BUDDHA SERIES

(Unit Wise Solved Question & Answers)

Course – B. Tech (ECE)

College – Buddha Institute of Technology

(AKTU CODE-525)

Department: Electronics and Communication Engineering

Subject: Optical Communication (BEC-057)

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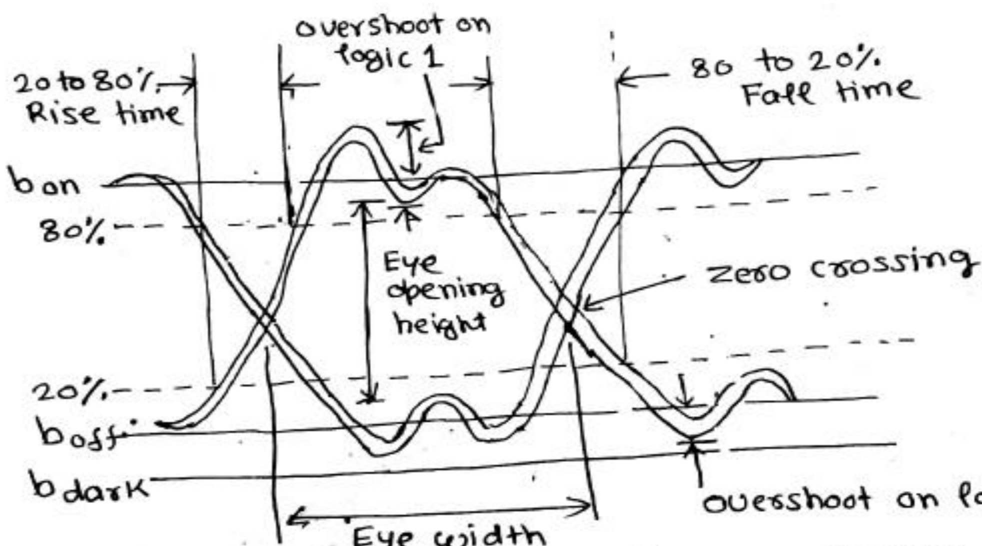
Unit – 5

Q1. Discuss Eye pattern features in an optical communication, also comment on ISI using Eye diagram.

[AKTU: 2021-22, 2022-23]

ANS:

Eye Diagram - The eye diagram is a powerful measurement tool for assessing the data handling ability of a digital transmission system. Eye diagram is used to evaluate the performance of wireline systems and it is also applicable to optical fiber data links. The eye pattern measurements are made in time domain and allow the effects of waveform distortion to be shown immediately on the display screen of standard BER test equipment.



General configuration of eye diagram showing the definition of fundamental measurement parameters

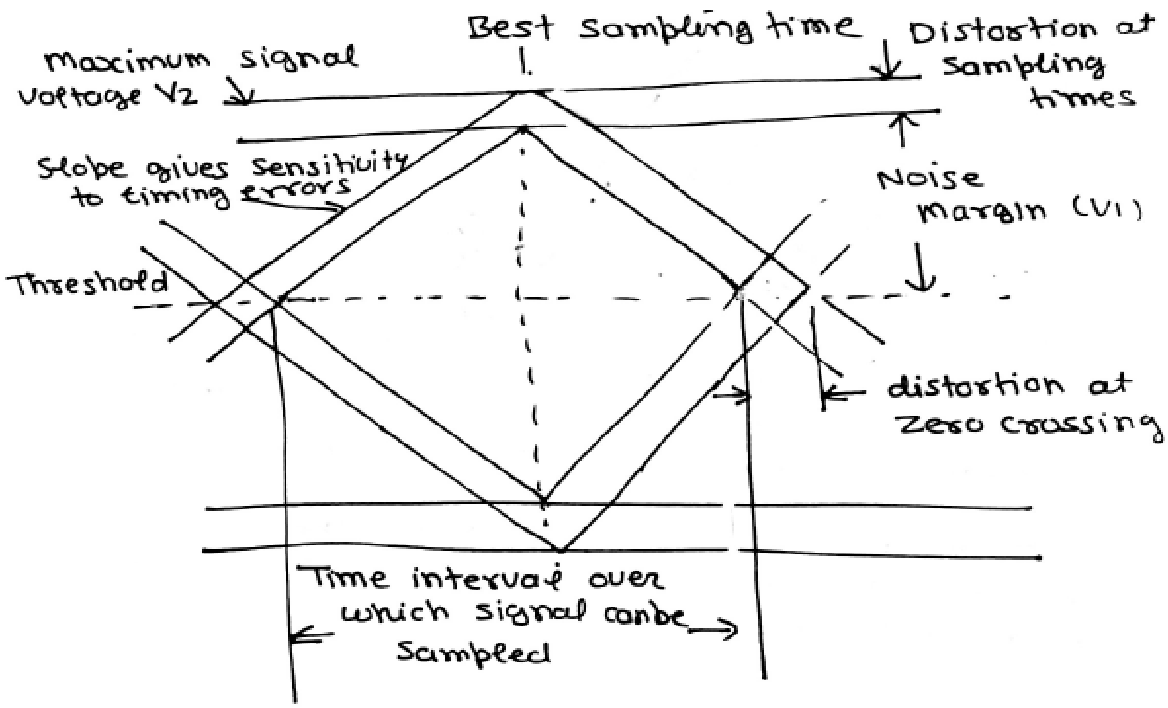
As shown in above eye diagram basic upper and lower bounds are determind by log one and logic zero levels shown by bon and boff respectively.

