Optical Receivers

Receiver Noise

- Shot Noise or Quantum Noise

- Dark Current Noise
  - Bulk Dark Current Noise
  - Surface Dark Current Noise

- Thermal Noise

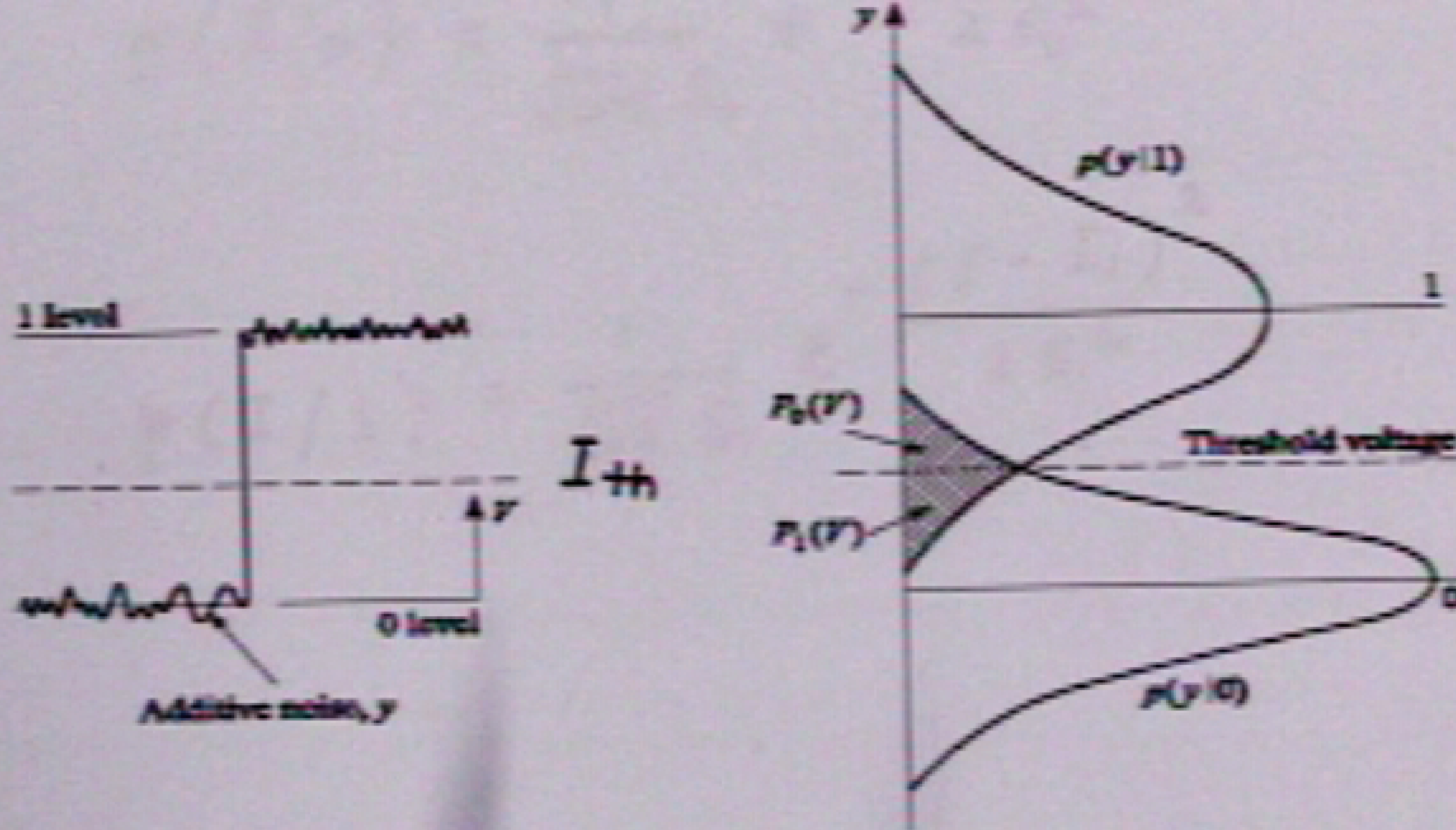
Bit Error Ratio Calculations

- Binary Data
- Unbiased Data
- Noise is Additive
- Variance of Noise is different for 0 and 1 bit

$$p(I/0) = \frac{1}{\sqrt{2\pi}\,\sigma_0} e^{-\frac{(I - I_0)^2}{2\sigma_0^2}}$$

$$p(I/1) = \frac{1}{\sqrt{2\pi}\,\sigma_1} e^{-\frac{(I - I_1)^2}{2\sigma_1^2}}$$

