Unit IV

Optical receivers: Fundamental receiver operation, digital receiver performance, eye diagrams, coherent detection: homodyne and heterodyne, burst mode receiver, analog receivers.

Digital links: Point to point links, link power budget, rise time budget, power penalties.

Analog links: Overview of analog links, carrier to noise ratio, multichannel transmission techniques.

An optical receiver consists of photo detector, an amplifier and signal processing circuitry. The receiver has the task of first converting the optical energy from the end of a fiber into an electric signal, and then amplifying this signal to a large enough level so that it can be processed by the electronics following the receiver amplifier.

4.1 Fundamental Receiver Operation

A receiver must be able to detect weak, distorted signals and make decisions on what type of data was sent based on an amplified and reshaped version of this distorted signal. Figure 4.1 illustrate the shape of a digital signal at different points along the optical link. The transmitter signal is a two level binary data stream consisting of either 0 or a 1 at a time slot of duration T_b. This time slot is referred to as a bit period. One of the simplest techniques for sending binary data is amplitude shift keying (ASK) or on-off keying (OOK), wherein a voltage level is switched between two values which are usually on or off. 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 zero occurs.

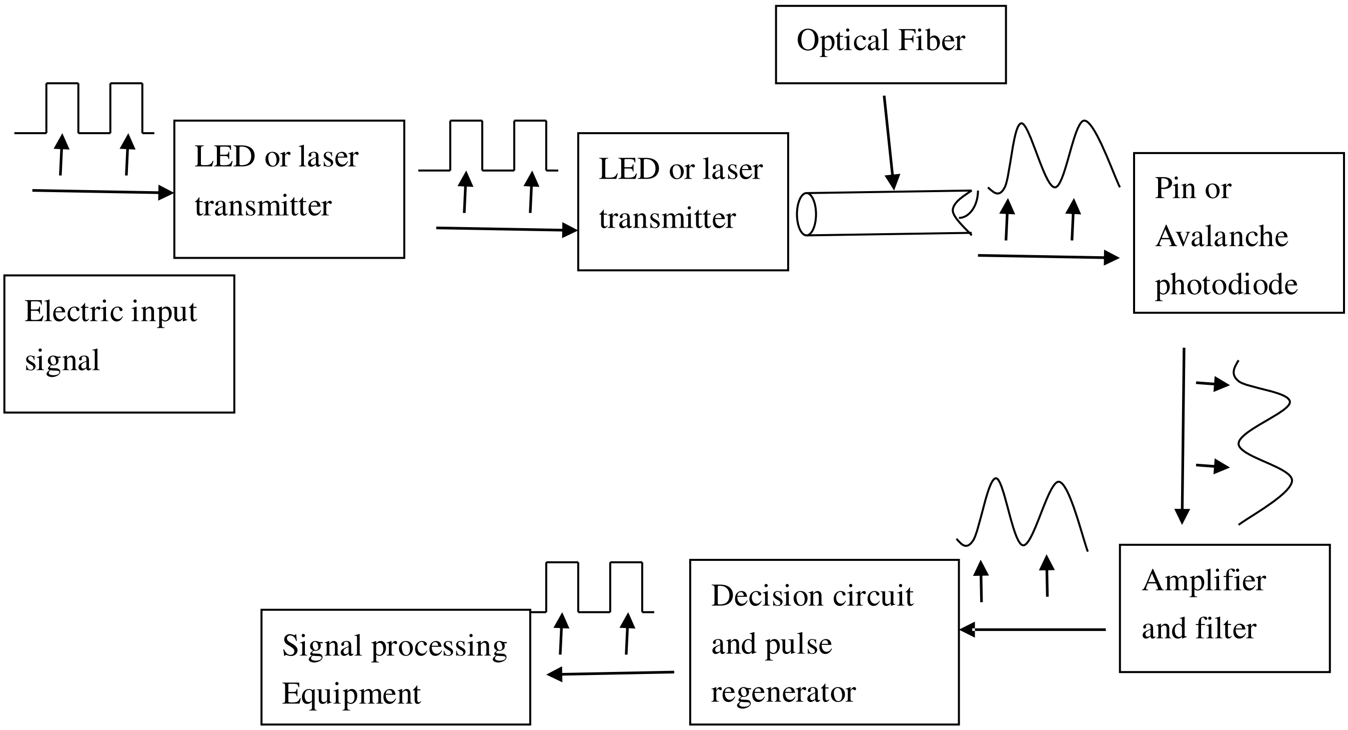

Fig. 4.1 Signal path through an optical data Link

The function of optical transmitter is to convert the electric signal to an optical signal. One way of doing this is by directly modulating the light source drive current with the information stream to produce a varying optical output power p(t). The optical signal that is coupled from the light source to the fiber becomes attenuated and distorted as it propagates along the fiber waveguide. Upon arriving at the end of the fiber, a receiver converts the optical signal back to an electrical format.