* The width of 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 eye opening is largest. The height is reduced due to amplitude distortion in the data signal. The vertical distance between the top of the eye opening and the maximum signal level gives the degree of distortion.

* The height of eye opening at the specified sampling time shows the noise margin or immunity to noise.

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



Simplified Eye diagram

* The rise time is defined as the time interval between the points where the rising edge of the signal reaches 10 percent of its final amplitude to the time when it reaches 90 percent of its final amplitude.

Q2. Write a short note on 'Error Control Techniques'.
ANS:

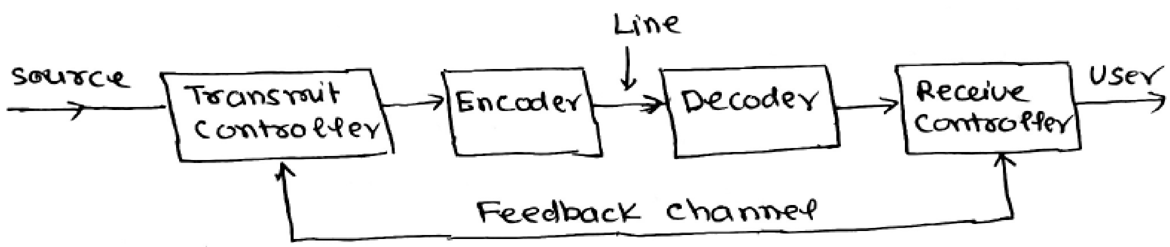
Error Control Techniques -

To control errors and to improve the reliability of a communication system, it is necessary to implement error detection and correction techniques.

Error detection methods encode the information bit stream to have a specific pattern. If segments in the received data stream violate this pattern, then errors have detected, and these errors must be corrected. There are two basic schemes for error correction -

(i) Automatic Repeat request (ARQ)
(ii) Forward error correction (FEC)

(i) Automatic Repeat Request - (ARQ) -



Basic setup for an automatic repeat request error correction scheme.

As shown in block diagram, the ARQ technique uses a feedback channel between receiver and transmitter to request message retransmission if errors are detected at the receiver. Since each such retransmission adds at least one round-trip time of latency, ARQ may not be feasible for applications in which data must arrive within fixed time.

