

# **Topic 6**

## **6. Generation of Bit-error**

6.1 Introduction

6.2 Receiver

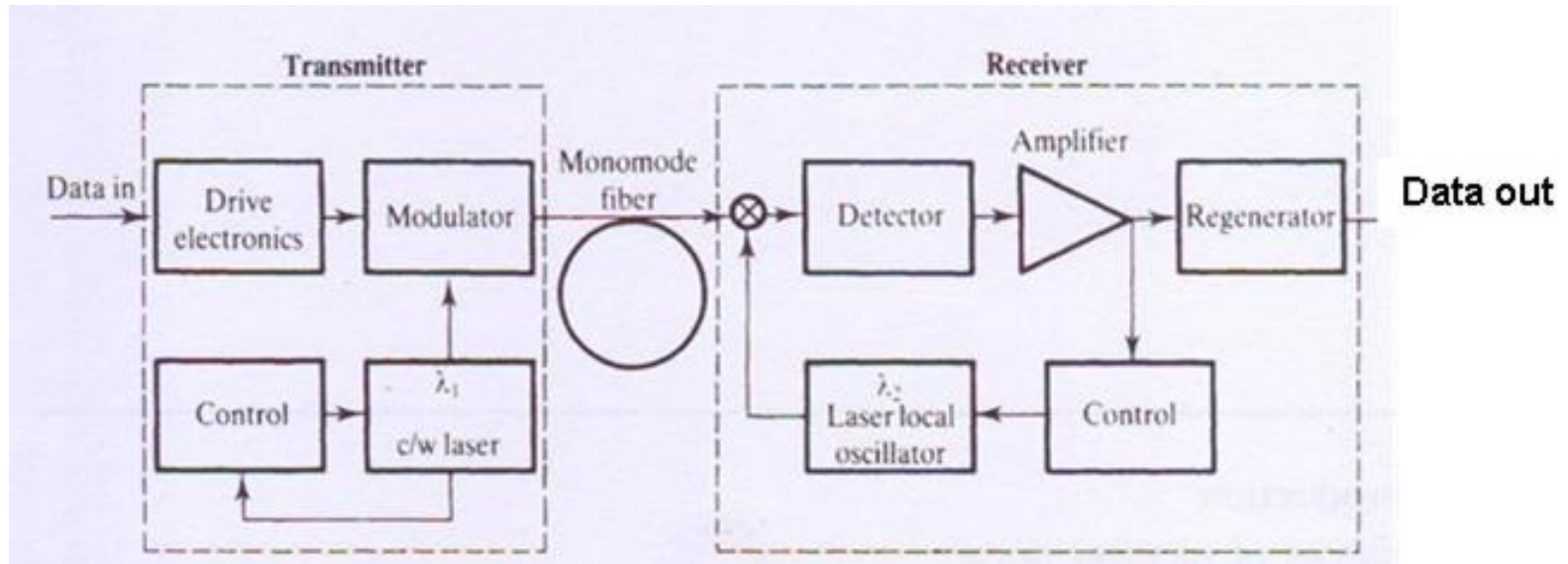
6.3 Mechanisms for error generation

6.4 Bit Error Rate

6.5 Eye diagram

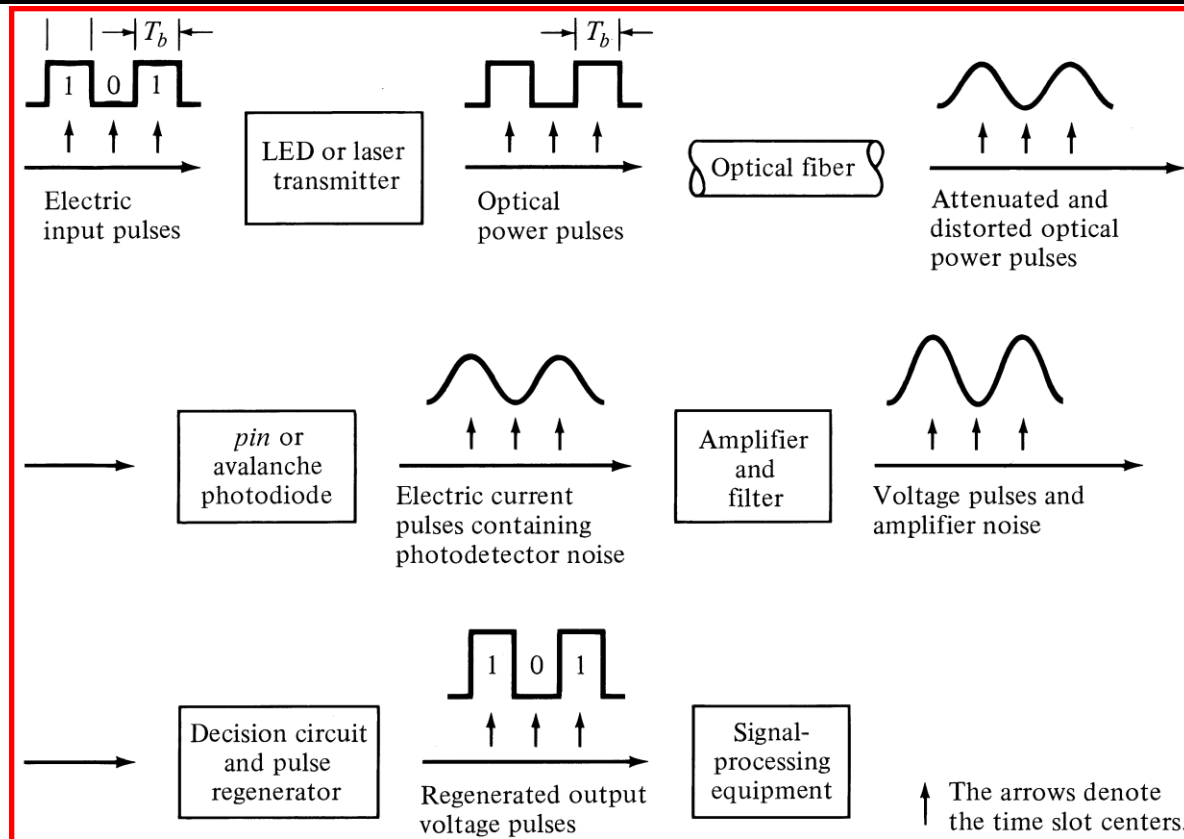
6.6 Power Penalties

