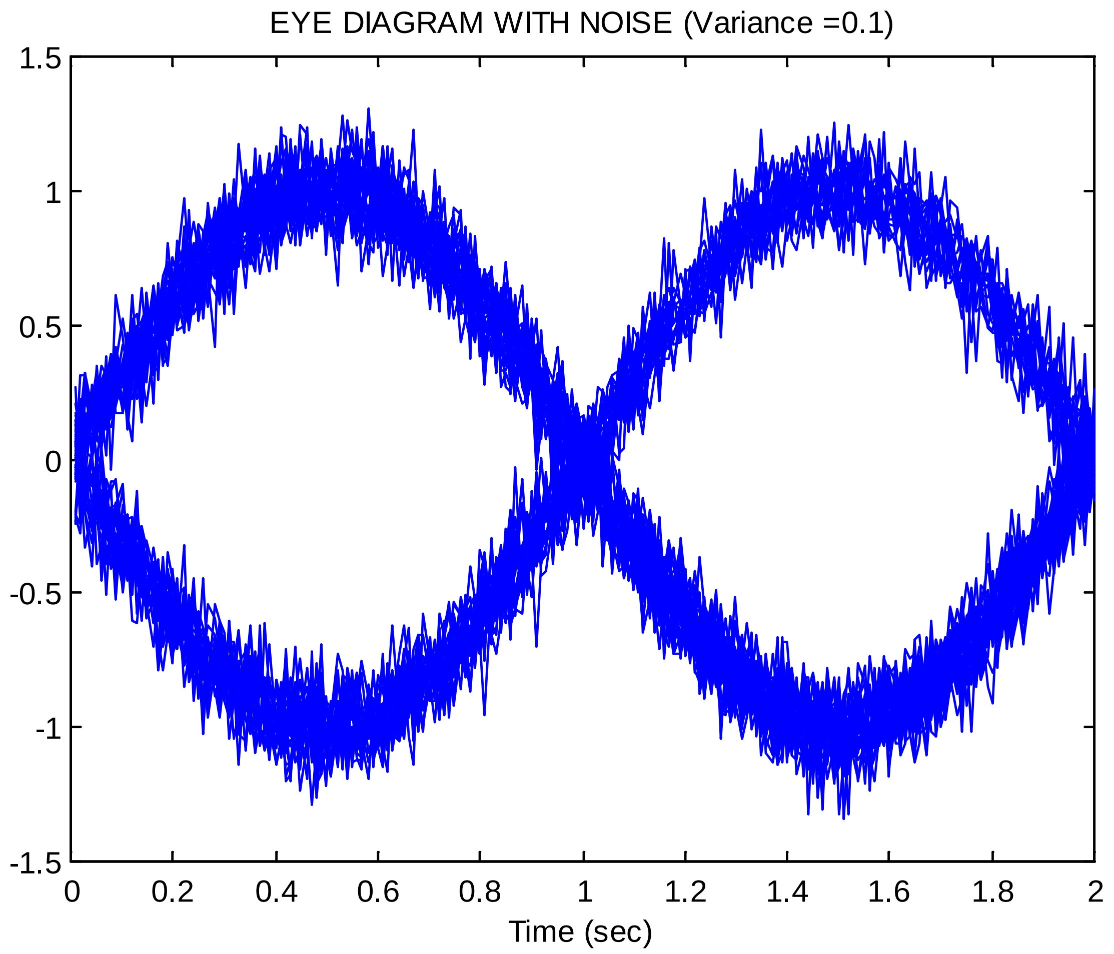
Concept of the **eye pattern**

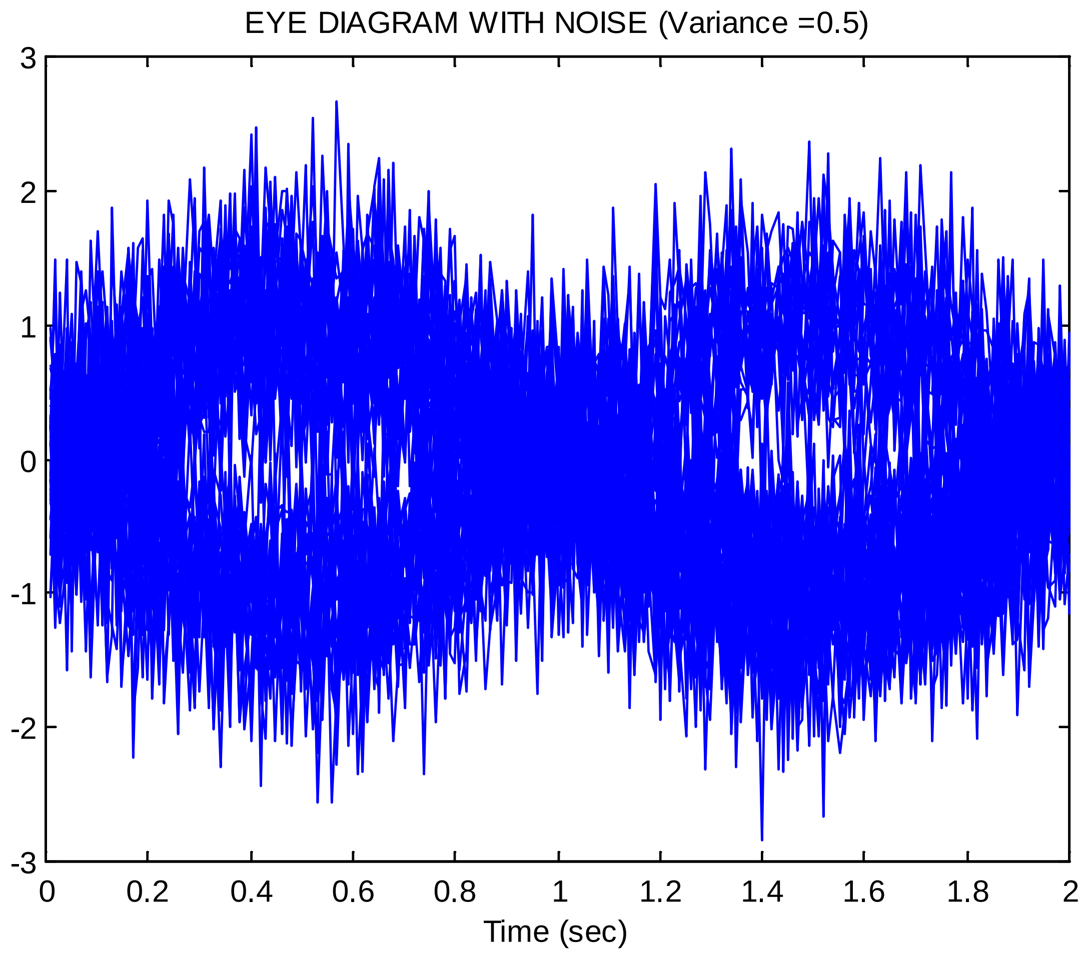
What does it tell?



D_A: Measure of distortion caused by ISI
J_T: Measure of Timing jitter
M_N: Measure of Noise margin
S_T: Measure of sensitivity to timing errors


EYE DIAGRAM
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (sec)


EYE DIAGRAM WITH NOISE (Variance =0.1)
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (sec)


EYE DIAGRAM WITH NOISE (Variance =0.5)
3
2
1
0
-1
-2
-3
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (sec)