Module - 2

(5) Describe briefly the Eye diagram showing the key performance parameters and fundamental measurement parameters with diagrams

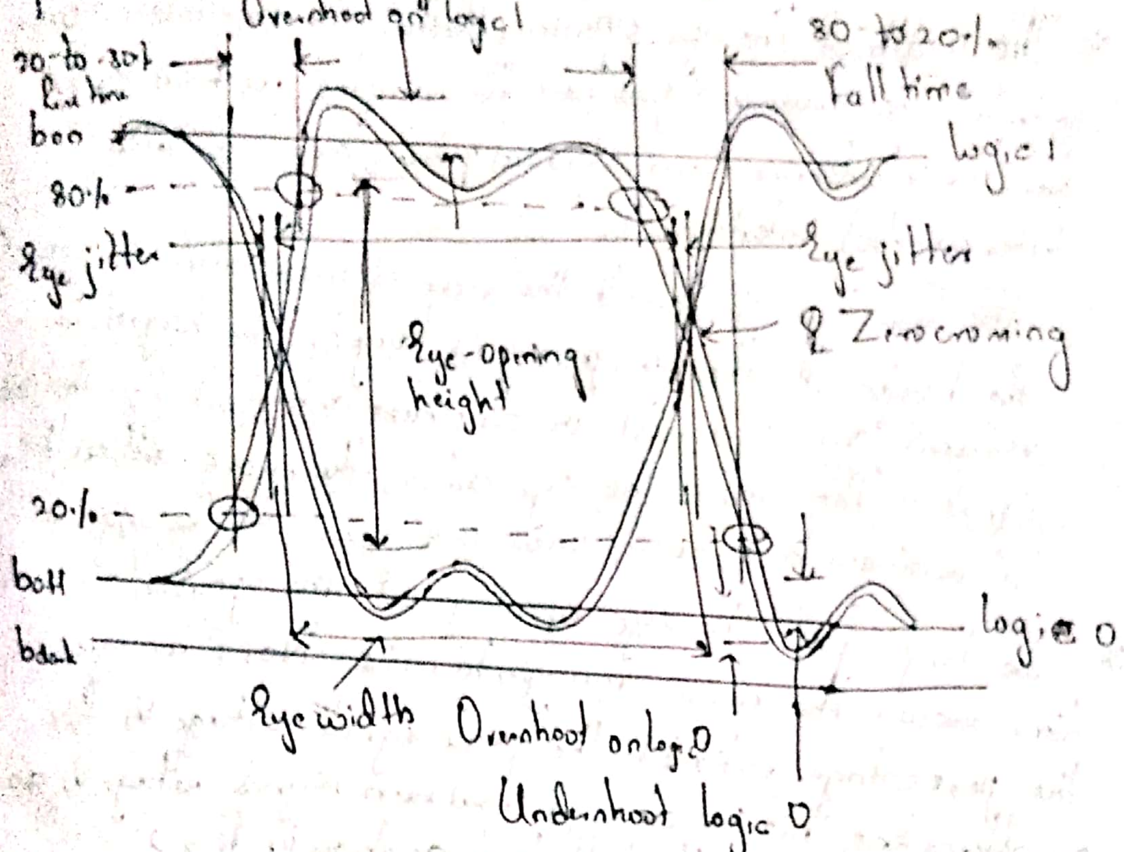


Fig 1:- General Configuration of an eye diagram showing the definitions of fundamental measurement parameters