# 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:

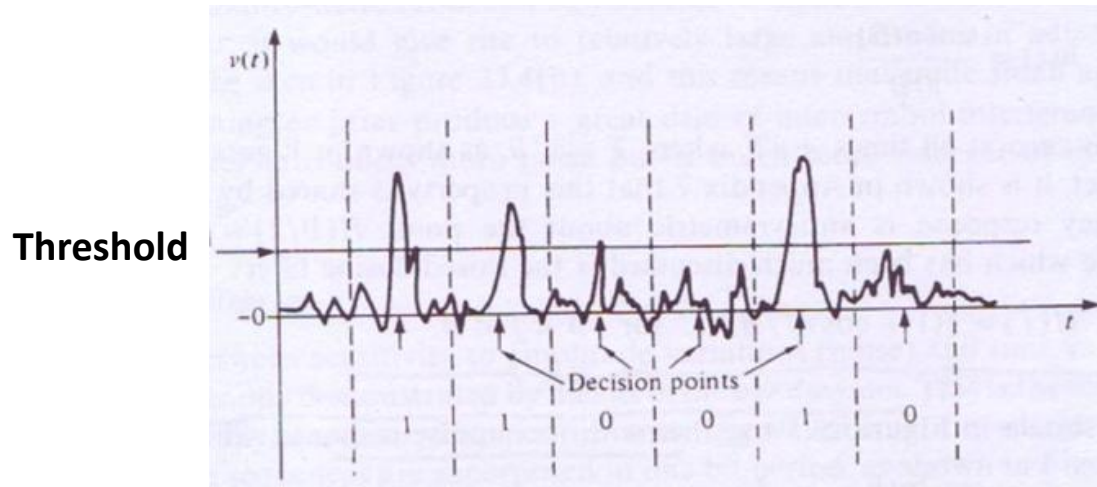
- Conversion from electric signals to optical signal: noise from detector
- Regeneration of optical signals: a decision circuit used during each bit period and compare to some pre-set threshold