Logic 0 and 1 probability distributions



Bit Error Ratio

$$BER = P(0/1)\,P(1) + P(1/0)\,P(0)$$

$$P(1) = P(0) = 1/2$$

$$BER = \frac{1}{2}\left\{ P(0/1) + P(1/0) \right\}$$

$$P(0/1) = \frac{1}{\sqrt{2\pi}\,\sigma_1} \int_{-\infty}^{I_{th}} e^{-\frac{(I - I_1)^2}{2\sigma_1^2}}\, dI$$

$$P(1/0) = \frac{1}{\sqrt{2\pi}\,\sigma_0} \int_{I_{th}}^{\infty} e^{-\frac{(I - I_0)^2}{2\sigma_0^2}}\, dI$$

Complementary Error Function

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-y^2}\, dy$$

$$P(0/1) = \frac{1}{2} \operatorname{erfc}\left(\frac{I_1 - I_{th}}{\sigma_1 \sqrt{2}}\right)$$

$$P(1/0) = \frac{1}{2} \operatorname{erfc}\left(\frac{I_{th} - I_0}{\sigma_0 \sqrt{2}}\right)$$

$$BER = \frac{1}{4}\left\{ \operatorname{erfc}\left(\frac{I_1 - I_{th}}{\sigma_1 \sqrt{2}}\right) + \operatorname{erfc}\left(\frac{I_{th} - I_0}{\sigma_0 \sqrt{2}}\right)\right\}$$