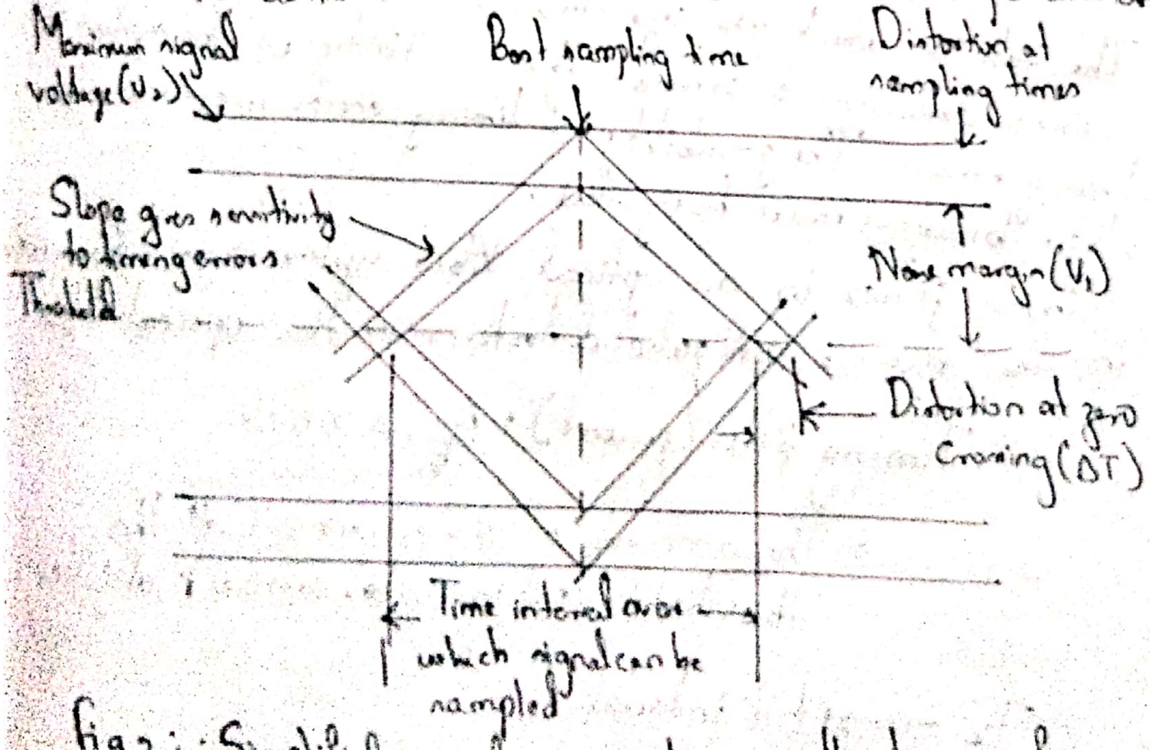


Fig 2:- Simplified eye diagram showing the key performance parameters.

fig 1 shows a type display pattern, which is known as an eye pattern & an eye diagram. The basic upper and lower boundary determined by the logic 1 and 0 levels, shown by b_{on} and b_{off} respectively.

* The width of the eye opening defines the time interval over which the received signal can be sampled without error due to interference from adjacent pulses (known as intersymbol interference).

* The best time to sample the received waveform is when the height of the eye opening is largest. The height is reduced as a result of amplitude distortion in the data signal. The more the eye closes, the more difficult is to distinguish between ones and zeros of the signal.

* The height of the eye opening at the specified sampling time shows the noise margin to noise. Noise margin is the percentage ratio of the peak signal voltage V_1 for an alternating bit sequence to maximum signal voltage V_2 as measured from the threshold level as shown in fig 2.

i.e. Noise margin $= \frac{V_1}{V_2} \times 100\%$

* The rate at which the eye closes as the sampling time is varied ~~determines~~ determines the sensitivity of the system to timing errors. The possibility of timing error increases the slope becomes more horizontal.

* Timing jitter in an optical fiber system arises from noise in the receiver and pulse distortion in the optical fiber.

$$\text{Timing jitter (percent)} = \frac{\Delta T}{T_b} \times 100\%$$

$\Delta T \longrightarrow$ The amount of distortion ΔT at the threshold level indicates amount of jitter

$T_b \longrightarrow$ 1 bit interval

* The rise time is defined as the time interval b/w the points where the rising edge of the signal reaches 10% of its final amplitude to the time where it reaches 90% of its final amplitude. (However, when measuring optical signals these points are often ob.)

Thus, the more distinct values at the 20% and 80% threshold points normally measured. To convert from the 20 to 80% rise to a 10 to 90% rise time, one can be the approximate relationship

$$T_{10-90} = 1.25 \times T_{20-80}$$

* Any nonlinear effects in the channel transfer characteristics will create an asymmetry in the eye pattern. If a purely random data stream is passed through a purely linear system, all the eye openings will be identical and symmetrical.

