Topic 6

6. Generation of Bit-error

6.1 Introduction

6.2 Receiver

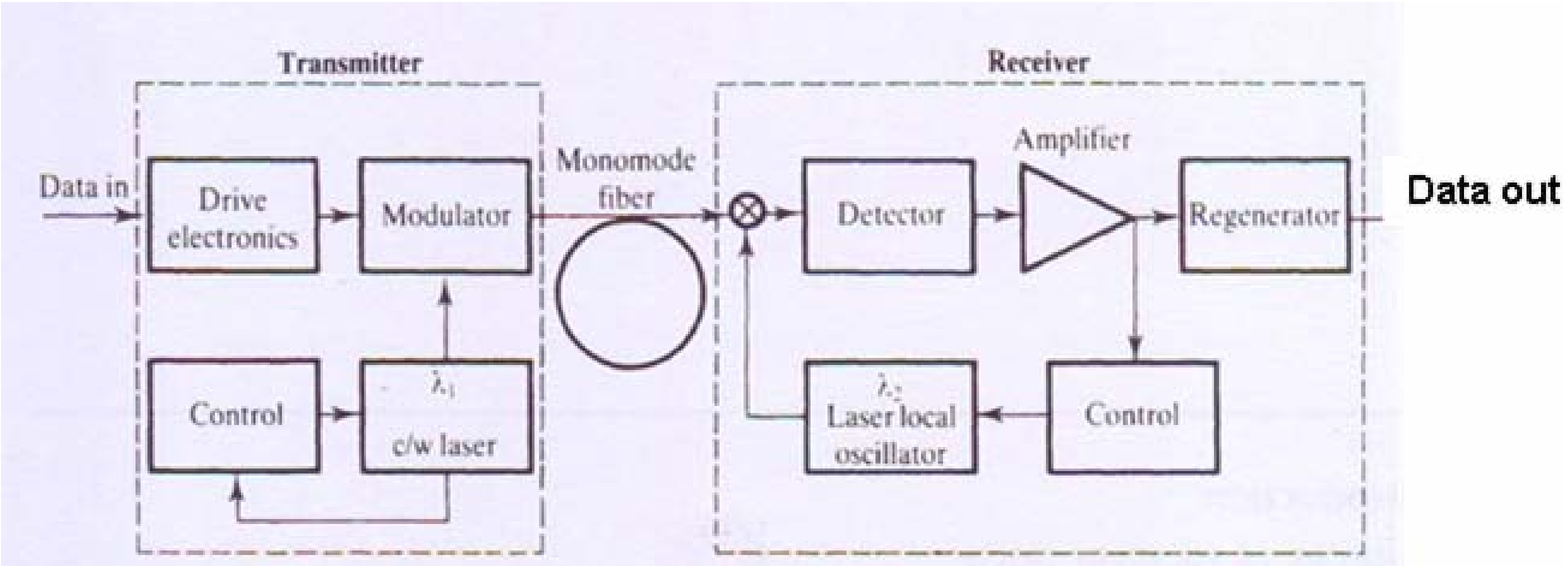
6.3 Mechanisms for error generation

6.4 Bit Error Rate

6.5 Eye diagram

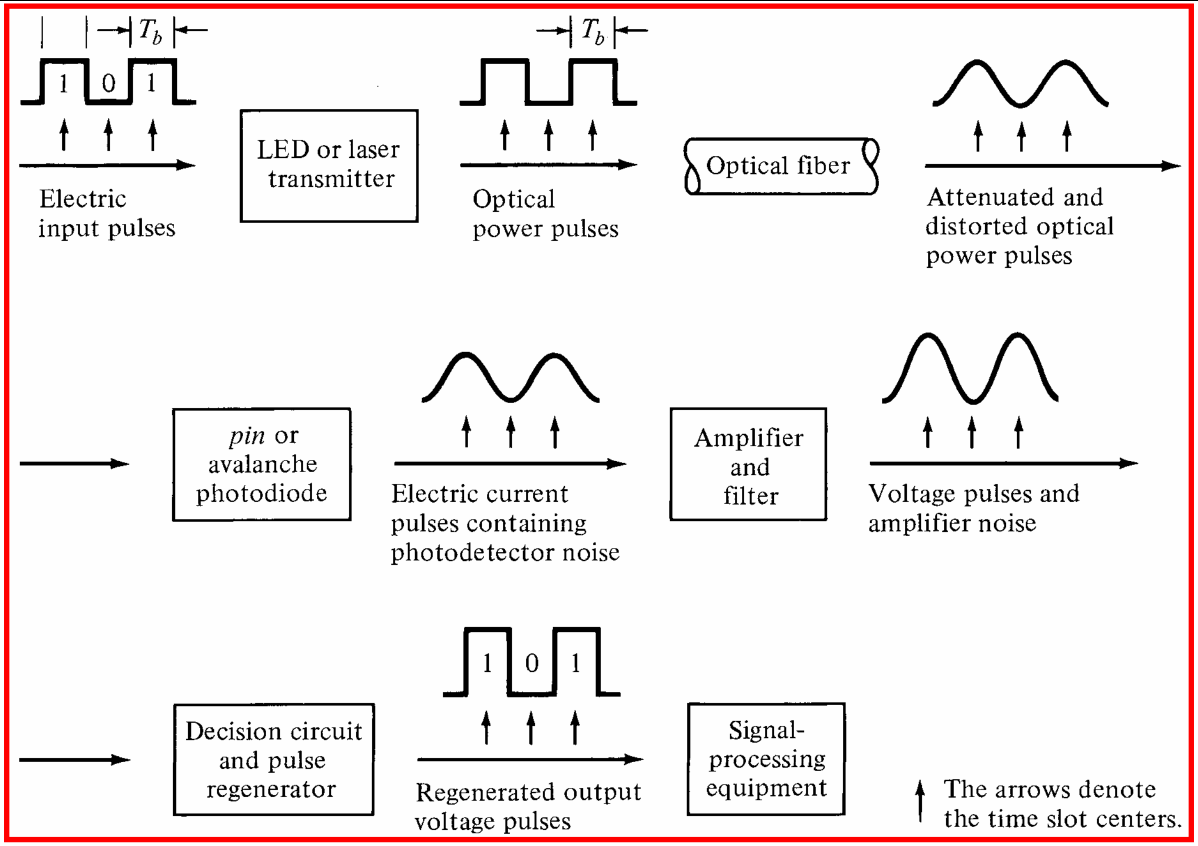
6.6 Power Penalties

Introduction (i)



- An optical communication contains **receiver and transmitter**:
- **Transmitter**: optical source (LD or LED), modulator, Drive electronics (convert electronic signals to optical signals)
- **Receiver**: photodetector, Amplifier and Regenerator (convert optical signals to electrical signals for data-out, or amplify for further process)

Block diagram of a digital fibre system