Figure 4.2 shows basic components of an optical receiver. The first element is either pin or an avalanche photodiode, which produces an electric current that is proportional to the received power level. Since this electric current is very weak, a front end amplifier boost it to a level that can be used by the following electronics. After the electric signal produced by the photodiode is amplified, it passes through a low pass filter to reduce the noise that is outside of the signal bandwidth.

This filter thus defines the receiver bandwidth. In addition, to minimize the effects of inter symbol interference (ISI) the filter can reshape the pulses that have become distort as they travelled through the fiber. This function is called equalization since it equalizes or cancels pulse-spreading effects. In the final optical receiver module shown in Fig. 4.2, a decision circuit samples the signal level at the midpoint of each time slot and compares it with the certain reference voltage known as the threshold level. If the received signal level is greater than the threshold level,1 is said to have been received. If the voltage is below the threshold level, 0 is assumed to have been received. To accomplish this bit interpretation the receiver must know where the bit boundaries are. This is done with the assistance of the periodic waveform called clock, which has a periodicity equal to the bit interval. Thus this function is called clock recovery or timing recovery.

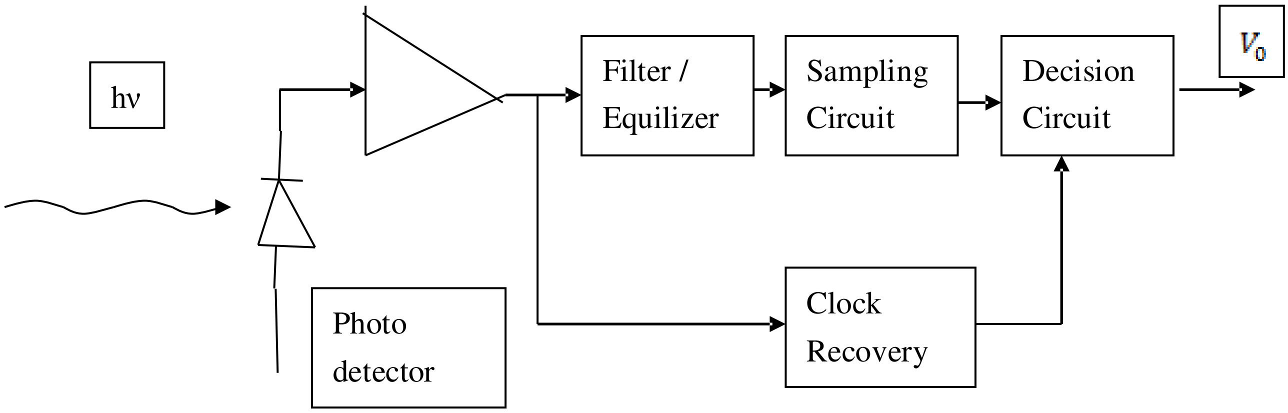

Fig. 4.2 The basic sections of an optical Receiver

There are many noises which affect the receiver operation such as shot noise arises from discrete nature of current flow in the device. Thermal noise arises from random motion of electrons in a conductor. Thermal noise arising from the detector load resistor and from amplifier electronics tend to dominate in application with low signal to noise ratio when pin photodiode is used.

4.2 Digital Receiver Performance Calculation

In digital receiver the amplified and filtered signal emerging from the equalizer is compared with a threshold level once per time slot to determine whether or not a pulse present at a photo detector in that time slot. In practice there are several standard ways of measuring the rate error occurrence in digital data stream. One common approach is to divide N_e of errors occurring over interval t by the number N_t of pulses (ones and zeros) transmitted during this interval. This is called either bit error rate Or the bit error rate, which is commonly abbreviated BER. Thus we have.

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

To compute the bit error rate at the receiver, we have to know the probability distribution of the signal at the equalizer output.

p_1(v)=$\int_{-\infty}^{v} p\left(\frac{y}{1}\right) dy$

Which is the probability that equalizer output voltage is less than v when 1 pulse was sent, and

p_0(v)=$\int_{-\infty}^{v} p\left(\frac{y}{0}\right) dy$

Which is the probability that output voltage exceeds v when a 0 was transmitted. The functions $p\left(\frac{y}{1}\right)$ and

$p\left(\frac{y}{0}\right)$.