(ii) Forward error correction (FEC) -

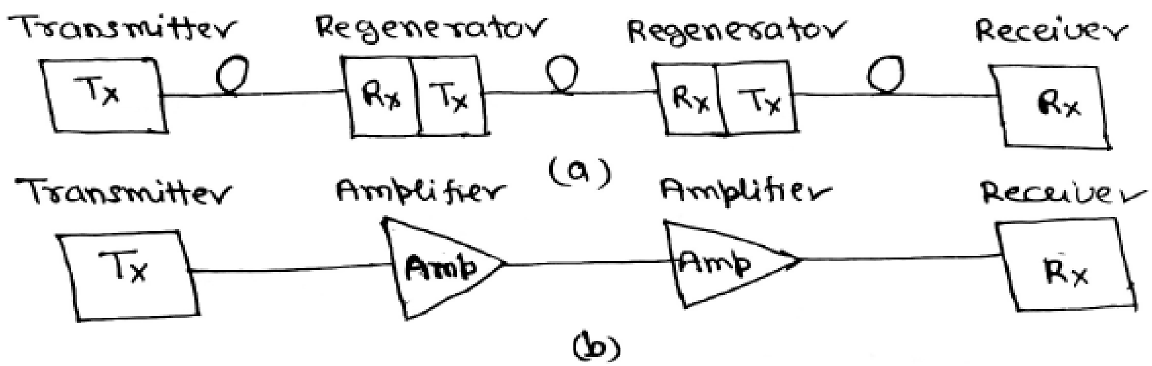
Forward error correction avoids the shortcomings of ARQ for high bandwidth optical networks requiring low delays.

In forward error correction techniques, the redundant information is transmitted along with the original information. If some of original data is lost or received in error, the redundant information is used to reconstruct it.

Q3. Write a short notes on point-to -point links.

ANS:

Point-to-Point Links- Point-to-point links constitute the simplest kind of lightwave system. Their role is to transport information, available in the form of a digital bit stream, from one place to another as accurately as possible. The link length can vary from less than a kilometer (short haul) to thousands of kilometers (long haul), depending on the specific application.



Point-to-point fiber links with periodic loss compensation through (a) regenerators (b) optical amplifiers. A regenerator consists of a receiver followed by a transmitter

* when the link length exceeds a certain value, in the range of 20 – 100 km depending on the operating wavelength, it becomes necessary to compensate for fiber losses otherwise the signal will be too weak and can not be detected reliably. As shown in fig, there are two techniques commonly used for loss compensation.

Until 1990, optoelectronic repeaters, called regenerators because they regenerator the optical signal were used. A regenerator is nothing but a receiver-transmitter pair that detects the incoming optical signal, recovers the electrical bit stream, and then converts it back into optical form by modulating an optical source. Fiber loss can also be compensated by using optical amplifiers which amplify the optical bit stream directly without requiring conversion of the signal to the electric domain.

* Until 2000, the regenerator spacing was in the range of 600 – 800 Km. Since then, ultralong-haul systems have been developed that are capable of transmitting optical signal over 3000 Km or more without using a regenerator.

Q4. Define quantum limit in optical communication. **[AKTU:2022-23, 2023-24]**

ANS:

Quantum Limit – An ideal photodetector which has unity quantum efficiency and which produces no dark current, that is no electron-hole pairs are generated in the absence of an optical pulse. In this condition, it is possible to find the minimum received optical power required for a specific bit error rate performance in a digital system. This minimum received power is known as the quantum limit.

Q5. Illustrate Power Penalty in an optical communication. Also explain different types of Power Penalties.

ANS: **[AKTU: 2021-22]**

Optical Power Penalties –

In Practical system, many factors degrade the performance of optical communication system. To compensate for the system degradation, the signal power has to be increased to achieve the same SNR or BER performance as that of an ideal system. This increase in power is called the power penalty. There are two types of signal degradation which can contribute to the power panalty.

(1) Degradation during propogation in the optical fiber.
(2) Degradation due to peripheral electronic and optic components in the system like lasers, photodetectors, couplers etc.

* Few major causes that degrade receiver sensitivity are modal noise, dispersive pulse broadening, mode partition noise, frequency chirping, reflection feedback noise etc.