Generation of errors:

- Conversion from electric signals to optical signal: noise from detector
- Regeneration of optical signals: a decision circuit used during each bit period and compare to some pre-set threshold

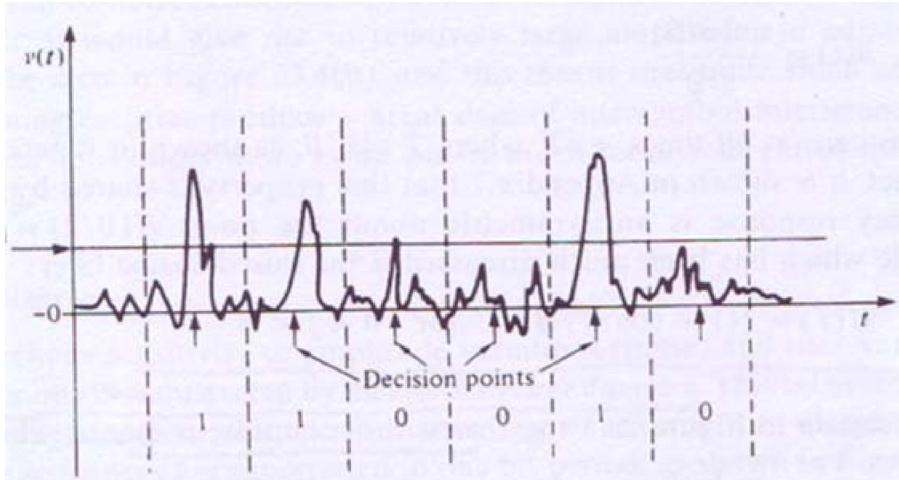
  Amplitude > threshold, "1" is regenerated

  Amplitude < threshold, "0" is regenerated

However, **internal or external disturbance** $\Rightarrow$ errors

Mechanisms for Error Generation

Threshold



- **Insufficient signal-to-noise ratio:**

When a “0” received, the voltage may be momentarily above the threshold $\Rightarrow$“0” becomes “1”