Are the conditional probability distribution functions that is $p\left(\frac{y}{x}\right)$ is the probability that the output voltage is y, given then an x was transmitted. If the threshold voltage is v_{th} then the error probability P_e is defined as

$P_e = aP_1(v_{th}) + aP_0(v_{th})$

The weighting factors a and b determined by the a priori distribution of the data. That is a and b are probabilities that are either a 1 or 0occurs, respectively.

4.3 Eye Diagrams

The eye diagram is powerful measurement tool for assessing the data handling ability of a digital transmission system. The method has been used extensively for evaluating the performance of wire line systems and also applies to optical fiber data links.

Eye Pattern Features:

The eye patterns measurements are made in the time domain and allow the effects of waveform distortion to be shown immediately on the display screen of the standard BER test equipment. Figure 4.3 shows a typical display pattern, which is known as an eye pattern or an eye diagram. The basic upper and lower bounds are determined by logic one and zero levels shown by b_{on} and b_{off}, respectively.

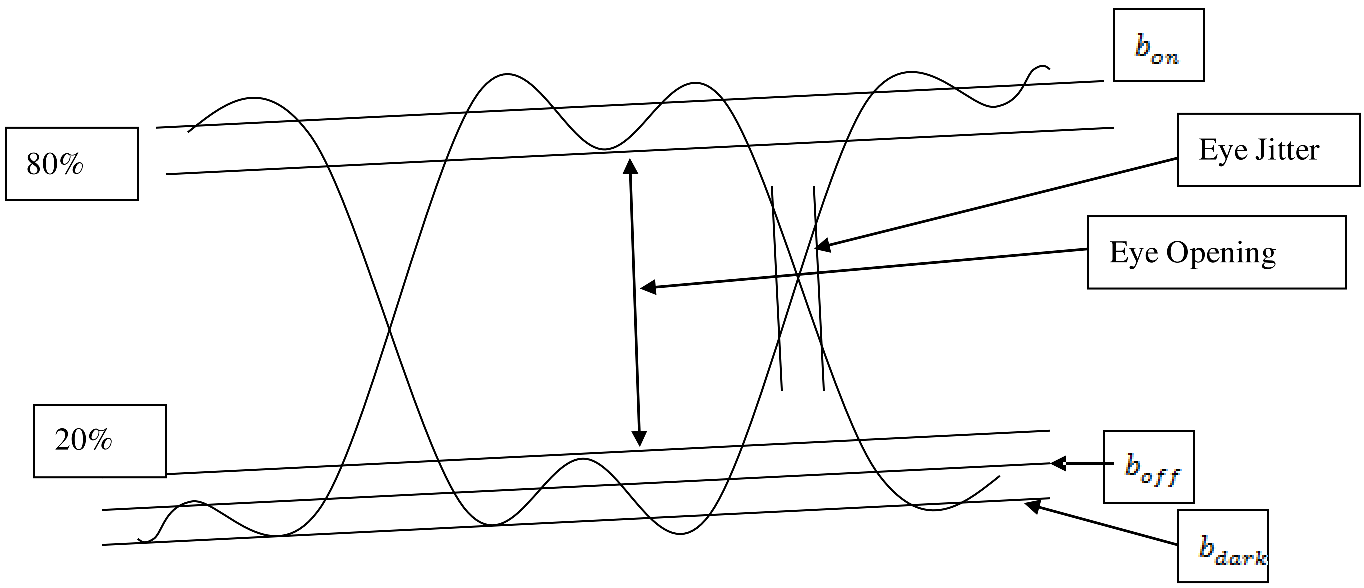

Fig.4.3 General Configuration of an eye diagram

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. This height is reduced as a result of amplitude distortion in the data signal. The vertical distance between top of the eye opening and the maximum signal level gives the degree of distortion .The more eye closes, the more difficult is to distinguish between ones and zeros in the digital signal.

The Timing jitter in an optical fiber system arises from noise in the receiver and pulse distortion in the optical fiber. Excessive jitter can result in bit errors, since jitter can produce uncertainties in clock timing. If the signal sampled in the middle of time interval (i.e. midway between the times when signal crosses the threshold level) then amount of distortion ΔT at the threshold level indicates the amount of jitter.

Timing Jitter=$\frac{\Delta T}{T_b}$X100 percent.