(4) Discuss the different generic structures of front amplifiers used at receiver ends in the optical networks.

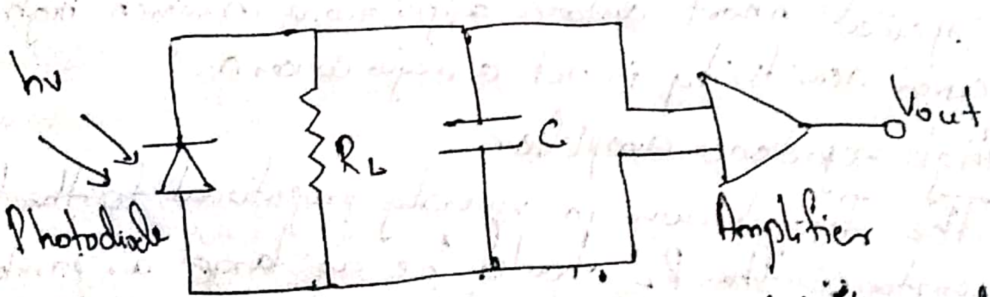


Fig 1:- Generic structure of low-impedance and high-impedance amplifiers.

front-end amplifiers in optical fiber communication systems can be classified into 3 categories:-

1. low-impedance
2. high-impedance
3. transimpedance designs.

1 low-impedance (LZ) pre-amplifier.

* The low impedance (LZ) preamplifier is the most straightforward, but not necessarily the optimum amplifier design. The basic structure is shown in fig 1.

* In this design, a photodiode operates into a low-impedance amplifier with an effective input resistance R_a. A load resistor R_b is parallel with R_a is used to match the amplifier impedance. The total preamplifier load resistance $R_L = R_a R_b / (R_a + R_b)$ is the parallel combination of R_a & R_b.

* A Small load resistance yields a large bandwidth. The drawback is that ~~Bo~~ for low load resistances, the thermal noise dominates. Thus, although low-impedance pre amplifiers can operate over a wide bandwidth, they do not provide high receiver sensitivities because only a small signal voltage can be developed across the total input impedance. This limits the use of these preamplifiers to special short-distance applications in which high receiver sensitivity is not a major concern.

2. High-impedance amplifier.

* The Thermal noise is inversely proportional to the load resistance. The R_L should be as large as possible to minimize thermal noise. Thus by increasing the value of R_L in fig 1 results in the high impedance amplifier design.

* Here, a tradeoff must be made b/w noise and receiver bandwidth. Thus for a high-impedance front end, a high load resistance results in low noise but also gives a low receiver bandwidth.

* Although equalizers sometimes can be implemented to increase the bandwidth, if the bandwidth is much less than the bit rate, then such a front-end amplifier cannot be used.