- **Timing variation**

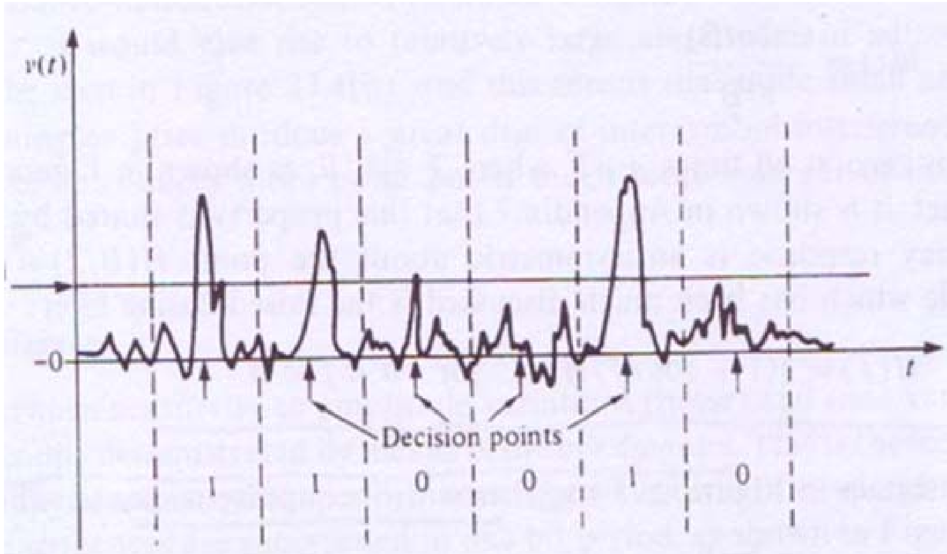
It causes the waveform to be sampled at other than its maximum amplitude

- **Intersymbol interference due to dispersion**

Some of the energy belongs to one particular bit period actually in one of the adjacent bit periods

Bit-Error-Rate

Threshold



Bit error: registered as a "1" when "0" was sent, or a "0" when a "1" was sent

BER = $N_e/N_t = N_e/Bt$

N_e : Number of errors
N_t : Total Number of bits
B : Bit rate
t : time

Typical BER: 10^{-9} ~ 10^{-12} (10^{-9} is a minimum requirement)

Fluctuating Signal Generated at Receiver

Prob. measuring "0" when "1" sent

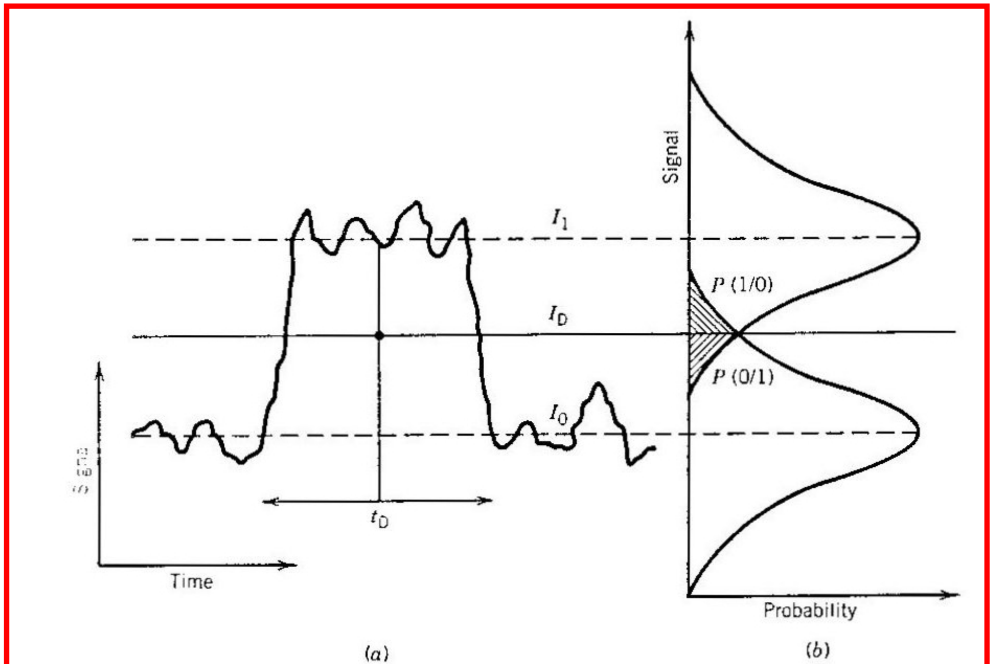
Prob. of "1" sent

Prob. of "0" sent

Prob. measuring "1" when "0" sent

BER = p(1)P(0/1) + p(0)P(1/0)

BER = ½ [P(0/1) +P(1/0)]



•P(0/1), P(1/0)
Depend on probability function of sampled I

•Prob Fn (I) – depends on noise sources

•For p-i-n photodiode main noise contribution is thermal (Gaussian) noise and shot noise (~Gaussian)