4.4 Coherent Detection

Optical communication systems which use homodyne or heterodyne detection are called coherent optical systems since their implementation depends on phase coherence of the optical carrier. The key principle of the coherent detection technique is to provide gain to the incoming optical signal by coming or mixing it with locally generated continuous wave optical field. Let's us consider the electric field of the transmitted optical signal to be plane wave having the form

E_s=$A_s$cos[w_s t+Φ_s(t)]

Where $A_s$is the amplitude of the optical signal field, w_s is the optical signal carrier frequency and Φ_s(t) is the phase of optical signal. The mixing of information and local-oscillator signals is done on the surface of photodetector. If the local oscillator (LO) field has the form

E_{LO}=$A_s$cos[w_{LO} t+Φ_{LO}(t)]

Where A_{LO} is the amplitude of local oscillator field, w_{LO} is local oscillator frequency and Φ_s(t) is the phase of oscillator frequency.

Then the detected current is proportional to the square of the total electric field of the signal falling on the photodetector. That is intensity

I_{ch}(t)=$(E_{LO} + E_s)^2$

Optical power is proportional to the intensity, at the photodetector.

Homodyne Detection

When the signal carrier and local oscillator frequencies are equal that is, w_{IF} =0 ($w_{IF} = w_s - w_{LO}$), we have the special case of homodyne detection. Homodyne detection brings the signal directly to the baseband frequency, so that no further electrical demodulation required. Homodyne detection yields most sensitive coherent systems.

Heterodyne Detection

When the signal carrier and local oscillator frequencies are not equal that is, $w_{IF} \not\approx 0$ ($w_{IF} = w_s - w_{LO}$), and optical phase locked loop is not needed, we have the special case of heterodyne detection. Heterodyne receiver are much easier to implement.

4.5 Burst Mode Receivers

For passive optical Networks (PON) applications, at the central office of the operational characteristics of an optical receiver differ significantly from those used in conventional point to point links. This arises from the fact that amplitude and phase information packets received in successive time slots from different network user locations can vary widely from packet to packet. Type of data pattern can be that there is no amplitude variation in the received logic ones, size of the packet may differ there amplitude is same. Or Signal amplitude can change from packet to packet depending on how far away each ONT is from central office. Fig. 4.4 shows received data pattern in conventional point to point links.

Since a conventional optical receiver is not capable of instantaneously handling rapidly changing differences in the signal amplitude and clock phase alignment, a specially designed Burst mode receiver is needed. These receivers can rapidly extract the decision threshold and determines the signal phase from a set of overhead bits placed at the beginning of each packet burst.

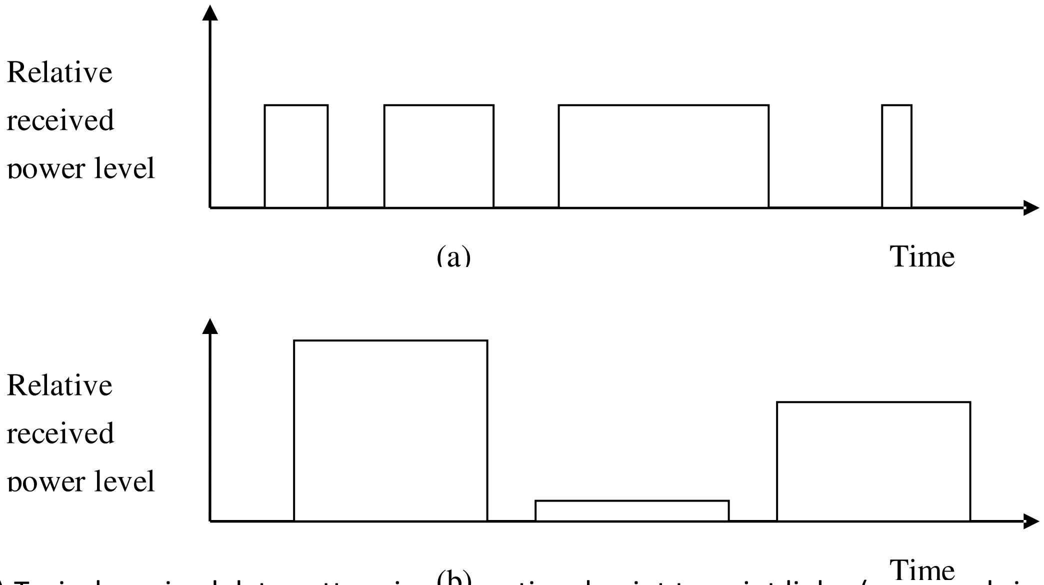

Fig.4.4 (a) Typical received data pattern in conventional point to point links; (b) Optical signal level variations in pulses that may arrive at OLT

4.6 Analog Receivers

In addition to wide usage of the fiber optics for transmission of digital signals, there are many potential applications for analog links. The simplest analog technique is to use amplitude modulation of the source. In this scheme, a time varying electrical signal s(t) is used to modulate an optical source directly about some bias point defined by bias current I_B . The transmitted optical power is thus of the form.