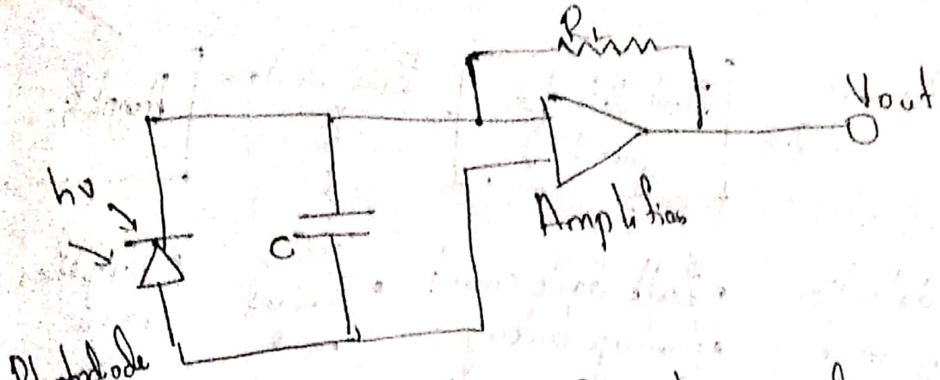


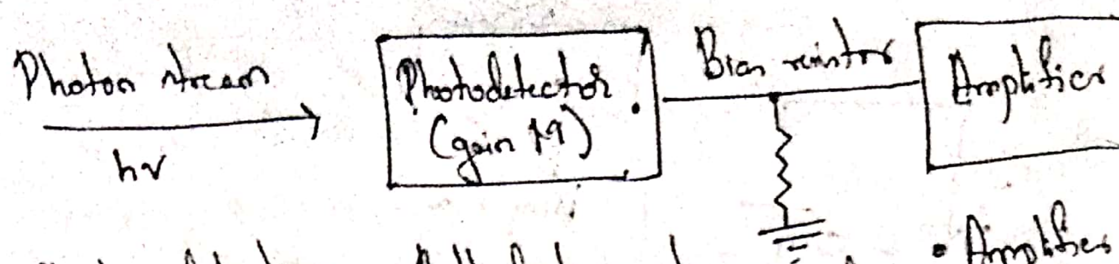
Fig 2 : Generic structure of a transimpedance amplifier

3. Transimpedance amplifier.

* The transimpedance amplifier design shown in fig 2 largely overcomes the drawbacks of the high impedance amplifier.
* In this case, R_L is used as a negative feedback resistor around an inverting amplifier. Now R_L can be larger as the negative feedback reduces the effective resistance seen by the photodiode by the factor of G, so that $R_p = R_L / (G+1)$, where G → gain of the amplifier.
* This means that compared to the high-impedance design the transimpedance bandwidth increased by a factor of G+1 for the same load resistance. Although ~~it~~ this does increase the thermal noise compared to a high impedance amplifier, the increase is usually is less than the factor of 2 and can be easily tolerated.
* Consequently, the transimpedance front-end design tends to be the amplifier of choice for optical fiber transmission link.

3) Describe briefly noise sources and disturbances in an optical pulse detection mechanism with diagrams with equations.

* Errors in the detection mechanism can arise from various noises and distrubances associated with the signal detection system as shown in fig. The term noise is used customarily to describe unwanted components of an electric signal that tend to disturb the transmission and processing of the signal in a physical system.



- Photon detection quantum noise (Poisson fluctuation)
- Bulk dark current
- Surface leakage current
- Statistical gain fluctuation
- Thermal noise
- Amplifier noise

fig :- Noise sources and disturbances in the optical pulse detection mechanism

* ~~The two most common fluctuations~~ samples of these spontaneous fluctuations of curren

* The two most common samples of these 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.

* When using a avalanche photodiode, an additional shot noise arises from the statistical nature of the multiplication process. This noise level increases with increasing avalanche gain M. Additional photodetector noises come from the dark current and leakage current.

* If the detector is illuminated by an optical signal $P(t)$, then the average number of electron-hole pairs $\hat{N}$ generated in a time τ is

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

where $\eta \rightarrow$ the detectors quantum efficiency
$h\nu \longrightarrow$ Photon energy
$E \longrightarrow$ Energy received in a time interval τ.

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

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

$P_r(n) \rightarrow$ the probability that n electrons are emitted in an interval τ.

* The random nature of the avalanche multiplication process gives rise to another type of shot noise. For a detector with a mean avalanche gain M and an ionization rate ratio k, the excess of noise factor F(M) for electron injection is

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

This equation is often approximated by the empirical expression $F(M) \simeq M^x$

where the factor x ranges between 0 and 1.0 depending on the photodiode material.

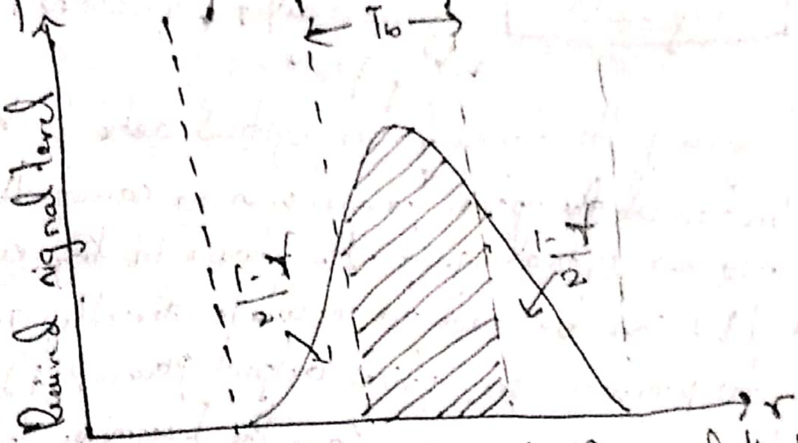


fig2:- Pulse spreading in an optical signal that leads to intersymbol ~~intersymb~~ interference.