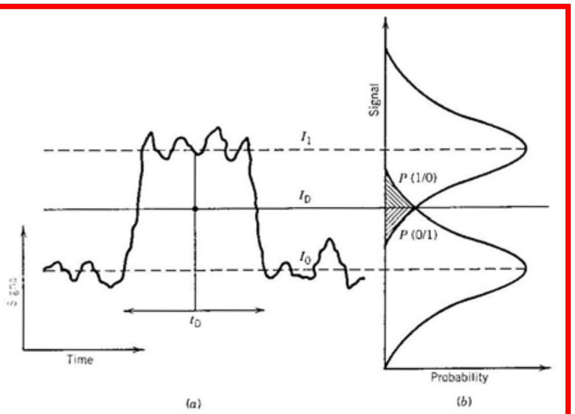
Calculation of BER

BER = p(1)P(0/1) + p(0)P(1/0)
BER = ½ [P(0/1) +P(1/0)]

Assumption: The received signals follow Gaussian probability distribution
The probability for the measured value falling in the range S to S+ds

$$p(s)ds = \frac{1}{\sqrt{2\pi}\sigma}\exp[-\frac{-(s-m)^2}{2\sigma^2}]ds$$

Where m: the mean value of signal ; σ: standard deviation of distribution



Based on the above equation, it can be obtained the relationship between BER and S/N

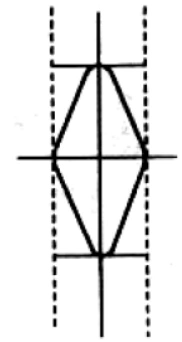
$$BER = \tfrac{1}{2}\left[1 - erf\left(\frac{1}{2\sqrt{2}}\frac{S}{N}\right)\right]$$

$$erf(x) = \frac{2}{\pi}\int_0^x e^{-y^2}dy$$

Signal-to-noise ratio

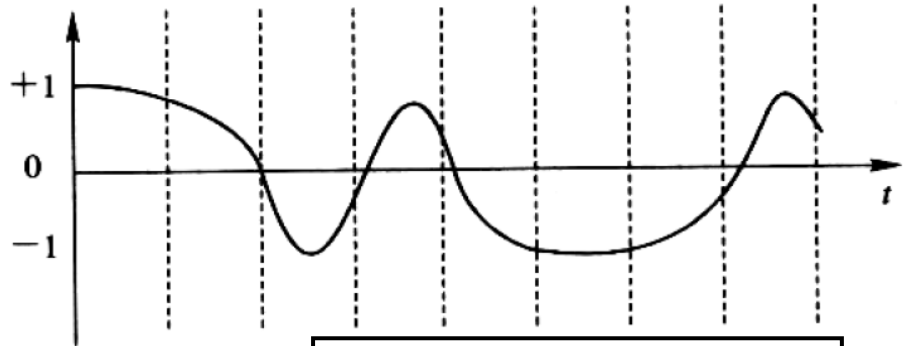
- **Increasing Signal-to-noise ratio ⇒ Decreasing BER**
- Very important for calculating **power budget**

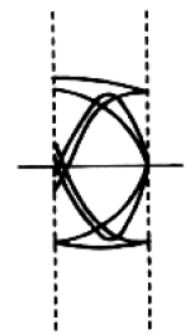
Eye Diagram (i)



Without degradation

Open eye





With degradation

Reduced size

•**A method indicating system performance:**

Eye diagram or pattern: Examination of the received waveform on an oscilloscope

•Display obtained over one bit duration:
Superimposing all possible pulse sequences

Eye Diagram (ii)

Reliable transmission **requires an open "eye"**

Power Penalty

•Bit errors due to optical dispersion can be reduced by **having a higher intensity signal at the receiver**

This is termed as the "**Dispersion Penalty**" and would appear in the power budget for the system

•The presence of power in logic level "0" gives some additional errors compared to ideal case where there is no power

– Extra receiver power is required to reduce these errors

– termed as **extinction ratio penalty**

T6 Summary

- The bit-error-rate which can be tolerated determines the power at the receiver for a given data rate.
- Power penalties are paid for e.g. dispersion, and non-zero extinction ratios.
- Due to dispersion and loss within a fibre it is necessary along a fibre link to regenerate the signal from time-to-time.
- A regenerator consists of a detector, electronics, and a transmitter which will resend an input signal - this must be tied to a specific data type though

T6 Tutorial Questions

T6.1 Consider an 800nm receiver (silicon p-i-n photodiode). Assume 20MHz bandwidth, 65% quantum efficiency, 1nA dark current, 8pF junction capacitance and a 3dB amplifier noise figure. The receiver is illuminated with 5 μW of optical power. Determine the noise currents due to shot noise, and thermal noise. What is the signal to noise ratio?