P(t)=P_t[1+ms(t)]. Where P_t is the average transmitted power, s(t)] is analog modulation signal and m is the modulation signal index defined by $m=\frac{\Delta I}{I_B}$. Here, ΔI is the variation in current about the bias point.

4.7 Point to point Links

The simplest transmission link is a point-point link that has transmitter on one end and a receiver on other end. The following key system requirements are needed in analyzing a link:

1) The desired or possible transmission distance
2) The data rate or channel bandwidth
3) The bit error rate(BER)

To fulfill these requirements designer has a choice of the following components and their associated characteristics:

1) Multimode or Single mode fibers
2) LED or LASER diode optical source
3) PIN or Avalanche photodiode

4.8 Link Power Budget

In the link power budget analysis one first determines the power margin between the optical Transmitter output and the minimum receiver sensitivity needed to establish a specified BER. This margin can then be allocated to connector. Splice and fiber losses, plus any additional margins required for the other components. If the choice of components did not allow the desired transmission distance to be achieved, the components might have to be changed or amplifiers might have to be incorporated in the link.

The link loss budget is derived from the sequential loss contributions of each element in the link. Each of these elements are is expressed in decibels(dB) as

Loss=10 log $\frac{P_{out}}{P_{in}}$

Where aP_{in} and P_{out} are optical power entering and leaving the loss element.

4.9 Rise Time Budget

Rise time budget is done to ensure that the desired overall system performance has been met. A rise time budget analysis is a convenient method for determining the dispersion limitation of an optical fiber link. In this approach, the total rise time t_{sys} of the link is the root mean square of the rise times from each contributor or t_i to the pulse rise time degradation:

$t_{sys}=(\sum_{i=1}^{N} t_i^2)^{1/2}$

The four basic elements that may significantly limit system speed are transmitter rise time, the group velocity dispersion rise time, the modal dispersion rise time and receiver rise time.

4.10 Power Penalties

The reduction in SNR is known as power penalty for that effect which degrade the link performance and generally is expressed in decibels. Thus if SNR_{ideal} and SNR_{impair} are signal to noise ratios for ideal and impaired cases, respectively, then power penalty PP_x for impairment x is given by

PP_x=-10 log $\frac{SNR_{impair}}{SNR_{ideal}}$

4.11 Overview of Analog Links

Figure 4.4 shows basic elements of analog link Transmitter contains either an LED or an Laser diode optical

optical source. One must take into account the frequency dependence of the amplitude, phase and group delay in the fiber. Thus the should have the flat amplitude and group delay response within the pass band required to send the signal free of linear distortion.

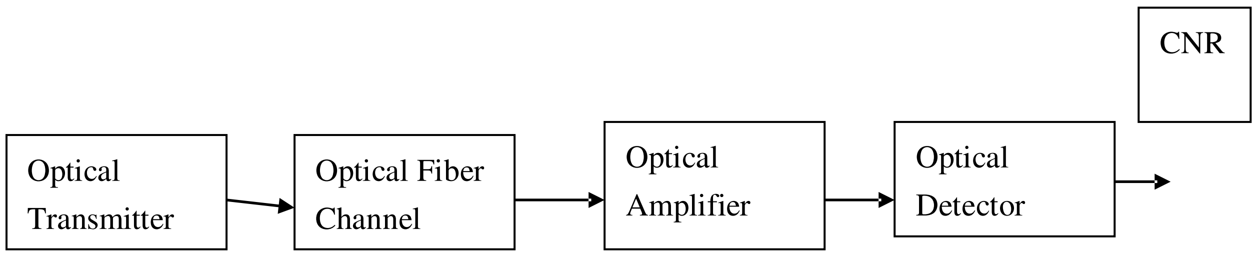

Fig. 4.4 Basic Elements of Analog Link

4.12 Carrier to Noise Ratio

In analyzing performance of analog systems, one usually calculates the ratio of rms carrier power to the rms noise power at the input of RF receiver following the photo detection process. This is known as carrier to noise ratio (CNR).

4.13 Multichannel Transmission Techniques

For sending multiple signal over the fiber one can employ multiplexing technique where a number of baseband signals are superimposed electronically on a set of N subcarriers that have different frequencies $f_1, f_2, f_3 \ldots f_n$. These modulated subcarriers are then combined electrically through frequency division multiplexing (FDM) to form composite signal that directly modulates a signal optical source.