① * Modal Noise –

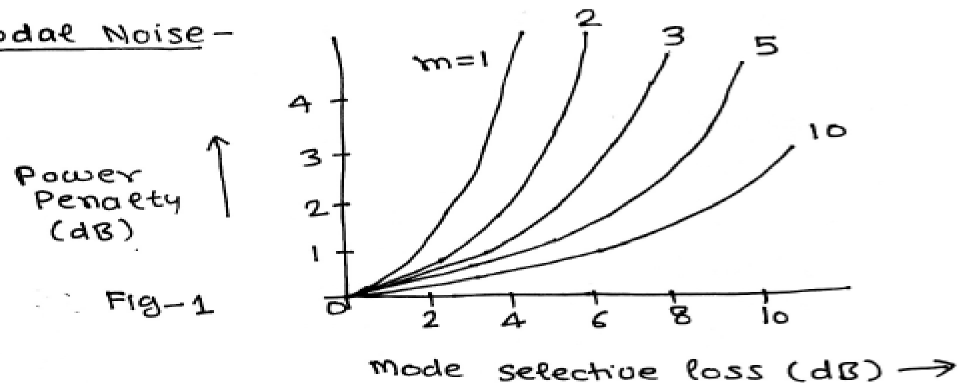


Fig-1

In multimode fiber, there is interference among various propagating modes which result in fluctuation in received power. These fluctuations are called modal noise. Fig-1 shows power panalty at $BER = 10^{-12}$, $\lambda = 1.3\,\mu m$, $B = 140$ mbps.

③ Frequency chirping – The change in carrier frequency due to change in refractive index is called frequency chirping.
Because of frequency chirping the spectrum of optical pulse gets broaden which degrades system performance. Fig-4 shows power panalty as a function of dispersion parameter $BLD\sigma_\lambda$ for several values of bit period.

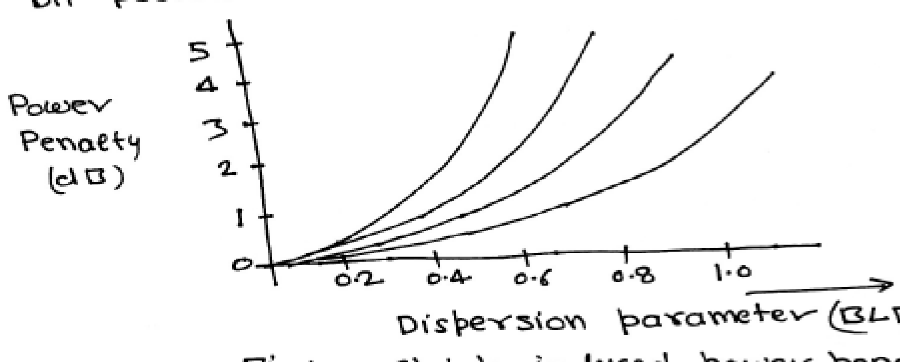


Fig4 – Chirp induced power penalty

④ Reflection Feedback and Noise – The light which reflects due to refractive index discontinuities at splices and connectors are unintentional which may degrade receiver performance.

Reflection in fiber link originate at glass air interface, its reflectivity is given by –

$$R_f = \frac{(n_f - 1)^2}{(n_f + 1)^2}$$

where n_f is refractive index of fiber material.

The noise that results from random intensity fluctuations is called relative intensity noise (RIN)

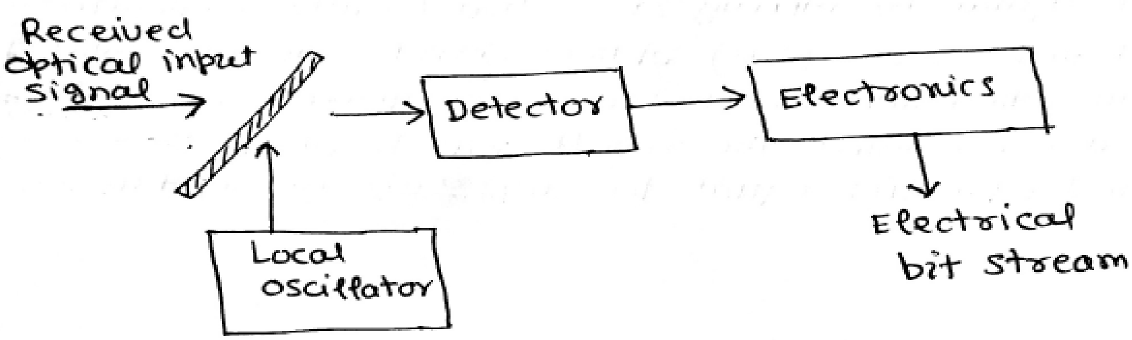
RIN is measured in dB / Hz

Q6. Explain coherent detection technique. Describe the homodyne detection and heterodyne detection. **[AKTU: 2022-23]**

ANS:

Coherent Detection Technique –

Coherent detection requires the receiver to have knowledge of the carrier phase, as the received signal is demodulated by a local oscillator that serves as an absolute phase reference.



Schematic diagram of a coherent detection scheme.

