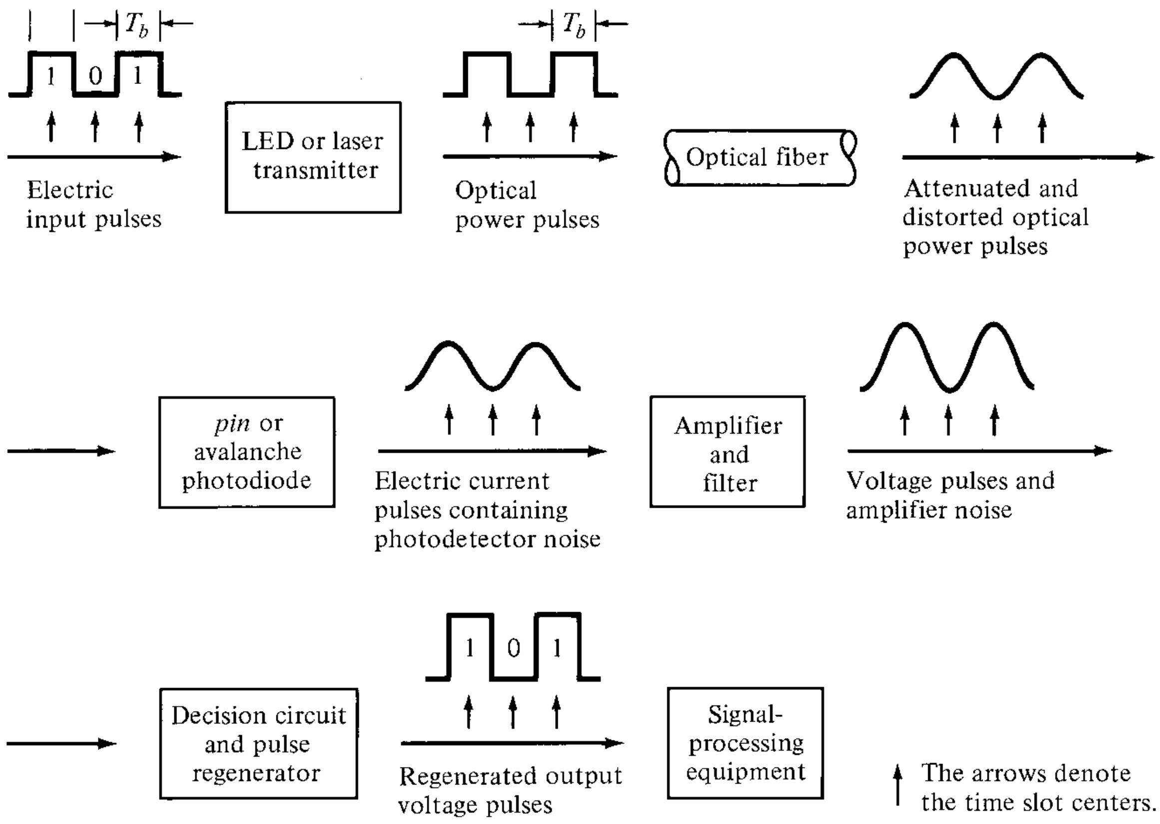
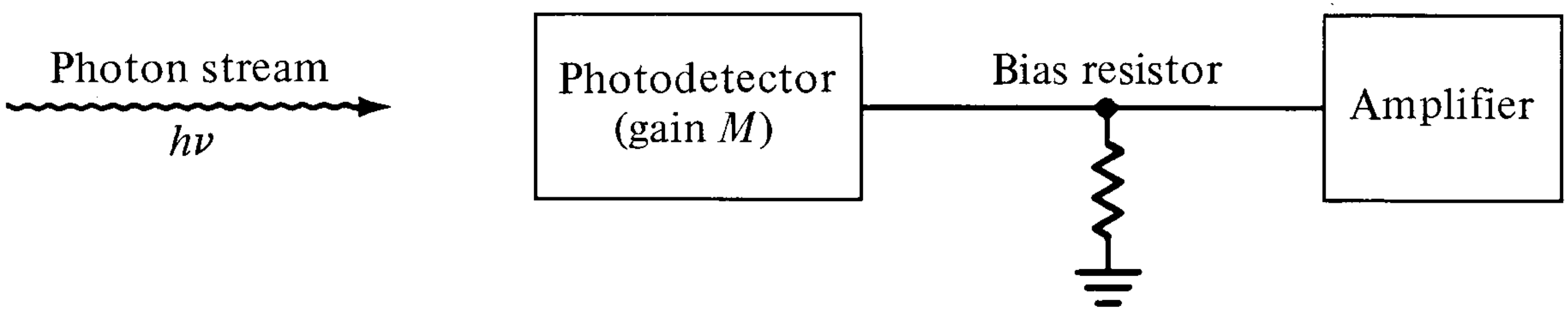
Photonic Transmission Systems (Digital & Analog)