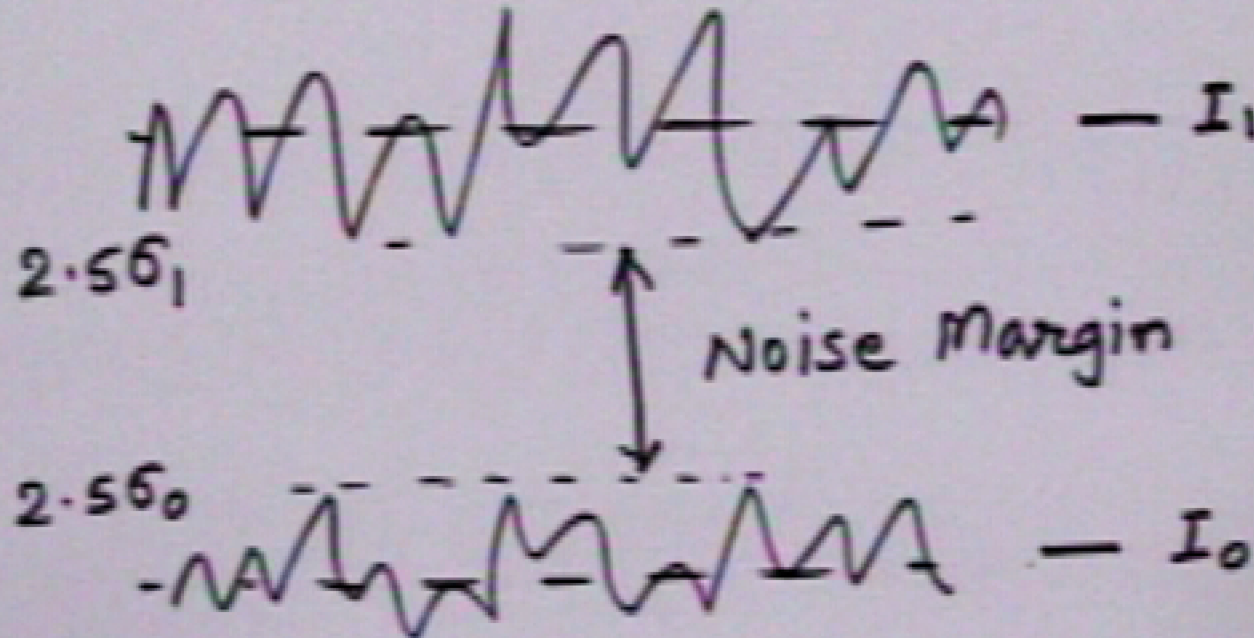
BER minimum when

$$\frac{I_1 - I_{th}}{\sigma_1} = \frac{I_{th} - I_0}{\sigma_0}$$

optimum threshold current

$$I_{th} = \frac{\sigma_0 I_1 + \sigma_1 I_0}{\sigma_0 + \sigma_1}$$

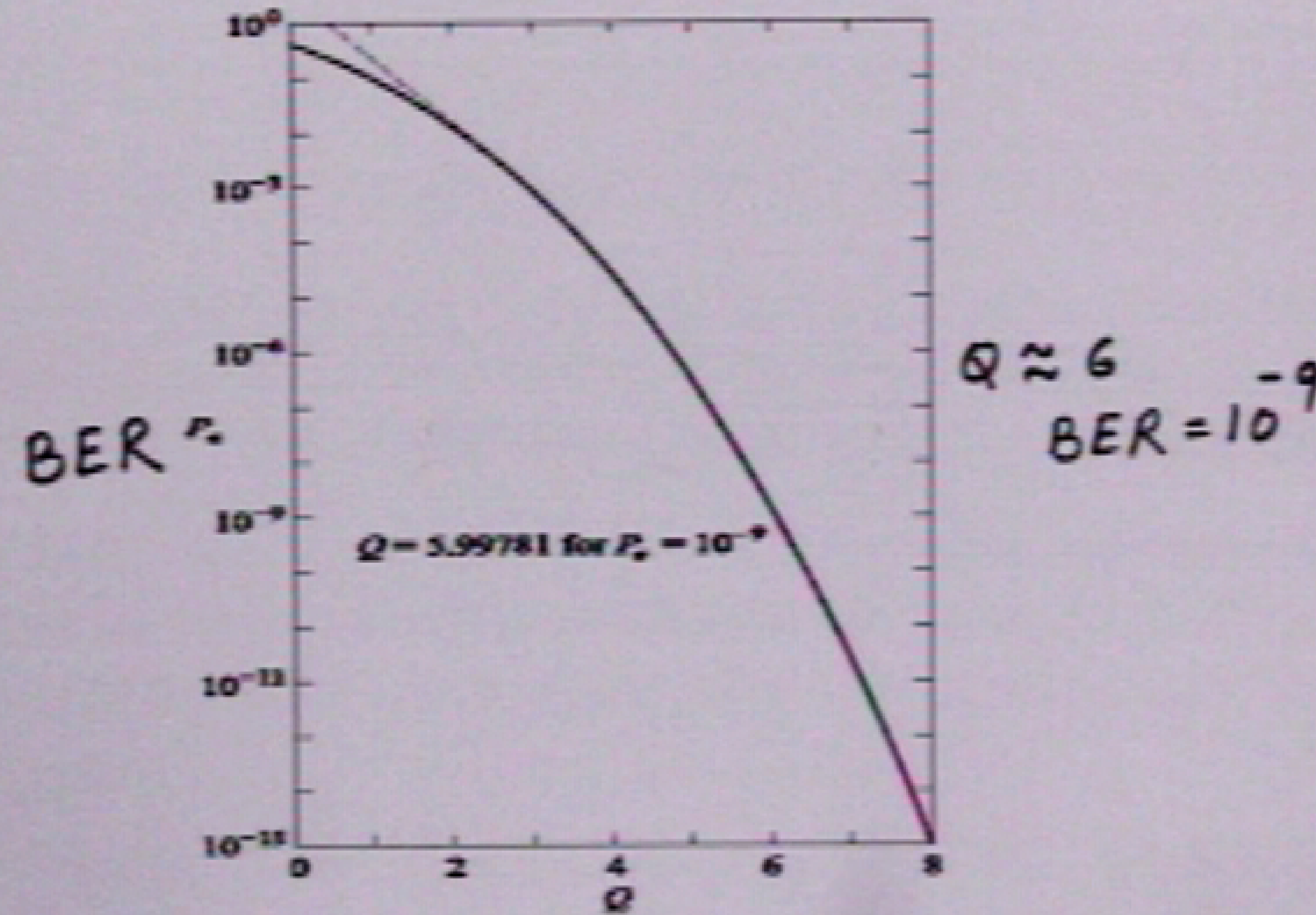
$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0}$$


I_1
$2.5\sigma_1$
Noise Margin
$2.5\sigma_0$
I_0

$$BER = \frac{1}{2}\,\mathrm{erfc}\left(\frac{Q}{\sqrt{2}}\right)$$

$$\simeq \frac{e^{-Q^2/2}}{Q\sqrt{2\pi}} \qquad Q > 3$$

BER versus Q factor



- Thermal Noise Dominated

$$\sigma_T >> \sigma_S$$

- Shot Noise Dominated

$$\sigma_S >> \sigma_T$$

Thermal Noise Dominated

$$SNR = \frac{R_L \mathcal{R}^2}{4KTB} P_{in}^2$$

$$SNR \propto R_L P_{in}^2$$

Noise Equivalent Power (NEP)

$$NEP = \frac{P_{in}}{\sqrt{B}} = \left(\frac{4KT}{R_L \mathcal{R}^2} \right)^{1/2}$$

$$1 - 10 \ pW/Hz^{1/2}$$

Shot Noise Dominated

$$\sigma_s >> \sigma_T$$

$$SNR = \frac{R P_{in}}{2 q B}$$

$$\propto P_{in}$$