The basic idea behind coherent detection is shown schematically in above figure. A coherent field is generated locally at the receiver using a narrow-linewidth laser, called the local oscillator (LO). It is combined with the incoming optical field using a beam combiner, typically a fiber coupler in practice. To see how such mixing can improve the receiver performance Let us we write optical signal using complex notation as

$$E_s = A_s \exp[-i(\omega_0 t + \phi_s)] \quad \text{—— (1)}$$

where ω_0 = Carrier frequency
A_s = Amplitude
ϕ_s = phase.

The optical signal (field) associated with the Local oscillator is given by-

$$E_{LO} = A_{LO} \exp[-i(\omega_{LO} t + \phi_{LO})] \quad \text{— (2)}$$

where A_{LO}, ω_{LO} and ϕ_{LO} represent the amplit frequency and phase of the local oscillator respectively. The optical power incident on the photodetector is given by

$$P = |E_s + E_{LO}|^2 \quad \text{—— (3)}$$

Using equation (1) and (2),

$$P(t) = P_s + P_{LO} + 2\sqrt{P_s P_{LO}} \cos(\omega_{IF} t + \phi_s - \phi_{LO})$$

where, $P_s = A_s^2$, $P_{LO} = A_{LO}^2$, $\omega_{IF} = \omega_0 - \omega_{LO}$

The frequency $\nu_{IF} = \omega_{IF}/2\pi$ is known as the intermediate frequency. When $\omega_0 \neq \omega_{LO}$, the optical signal is demodulated in two stages.

Its carrer frequency is first converted to an intermediate frequency V_{IF}. The resulting radio frequency is then processed electronically to recover the bit stream. It is not always necessary to use an intermediate frequency. In fact, there are two different coherent detection techniques to choose from, depending on whether or not ω_{IF} equals zero. They are known as homodyne and heterodyne detection techniques.

① Homodyne Detection Technique -

* In this coherent detection technique the local oscillator frequency ω_{LO} is selected to coincide with the signal - carrier frequency ω_0 so that $\omega_{IF} = 0$.

* In this case photo current is given by

$$I(t) = R_d (P_S + P_{LO}) + 2 R_d \sqrt{P_S(t) P_{LO}} \cos(\phi_S - \phi_{LO})$$

where R_d = detector responsivity

Typically, $P_{LO} >> P_S$ and $P_S + P_{LO} \approx P_{LO}$. The Last term in above equation contains the information transmitted and is used by the decision circuit. Consider the case in which the Local oscillator phase is locked to the signal phase so that $\phi_S = \phi_{LO}$. Then the homodyne signal is given by

$$I_p(t) = 2 R_d \sqrt{P_S(t) P_{LO}}$$

* The main advantage of homodyne detection is the average electrical power is increased by a factor of $4 P_{LO} / \bar{P}_S$. Since P_{LO} can be made much larger than $\bar{P}_S$, hence power enhancement can exceed 20 dB. The homodyne detection also improves SNR by a large factor

(ii) <u>Heterodyne Detection Technique</u>- In case of heterodyne detection, the local oscillator frequency ω_{LO} is chosen to different from the signal carrier frequency ω_0 such that the intermediate frequency ω_{IF} is in microwave region ($\nu_F \sim 1GHz$)
In this case the photo current is given by -

$$I(t) = R_d (P_s + P_{LO}) + 2R_d\sqrt{P_s P_{LO}} \cos(\omega_{IF} t + \phi_s - \phi_{LO}) \quad \text{--- (1)}$$

where R_d = Responsivity of the detector

P_s = Power of the received optical field

P_{LO} = Power of the locally generated optical field.

ω_{IF} = Intermediate frequency

ϕ_s = Phase of the received optical field

ϕ_{LO} = Phase of the locally generated optical field.

Since, $P_{LO} >> P_s$ in practice, the direct current (dc) term is nearly constant and can be removed easily using bandpass filters. The heterodyne signal is then given by the AC term in the equation (1) by

$$I_{ac}(t) = 2R_d\sqrt{P_s P_{LO}} \cos(\omega_{IF} t + \phi_s - \phi_{LO})$$

The information can be transmitted through amplitude, phase or frequency modulation of the optical carrier. The local oscillator amplifies the received signal by a large factor, thereby improving the SNR. However, the SNR is lower by a factor of 2 (or 3 dB) compared to homodyne case. This reduction is referred as the heterodyne detection penalty.