Digital Transmission System (DTS)



- The design of optical receiver is much more complicated than that of optical transmitter because the receiver must first detect weak, distorted signals and the n make decisions on what type of data was sent.

Error Sources in DTS



- Photon detection quantum noise (Poisson fluctuation)

- Bulk dark current
- Surface leakage current
- Statistical gain fluctuation (for avalanche photodiodes)

- Thermal noise

- Amplifier noise

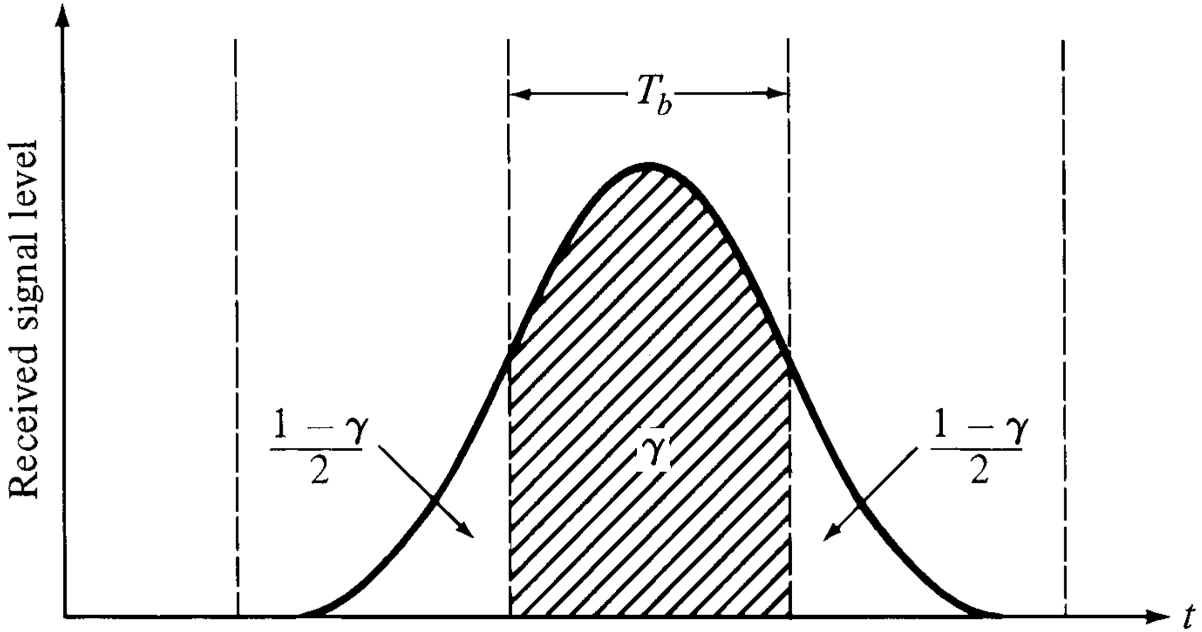
Average number and Actual of electron-hole pairs in photo detector

$$\overline{N} = \frac{\eta}{h\nu}\int_0^{\tau} P(t)dt = \frac{\eta}{h\nu} E$$

$$P_r(n) = \overline{N}^n \frac{e^{-\overline{N}}}{n!}$$

$\overline{N}$ is the average number of electron-hole pairs in photodetector, η is the detector quantum efficiency and E is energy received in a time interval τ and $h\nu$ is photon energy, where $P_r(n)$ is the probability that n electrons are emitted in an interval τ.