* In fig 2 the fraction of energy remaining in the appropriate time slot is designated by γ, so that $1-\gamma$ is the fraction of energy that has spread into adjacent time slots.

(2) Describe the signal path through an optical digital signal transmission with diagrams and basic sections of an optical receiver.

* The typical digital ~~s~~ fiber transmission link is shown in fig. The transmitted signal is a two-level binary data stream consisting of either a 0 & a 1 in a time slot of duration T_b. The resultant signal wave thus consists of a voltage pulse of amplitude V relative to the zero voltage level when a binary 1 occurs and a zero voltage level space when a binary 0 occurs.

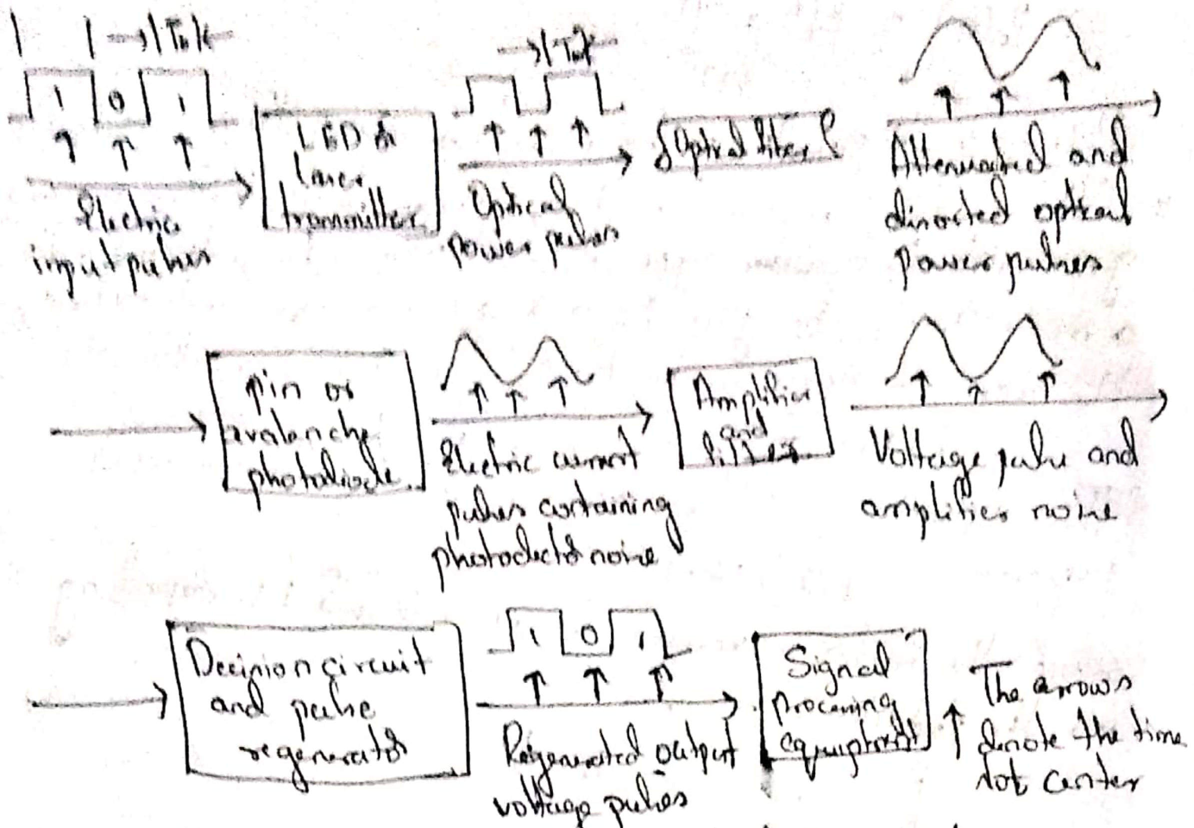


Fig:- Signal path through an optical data link.