Amplitude > threshold, "1" is regenerated

Amplitude < threshold, "0" is regenerated

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

# Mechanisms for Error Generation



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

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

- **Timing variation**

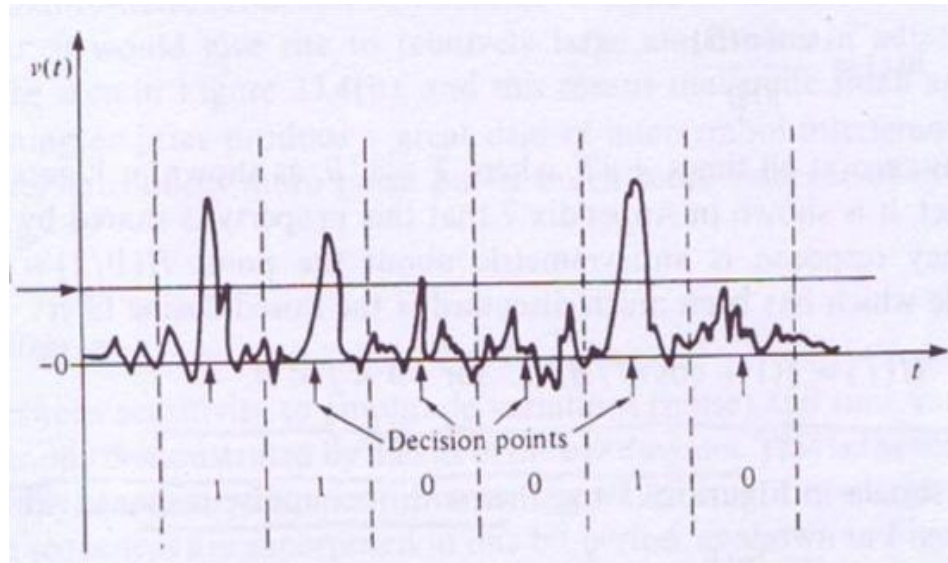
It causes the waveform to be sampled at other than its maximum amplitude

- **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

$$\text{BER} = N_e / N_t = N_e / Bt$$

$N_e$  : Number of errors

$N_t$  : Total Number of bits

$B$  : Bit rate

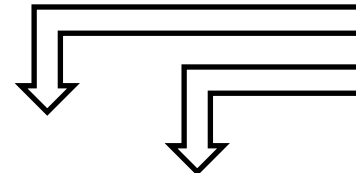
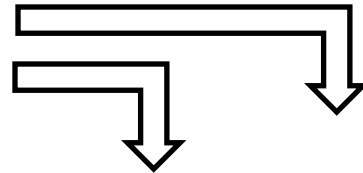
$t$  : time

**Typical BER:  $10^{-9} \sim 10^{-12}$  ( $10^{-9}$  is a minimum requirement)**

# Fluctuating Signal Generated at Receiver

Prob. measuring  
"0" when "1" sent

Prob. of "1" sent

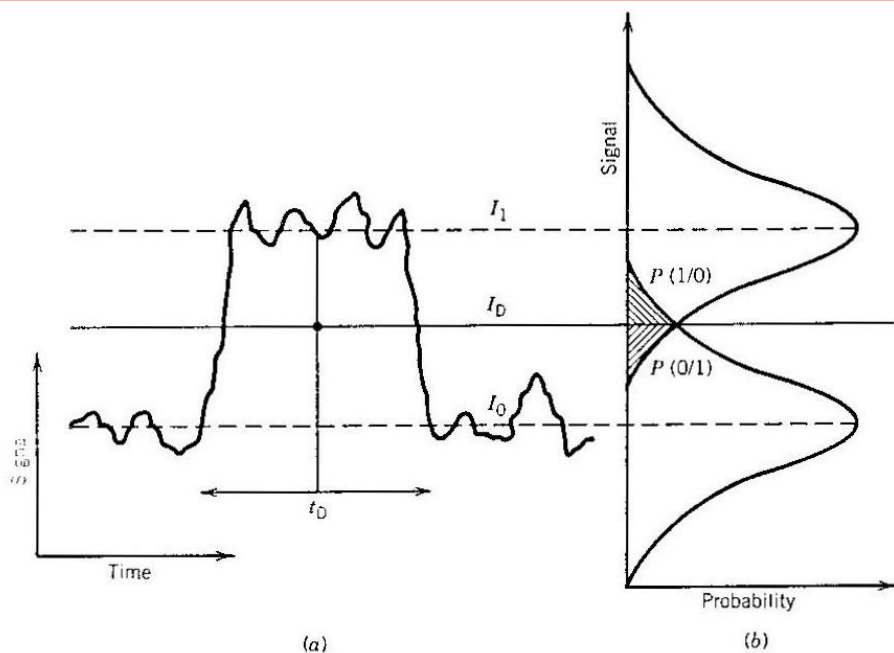


Prob. of "0" sent

Prob. measuring  
"1" when "0" sent

$$\text{BER} = p(1)P(0/1) + p(0)P(1/0)$$

$$\text{BER} = \frac{1}{2} [P(0/1) + P(1/0)]$$



- $P(0/1)$ ,  $P(1/0)$

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 ( $\sim$ Gaussian)

