Error Sources

✓ Errors in the detection mechanism can arise from various noises and disturbances associates with the signal detection system.

✓ The two most common samples of the spontaneous fluctuations are shot noise and thermal noise.

✓ Shot noise arises in electronic devices because of the discrete nature of current flow in the device.

✓ Thermal noise arises from the random motion of electrons in a conductor.

✓ The random arrival rate of signal photons produces a quantum (or shot) noise at the photodetector. This noise depends on the signal level.

✓ This noise is of particular importance for PIN receivers that have large optical input levels and for APD receivers.

✓ When using an APD, an additional shot noise arises from the statistical nature of the multiplication process. This noise level increases with increasing avalanche gain *M*.

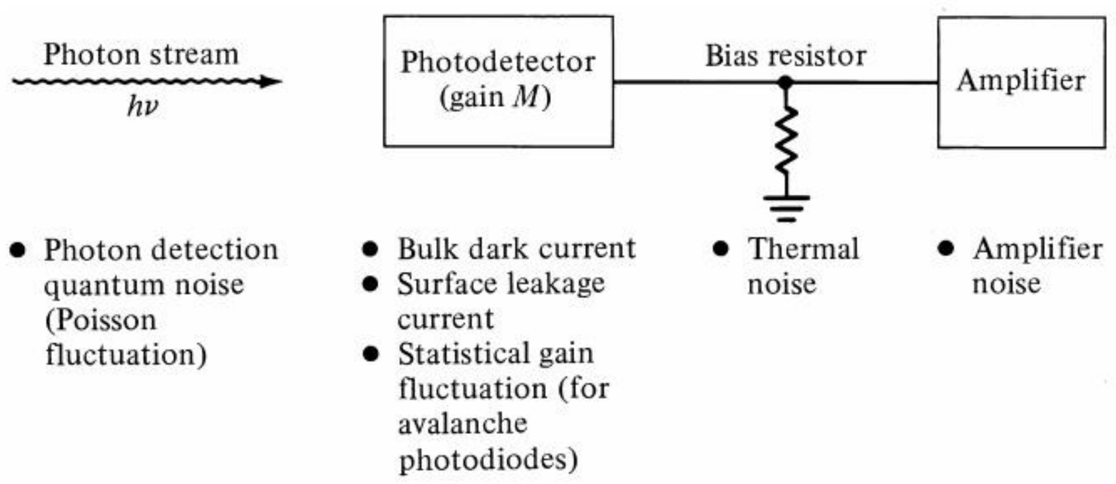

Figure 4.2 Noise sources and disturbances in the optical pulse detection mechanism.

[Source: htpp://img.brainkart.com]

✓ Thermal noises arising from the detector load resistor and from the amplifier electronics tend to dominate in applications with low SNR when a PIN photodiode is used.

✓ When an APD is used in low-optical-signal level applications, the optimum avalanche gain is determined by a design tradeoff between the thermal noise and the gain-dependent quantum noise.

✓ The primary photocurrent generated by the photodiode is a time-varying Poisson process.

✓ If the detector is illuminated by an optical signal *P*(*t*), then the average number of electron-hole pairs generated in a time t is

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

where h is the detector quantum efficiency, *h*n is the photon energy, and *E* is the energy received in a time interval .

✓ The actual number of electron-hole pairs *n* that are generated fluctuates from the average according to the Poisson distribution

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

where *P*r(*n*) is the probability that *n* electrons are emitted in an interval t