Q7. Discuss Free space optics (FSO) based communication systems. **[AKTU; 2021-22]**

ANS:

Free-space optical Communication (FSO)

* Free space optics (FSO) is an optical communication technique that propagate light in free space means air, outer space, vacuum. Currentey, FSO is capable several Gbps of data, voice and video communication through the air, allowing optical connectivity without requiring fiber-optical cable.

* Links typically operate between 780 – 1600 nm wavelengths bands and use O/E and E/O converters. FSO requires light, which can be focused by using either LEDs or Lasers. The use of Lasers is a simple concept similar to optical transmissions using fiber optic cables. Light travels through air faster than it does trough glass, so it is fair to classify FSO as optical communications at the speed of light. FSO communication is considered as an alternative to radio relay link Line-of-Sight (LOS) communication systems.

* FSO communications can provide high data rates in Gbits/s ranges through the atmosphere for ranges from a few hundreds of meters to a few kilometers. FSO Links include the following–
  * Chip-to-Chip communication
  * Indoor infrared (IR)
* Inter-building communication
* free-space Laser communications including airborne, spaceborne and deep space mission

* FSO components are contain three stages :
  (I) transmitter to send optical radiation through the atmosphere.
  (II) Free space transmission channel
  (III) Receiver to process the received signal.

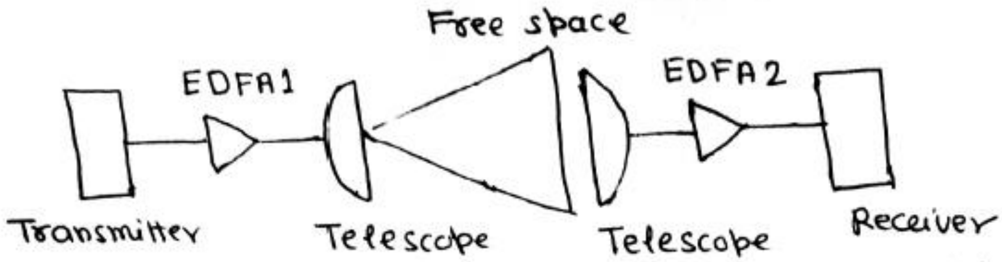
* Typical FSO links are between 300m to 5 Km, although longer distances can be deployed such as 8 to 11 Km are possible depending upon speed and required availability.

* Some FSO applications are-
  (i) Telecommunication and computer networking
  (ii) Point-to-point LOS links.
  (iii) Temporary network instalation for events or other purpose as disaster recovery.
  (IV) For commonication between spacecrafts.
  (V) military applications
  (VI) metro-network extensions
  (VII) Fiber backup

* Free space optical communication system is. influenced by atmospheric attenuation by fog, haze, rainfall and scintillation, which limits the performance and reliability of FSO.

<u>Technical advantages of FSO:-</u>

* Ease of deployment
* can be used to power devices
* License free longe-range operation
* High bit rates
* Low bit error rates
* Full-duplex operation
* Reduced size, weight and power consumption compared to RF antennas.



(Typical FSO system.)

As shown in fig, a typical FSO system includes a high power optical source Laser or LED. Visible/IR energy is modulated with data to be transmitted. A telescope is used to transmit light through the atmosphere to another telescope that receives the information. Receiving telescope is connected to a high sensitivity receiver through an optical fiber.

* FSO communication offers a high data rate to meet the increasing demand of broadband traffic mostly driven by Internet access and HDTV broadcasting services.
* Compared to fiber optics technology, FSO offers much more flexibility in designing optical network architecture at very high speed at tens and hundreds of Gbit/s rates.
* However, FSO communication is affected by atmospheric effects, which limits the sensitivity and achievable data rates with acceptable BER.