* The function of the optical transmitter is to convert the electric signal into an optical signal. As shown in fig, an electric current $i(t)$ can be used to modulate directly an optical source to produce an optical output power $P(t)$. Thus, in the optical signal emerging from the ~~transmis~~ transmitter, a 1 is represented by a pulse of optical power (light) of duration T_b, whereas 0 is the absence of any light.
* The optical signal that gets coupled from the light source to the fiber becomes attenuated and distorted as it propagates along the fiber waveguide. Upon reaching the receiver, either a pin or an avalanche photodiode converts the optical signal back to an electrical format. After the electrical signal produced by the photodetector is amplified and filtered, a decision circuit compares the signal in each time slot with a certain reference voltage known as the threshold level. If the receiver signal level is greater than the threshold level, a 1 is said to have been received. If the voltage is below the threshold level, a 0 is assumed to have been received.

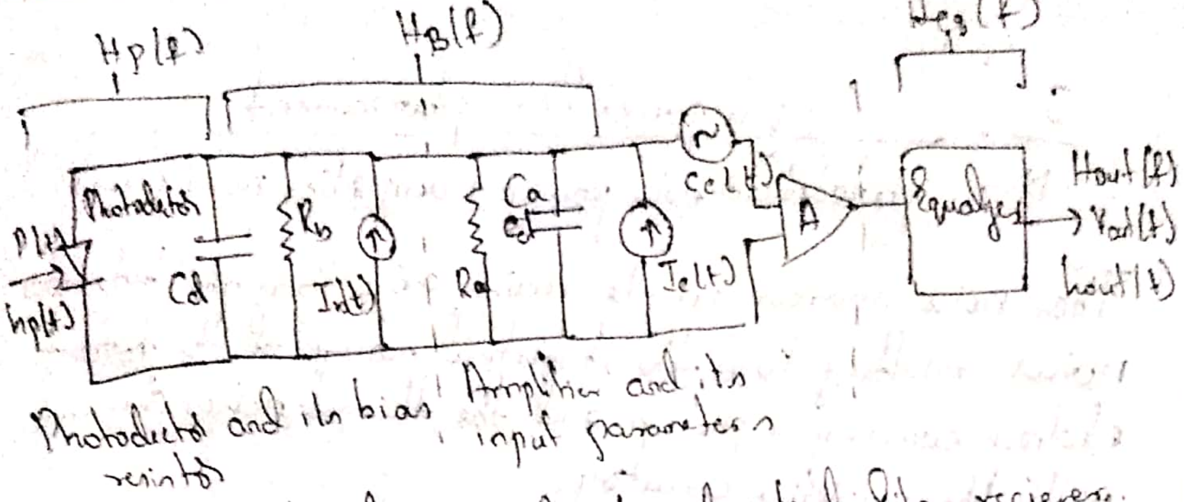


fig: Schematic diagram of a typical optical ~~fiber~~ reciever.

The 3 basic stages of the reciever are:

1. Photodector 2. Amplifier 3. Equalizer.

1. Photodector :- The photodector can be either be an avalanche photodiode with a mean gain M or a pin photodiode for which M = 1. The photodiode has a quantum efficiency η and a capacitance Cd. The detector bias resistor has a resistance Rb which generates a thermal noise current Ib(t)

2. Amplifier :- The amplifier has an input impedance represented by the parallel combination of a resistance Ra and a shunt capacitance Ca. The input noise current source ia(t) arises from the thermal noise of the amplifier input resistance Ra, whereas the noise voltage source ea(t) represents the thermal noise of an amplifier channel.

3. Equalizer :- The equalizer that follows the amplifier is normally a linear frequency-shaping filter that is used to mitigate the effects of signal distortion and intersymbol interference.

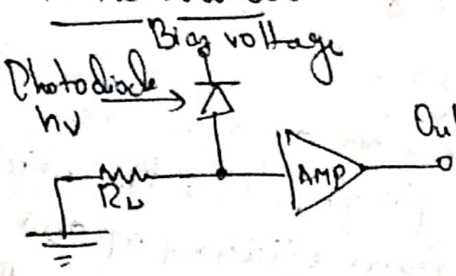
① Describe briefly signal to noise ratio at the output of an optical receiver with expressions and describe the different types of noise sources in the case of photodetectors with expressions.