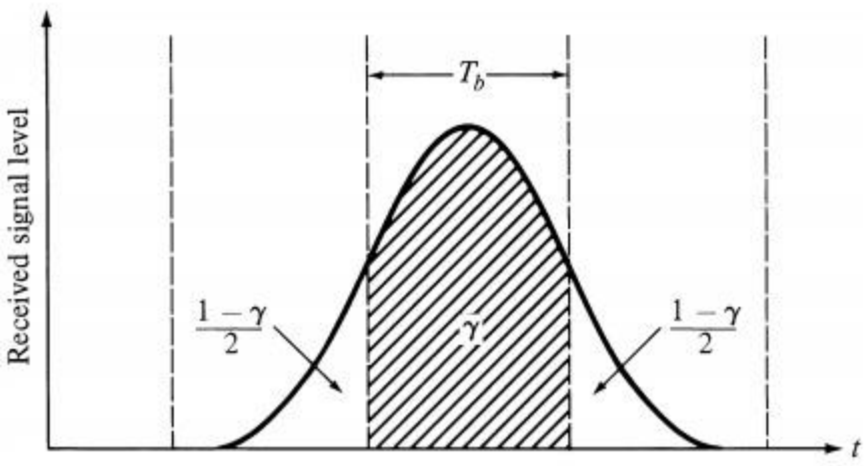

Figure 4.3 Pulse spreading in an optical signal that leads to ISI.

[Source: htpp://img.brainkart.com]

✓ For a detector with a mean avalanche gain *M* and an ionization rate ratio *k*, the excess noise factor *F*(*M*) for electron injection is where the factor *x* ranges between 0 and 1.0 depending on the photodiode material.

$$F(M) = kM + \left(2 - \frac{1}{M}\right)(1-k)$$

Or

$$F(M) \cong M^x$$

✓ A further error source is attributed to *intersymbol interference* (ISI), which results from pulse spreading in the optical fiber.

✓ The fraction of energy remaining in the appropriate time slot is designated by so that 1-g is the fraction of energy that has spread into adjacent time slots.

Receiver Configuration

✓ A typical optical receiver is shown in Figure 4.4. The three basic stages of the receiver are a photodetector, an amplifier, and an equalizer.

✓ The photo-detector can be either an APD with a mean gain *M* or a PIN for which *M*=1.

✓ The photodiode has a quantum efficiency h and a capacitance *C*d.

✓ The detector bias resistor has a resistance *R*b which generates a thermal noise current *i*b(*t*).

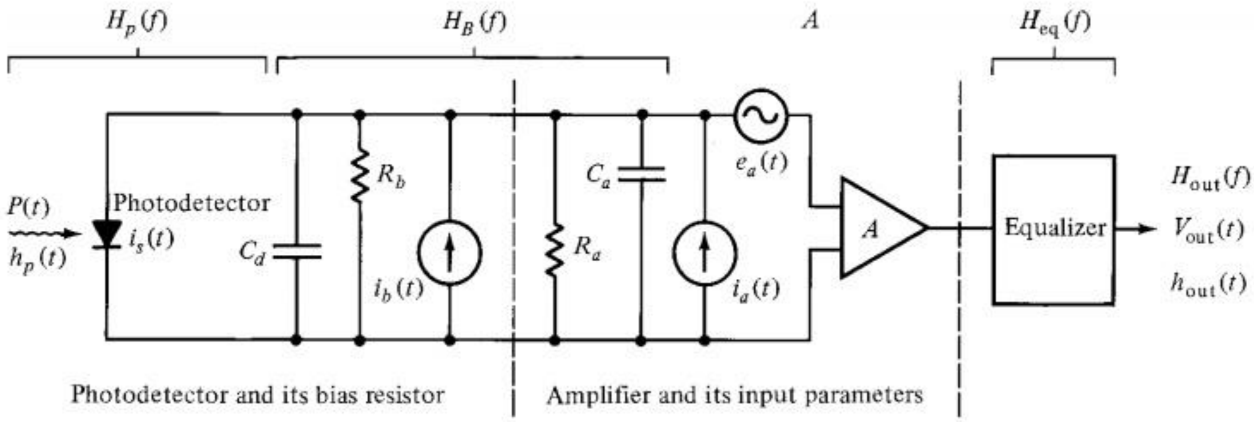

Figure 4.4 Schematic diagram of a typical optical receiver.