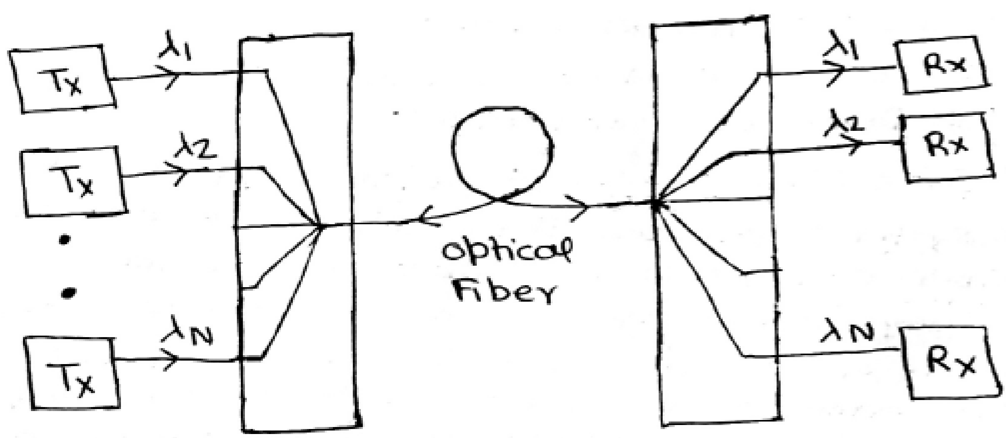
Q8. Describe the multichannel & multiplexing transmission techniques in fiber optics.

[AKTU: 2022-23]

ANS:

Wavelength division multiplexing-

Multichannel Transmission Techniques in optical Fiber - wavelength - division multiplexing (WDM) is the technique of transmitting multiple channels of information through a single optical fiber by sending multiple light beams of different wavelengths through the fiber, each modulated with a seperate information channel.



multichannel point-to-point fiber link. seperate transmitter - receiver pairs are used to send and receive the signal at different wavelength

* In fiber- optical communications, wavelength division multiplexing (WDM) is a technology which multipleexes a number of optical carrier signals onto a single optical fiber by using different wavelengths of laser light. This technique enables bidirectional communications over a single strand of fiber (also called wavelength - division duplexing) as well as multiplication of capacity.

* The term WDM is commonly applied to an optical carrier, which is described by its wavelength, whereas frequency-division multiplexing is applied to a radio carrier which is described by frequency. This is purely conventional because wavelength and frequency communicate the same information. Specifically, frequency multiplied by wavelength equals velocity of the carrier wave.

* There are two types of WDM –
  (i) Coarse WDM or CWDM
  (ii) Dense WDM or DWDM

(i) Coarse WDM (CWDM): CWDM is defined by WDM systems with less than eight active wavelengths per fiber. CWDM is used for short range communications, so it employs wide-range frequencies with wavelengths that are spread far apart. Standardized channel spacing permits room for wavelength drift as lasers heat and cool down during operation. CWDM is a compact and cost effective option when spectral efficiency is not an important requirement.

(ii) Dense WDM (DWDM) – DWDM is defined in terms of frequencies. DWDM's tight wavelength spacing fits more channels onto a single fiber, but costs more to implement and operate. DWDM is for systems with more than eight active wavelengths per fiber.

With DWDM, vendors have found various techniques for cramming 40, 88 or 96 wavelengths of fixed spacing into the C-band spectrum of a fiber.

Q9. What are the advantages of coherent optical communication system? [AKTU: 2020-21

ANS:

Advantages of coherent optical Communication System

A coherent optical communication system has the following advantages -

(i) High sensitivity and long relay distance.
(ii) Good selectivity and large communication capacity.
(iii) Permits to use vari of modulation methods.

(i) High Sensitivity and long relay distance -

Coherent detection in coherent optical communication can improve receiver sensitivity. Under the Same conditions, the sensitivity of coherent receiver is about 20 dB higher than that of the ordinary receiver, which can achieve high performance close to shot noise limit, thus increasing the transmission distance of the optical signal without relay.

(ii) Good Selectivity and Large communication capacity -

Coherent detection enhances the selectivity of the receiver. In an optical coherent communication system, the magnitude of the output photocurrent after coherent mixing is proportional to the product of the signal optical power and the local oscillator optical power. Since the local oscillator optical power is significantly higher than the signal optical power, the sensitivity of the receiver is greatly enhanced, enabling the detector to reach the quantum noise limit, and thus also extending the transmission distance of optical signal.

(iii) Permits to use variety of modulation methods -

In coherent optical communication, in addition to amplitude modulation of light, various modulation techniques such as PSK, DPSK and QAM can also be used.