InterSymbol Interference (ISI)



Pulse spreading in an optical signal, after traversing along optical fiber, leads to ISI. Some fraction of energy remaining in appropriate time slot is designated by γ, so the rest is the fraction of energy that has spread Into adjacent time slots.

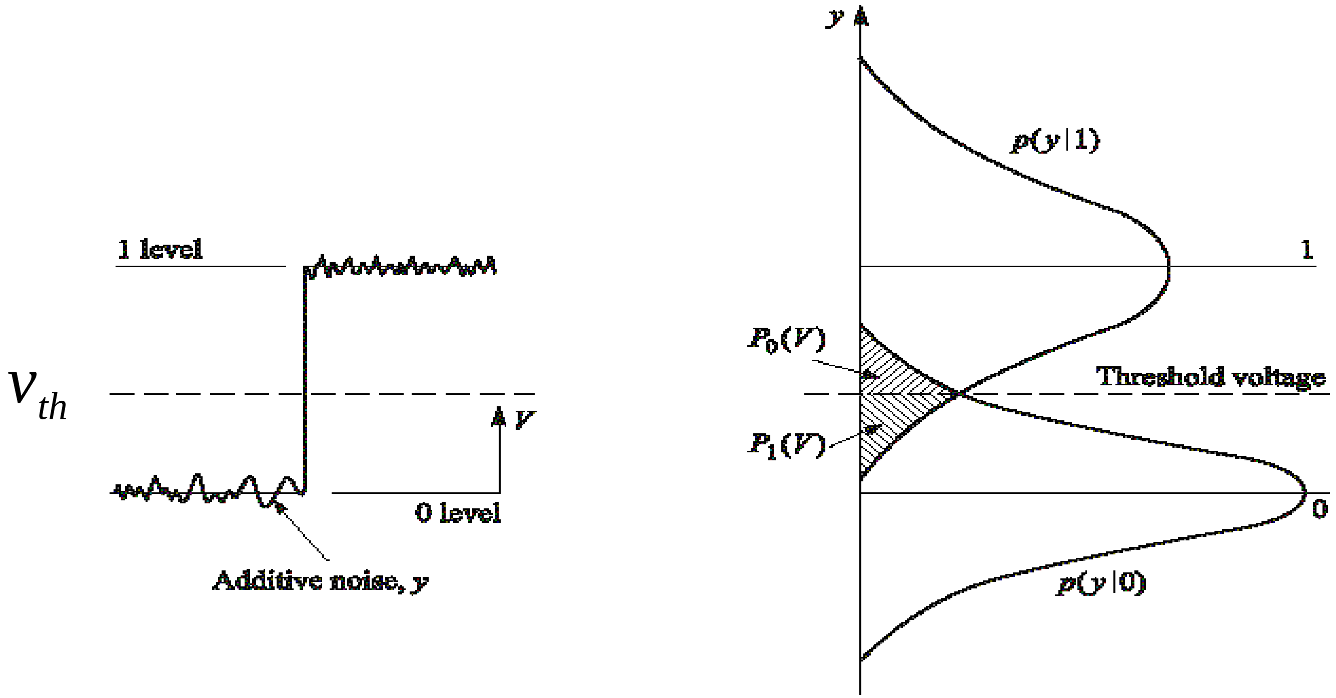
Bit Error Rate (BER)

$$\mathrm{BER} = \text{Probability of Error} =$$

$$\frac{\text{Number of error over a certain time interval } t}{\text{total number of pulses transmitted during } t} =$$

$$\frac{N_e}{N_t} = \frac{N_e}{Bt} \qquad B = 1/T_b$$

- **Probability of Error**= probability that the output voltage is less than the threshold when a 1 is sent + probability that the output voltage is more than the threshold when a 0 has been sent.