[Source: htpp://img.brainkart.com]

Amplifier Noise Sources:

✓ The input noise current source *i*a(*t*) arises from the thermal noise of the amplifier input resistance *R*a;

✓ The noise voltage source *ea*(*t*) represents the thermal noise of the amplifier channel.

✓ The noise sources are assumed to be Gaussian in statistics, flat in spectrum (which characterizes *white* noise), and uncorrelated (statistically independent).

The Linear Equalizer:

✓ The equalizer is normally a linear frequency shaping filter that is used to mitigate the effects of signal distortion and inter symbol interference (ISI).

✓ The equalizer accepts the combined frequency response of the transmitter, the fiber, and the receiver, and transforms it into a signal response suitable for the following signal processing electronics.

✓ The binary digital pulse train incident on the photo-detector can be described by

$$P(t) = \sum_{n=-\infty}^{\infty} b_n h_p(t - nT_b)$$

✓ Here, *P*(*t*) is the received optical power, *T*b is the bit period, *b*n is an amplitude parameter representing the *n*th message digit, and *h*p(*t*) is the received pulse shape.

✓ Let the nonnegative photodiode input pulse *h*p(*t*) be normalized to have unit area

$$\int_{-\infty}^{\infty} h_p(t)dt = 1$$

then *b*n represents the energy in the *n*th pulse.

✓ The mean output current from the photodiode at time *t* resulting from the pulse train given previously is

$$\langle i(t) \rangle = \frac{\eta q}{h\nu} MP(t) = R_0 \sum_{n=-\infty}^{\infty} b_n h_p(t - nT_b)$$

where *R*o = h*q*/*h*n is the photodiode responsivity.

✓ The above current is then amplified and filtered to produce a mean voltage at the output of the equalizer.

PROBABLITY OF ERROR

- The digital receiver performance can be evolved by measuring of error and quantum limit.
- In practice, several standard ways are available to measuring the rate of error occurrences in a digital data stream.

- **Bit error rate or the error rate [BER]**

Bit error rate is defined by the ratio between number of errors (Ne) occurring over a certain time interval t to the number of error (Nt) during this interval.

$$BER = \frac{N_e}{N_t} = \frac{N_e}{B_t}$$

Where $B=1/T_b$ is the bit rate (is the pulse transmission rate).

- The error rates the optical fiber telecommunication system range from 10^{-9} to 10^{-12}.
- The probability distribution of signal at the equalizer output should be known to compute BER. Here the decision is made as to whether a 0 or a 1 is sent.

$$P_1(v) = \int_{-\infty}^{v} p(y/1)dy$$

$$P_0(v) = \int_{v}^{\infty} p(y/0)dy$$

P_1 (v) is the probability that the equalizer output voltage is less than v when log"1" is sent.

P_0 (v) is the probability that the equalizer output voltage exceeds "v" when logic 'o' is sent.

- The figure shows the probability distribution for received logic 0 and 1.The function P(y/1) and P(y/0) are the conditional probability distribution functions, that is P(y/x) is the probability that the output voltage is y, given that an x was transmitted.
- If the threshold voltage is v_{th} then the error probability P_e is defined as

$$P_e = a\,P_1(v_{th}) + b\,P_0(v_{th})$$

- The weighing factors a and b determined by the priori distribution of the data and b are the probabilities that either a 1 or 0 occurs.
- To calculate the "p_e", the mean and standard deviation of the output voltage V_{out} (t) should be known.
- Thus, let us assume that a signal S (Which can be either a noise disturbance or a desired information bearing signal) has a Gaussian probability distribution function with a mean value m.

$$f(s)\ ds = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(s-m)^2/2\sigma^2} \cdot ds$$