# Calculation of BER

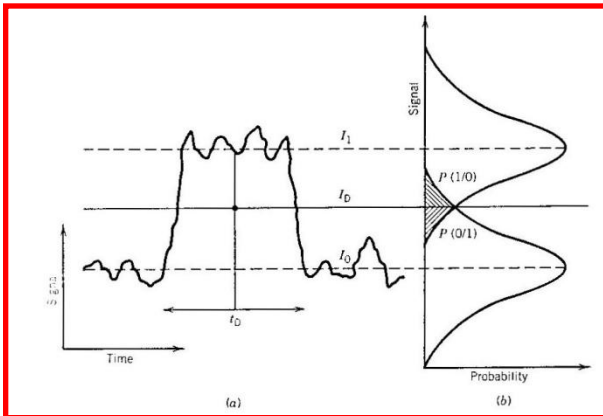
$$\text{BER} = p(1)P(0/1) + p(0)P(1/0)$$

$$\text{BER} = \frac{1}{2} [P(0/1) + P(1/0)]$$

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

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

Where  $m$ : the mean value of signal ;  $\sigma$ : standard deviation of distribution



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

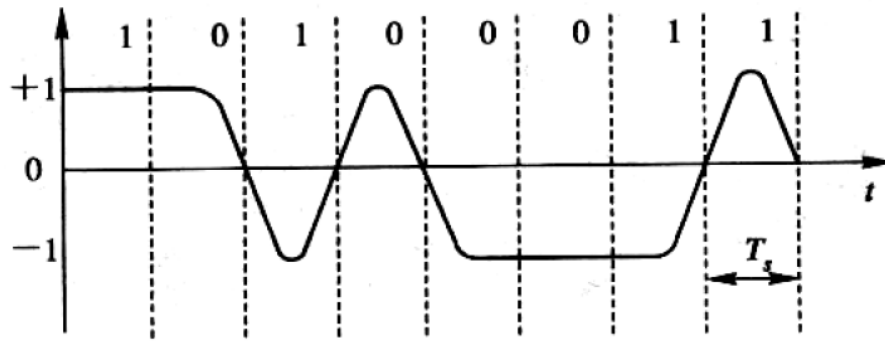
$$\text{BER} = \frac{1}{2} \left[ 1 - \text{erf}\left(\frac{1}{2\sqrt{2}} \frac{S}{N}\right) \right]$$

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

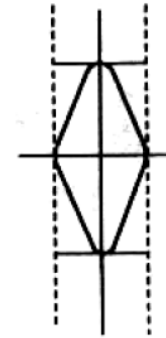
**Signal-to-noise ratio**

- **Increasing Signal-to-noise ratio  $\Rightarrow$  Decreasing BER**
- Very important for calculating **power budget**

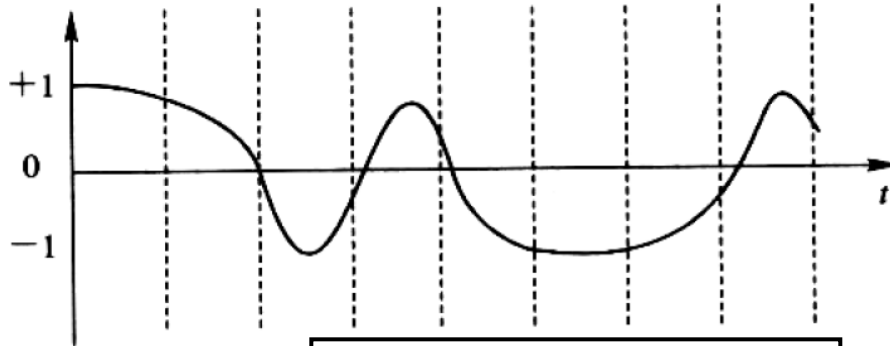
# Eye Diagram (i)



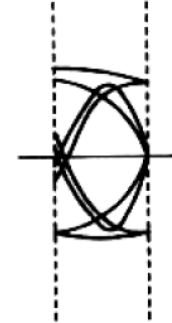
Without degradation



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 two bit duration:  
Superimposing all possible pulse sequences



## Eye Diagram (ii)



Agilent

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  $\mu$ W of optical power. Determine the noise currents due to shot noise, and thermal noise. What is the signal to noise ratio?