Probability distributions for received logical 0 and 1 signal pulses.
the different widths of the two distributions are caused by various signal distortion effects.

$$P_1(v) = \int_{-\infty}^{v} p(y\,|\,1)\,dy \quad \text{probablity that the equalizer output voltage is less than } v, \text{if } 1 \text{ transmitted}$$

[7-6]

$$P_0(v) = \int_{v}^{\infty} p(y\,|\,0)\,dy \quad \text{probablity that the equalizer output voltage exceeds } v, \text{if } 0 \text{ transmitted}$$

$$\boxed{\begin{aligned} P_e &= q_1 P_1(v_{th}) + q_0 P_0(v_{th}) \\ &= q_1 \int_{-\infty}^{v_{th}} p(y\,|\,1)dy + q_0 \int_{v_{th}}^{\infty} p(y\,|\,1)dy \end{aligned}} \qquad [7\text{-}7]$$

- Where q_1 and q_0 are the probabilities that the transmitter sends 0 and 1 respectively. $q_0 = 1 - q_1$

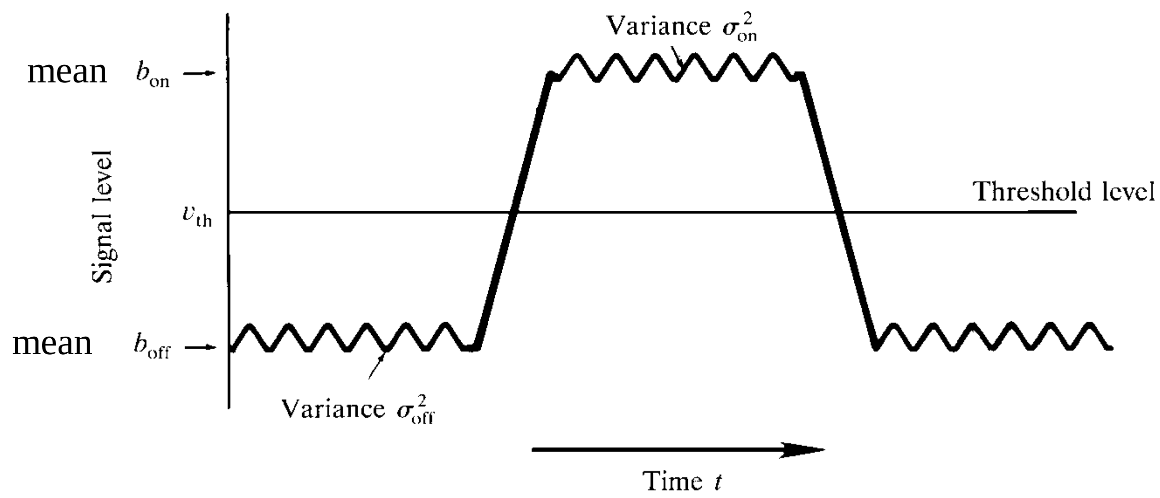
- For an unbiased transmitter $q_0 = q_1 = 0.5$

Gaussian Distribution

$$P_1(v_{th}) = \int_{-\infty}^{v_{th}} p(y\,|\,1)dy = \frac{1}{\sqrt{2\pi}\sigma_{\text{on}}}\int_{-\infty}^{v_{th}} \exp\left[-\frac{(v-b_{on})^2}{2\sigma_{\text{on}}^2}\right]dv$$

$$P_0(v_{th}) = \int_{v_{th}}^{\infty} p(y\,|\,0)dy = \frac{1}{\sqrt{2\pi}\sigma_{\text{off}}}\int_{v_{th}}^{\infty} \exp\left[-\frac{(v-b_{\text{off}})^2}{2\sigma_{\text{off}}^2}\right]dv$$