The power signal-to-noise ratio S/N at the output of an optical receiver is defined by

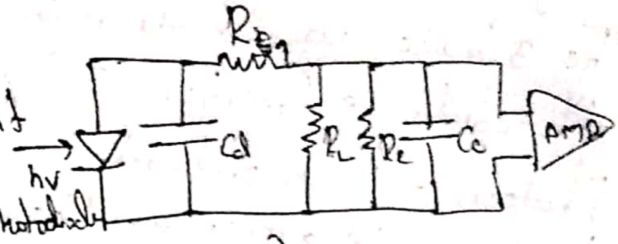
$$\frac{S}{N} = \frac{\text{signal power from photocurrent}}{\text{photodetector noise power} + \text{amplifier noise power}}$$

The noise sources in the receiver arise from the photodetector noises resulting from the statistical nature of the photon-to-electron conversion process and the thermal noises associated with the amplifier circuitory.

Noise sources



(a)



(b)

fig: (a) Simple model of a photodetector receiver
(b) its equivalent circuit.

* The photodiode has a small series resistance R_S, a total capacitance C_d consisting of junction and packaging capacitances, and the bias resistor R_L. The amplifier following the photodiode has an input capacitance C_a and a resistance R_a. For practical purposes, R_s is much smaller than the load resistance R_L and can be neglected.
* If a modulated signal of optical power $P(t)$ falls on the detector, the primary photocurrent $i_{ph}(t)$ generated is

$$i_{ph}(t) = \frac{\eta q}{h\nu} P(t)$$

* The primary current consists of a dc value I_p, which is the average ~~photodetector~~ photocurrent due to the signal power and the signal component $i_p(t)$. For pin photodiodes the mean-square signal current $\langle i_N^2 \rangle$ is

$$\langle i_N^2 \rangle = \sigma_{S\,pin}^2 = \langle i_p^2(t) \rangle$$

where σ is the variance. For avalanche photodetectors,

$$\langle i_S^2 \rangle = \sigma_{S\,APD}^2 = \langle i_p^2(t) \rangle M^2$$

Scanned with CamScanner

where M is the average of the statistically varying avalanche gain as defined in eqn.

* For a sinusoidally varying input signal of modulation index m, the signal component (i_p^2) is of the form

$$\langle i_p^2(t) \rangle = \sigma_p^2 = \frac{m^2}{2} I_p^2$$

* The quantum noise current has a mean square value in a bandwidth B which is proportional to the average value of the photocurrent I_p:

$$\langle i_Q^2 \rangle = \sigma_Q^2 = 2q I_p B M^2 F(M)$$

where $F(M)$ is a noise figure associated with the random nature of the avalanche process.

* The mean-square value of bulk dark current is given by

$$\langle i_{DB}^2 \rangle = \sigma_{DB}^2 = 2q I_D M^2 F(M) B.$$

where $I_D \rightarrow$ Primary detector bulk dark current.

* The mean square value of the surface dark current is given by

$$\langle i_{DS}^2 \rangle = \sigma_{DS}^2 = 2q I_L B.$$

where $I_L \rightarrow$ Surface leakage current

* The dark current and the signal current are uncorrelated, the total mean-square photodetector noise current $\langle i_N^2 \rangle$ can be written as

$$\langle i_N^2 \rangle = \sigma_N^2 = \langle i_Q^2 \rangle + \langle i_{DB}^2 \rangle + \langle i_{DS}^2 \rangle = \sigma_Q^2 + \sigma_{DB}^2 + \sigma_{DS}^2$$

$$= 2q(I_p + I_D) M^2 F(M) B + 2q I_L B.$$

* The photodetector load resistor contributes a mean-square thermal noise current

$$\langle i_T^2 \rangle = \sigma_T^2 = \frac{4 k_B T}{R_L} B$$

where $k_B \rightarrow$ Boltzmann's constant

$T \rightarrow$ absolute temperature.