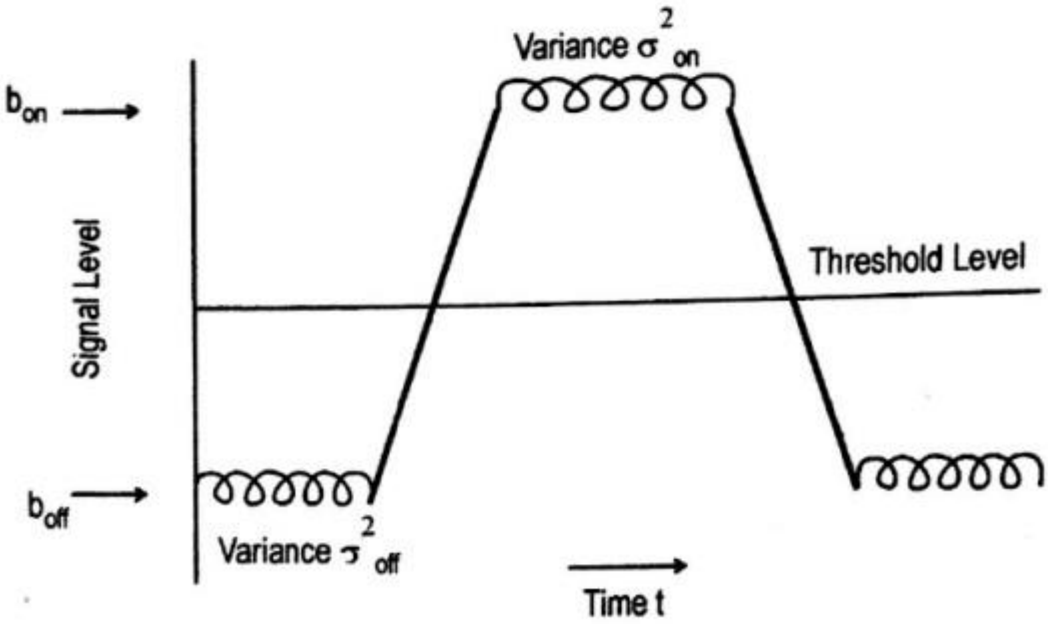

Figure 4.5 Gaussian Noise Statistics of a Binary Signal

[Source: htpp://img.brainkart.com]

- Now, we can use the probability density function to determine the probability of error for a data stream in which the 1 pulse are all of amplitude V.
- The above figure shows, the mean and variance of the Gaussian output for a 1 pulse are b_{on} and σ_{on2}, respectively, whereas for a 0 pulse they are b_{off} and σ_{off2}, respectively.

PROBABILITY OF ERROR WHEN 0 PULSE SENT

- Let us first consider the case of o pulse being sent. So that no pulse is present at the decoding time. The probability that noise will exceed the threshold voltage v_{th} and be 1 pulse.

$$P_0(v_{th}) = \int_{v_{th}}^{\infty} p(y/0)dy = \int_{v_{th}}^{\infty} f_0(y)dy$$

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

- Where the subscript 0 denotes the presence of a 0 bit.

PROBABILITY OF ERROR WHEN 1 PULSE SENT

- Transmitted pulse 1 is misinterpreted as a o by the electronics following the equalizer.

$$P_1(v_{th}) = \int_{-\infty}^{v_{th}} p(y/1)dy = \int_{-\infty}^{v_{th}} f_1(v)dv$$

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

Where the subscript 1 denotes the presence of a 1 bit.

QUANTUM LIMIT

- An ideal photodetector which has unity quantum efficiency and which produces no dark current, that is no electron holde pairs are generated in the absence of an optical pulse.

- This condition, it is possible to find the minimum received optical power required for a specific nit error rate performance in a digital syatem. This minimum received power level is known as the quantum limit.

- Assume an optical pulse of energy E falls on the photodeetector in a time interval τ. This can only be interpreted by the receiver as a 0 pulse if no electron hole pairs are generated with the pulse with the pulse present.

- The probability that n=0 electrons are emitted in a time interval τ is

$$P_r(o) = e^{-\overline{N}}$$

where the average number of electron-hole pairs, $\overline{N} = \eta E / h\nu$.

- Thus for a given probability $P_r(o)$, we can find the minimum energy E required at a specific wavelength λ.