[7-8]



- If we assume that the probabilities of 0 and 1 pulses are equally likely, then using eq [7-7] and [7-8] , BER becomes:

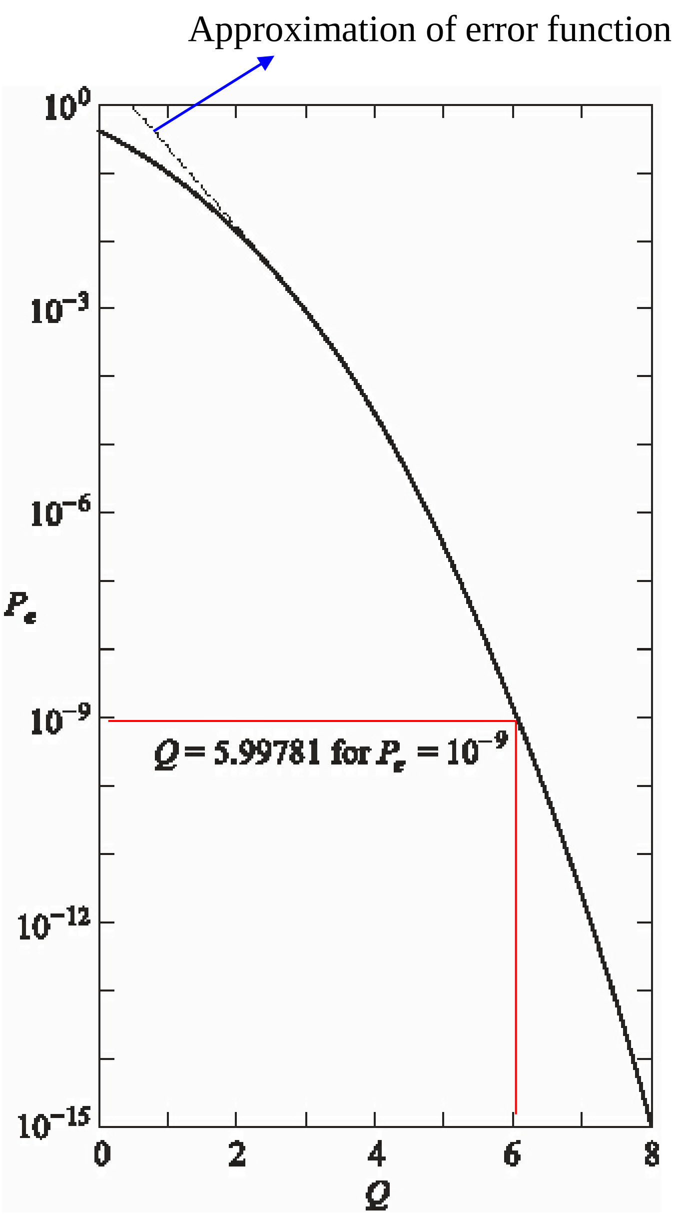
$$\mathrm{BER} = P_e(Q) = \frac{1}{\sqrt{\pi}} \int_{Q/\sqrt{2}}^{\infty} \exp(-x^2)dx = \frac{1}{2}\left[1 - \mathrm{erf}\,(\frac{Q}{\sqrt{2}})\right]$$

$$\approx \frac{1}{\sqrt{2\pi}} \frac{\exp(\text{-}Q^2/2)}{Q} \qquad [7\text{-}9]$$

$$Q = \frac{v_{th} - b_{\mathrm{off}}}{\sigma_{\mathrm{off}}} = \frac{b_{\mathrm{on}} - v_{th}}{\sigma_{\mathrm{on}}} \qquad [7\text{-}9]$$

$$\mathrm{erf}\,(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-y^2)dy \qquad [7\text{-}10]$$

Variation of BER vs Q, according to eq [7-9].



Special Case

In special case when:

$$\sigma_{\text{off}} = \sigma_{\text{on}} = \sigma \;\; \& \, b_{\text{off}} = 0, b_{\text{on}} = V$$

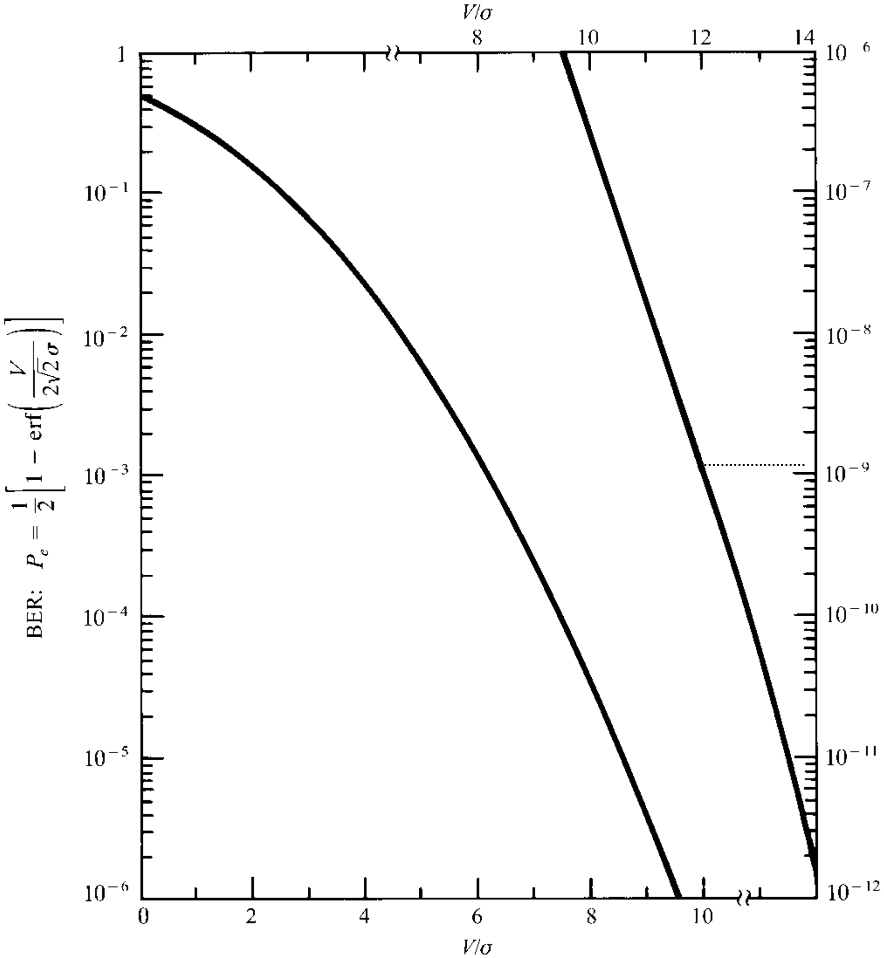
From eq [7-29], we have: $v_{th} = V/2$

Eq [7-8] becomes:

$$P_e(\sigma) = \frac{1}{2}\left[1 - \operatorname{erf}\left(\frac{V}{2\sqrt{2}\sigma}\right)\right]$$

[7-11]

$\frac{V}{\sigma}$ is peak signal-to-rms-noise ratio.



Quantum Limit

- Minimum received power required for a specific BER assuming that the photodetector has a 100% quantum efficiency and zero dark current. For such ideal photo-receiver,

$$P_e = P_1(0) = \exp(-\overline{N})$$

- Where $\overline{N}$ is the average number of electron-hole pairs, when the incident optical pulse energy is E and given with 100% quantum efficiency

. $(\eta = 1)$

- Note that, in practice the sensitivity of receivers is around 20 dB higher than quantum limit because of various nonlinear distortions and noise effects in the transmission link.

Analog Transmission System

- In photonic analog transmission system the performance of the system is mainly determined by signal-to-noise ratio at the output of the receiver.
- In case of amplitude modulation the transmitted optical power *P(t)* is in the form of:

$$P(t) = P_t[1 + ms(t)]$$

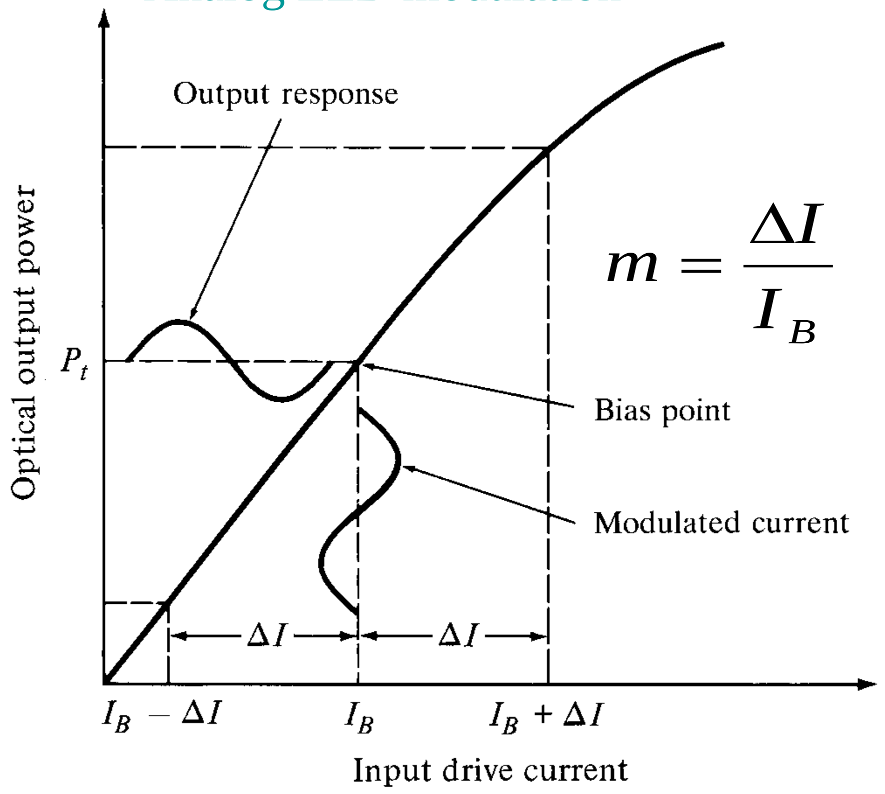
where *m* is modulation index, and *s(t)* is analog modulation signal.

- The photocurrent at receiver can be expressed as:

$$i_s(t) = \Re_0 M P_r [1 + ms(t)]$$

[7-13]

Analog LED modulation



$$m = \frac{\Delta I}{I_B}$$

Receiver sensitivity

- Minimum optical power the receiver can detect for specified BER
- There is no optical power in zero pulse

$$\Re = \frac{I_P}{P} = \frac{\eta q}{h\nu}$$

$$P = \frac{I_P}{\Re}$$

$$Q = \frac{v_{th} - b_{\text{off}}}{\sigma_{\text{off}}} = \frac{b_{\text{on}} - v_{th}}{\sigma_{\text{on}}} = \frac{b_{\text{on}} - b_{\text{off}}}{\sigma_{\text{on}} + \sigma_{\text{off}}} = \frac{I_{\text{on}} - I_{\text{off}}}{\sigma_{\text{on}} + \sigma_{\text{off}}}$$

$$= \frac{I_{\text{on}}}{\sigma_{\text{on}} + \sigma_{\text{off}}}$$

$$PSensitivity = P/2 = (\sigma_{\text{on}} + \sigma_{\text{off}})Q/2RM$$

- By substituting shotnoise and thermal noise

$$PSensitivity = (1/R)\frac{Q}{M}\left[\frac{qMF(M)BQ}{2} + \sigma_T\right]$$

- For pin photon diode M=1 and F(M) =1 B is bit rate,electrical bandwidth is half the bitrate B