In this section we will discuss the overview of optical components. Important optical components are as follows :

1. Optical couplers
2. Tunable sources and filters.
3. Optical MUX/DEMUX
4. Fiber grating
5. Arrayed Waveguide Grating (AWG)
6. Optical circulators
7. Attenuators
8. Wavelength converters.

4.1 OPTICAL COUPLERS

UQ. Define Four Wave Mixing (FWM).

(MU – Q. 1(d), Dec. 17, 5 Marks)

- A fiber optic coupler is a device that can distribute the optical signal from one fiber among two or more fibers, or combine the optical signal from two or more fibers into a single fiber.
- Usually, optical signals are attenuated more in an optical coupler than in a connector or a splice because the input signal is not directly transmitted from one fiber to another, but divided among the output ports. Here the **coupling ratio** should be minimum.
- It can be an optical fiber device with one or more input fibers and one or several output fibers. Light from an input fiber can appear at one or more outputs, with the power distribution potentially depending on the wavelength and polarization.
- It can also be a device for coupling (launching) light from free space into a fiber; see the article on fiber launch systems.
- The coupling ratio is defined as the ratio of output optical power to total input power.

4.2 CLASSIFIED BY SHAPE

Optical couplers classified by shape, as:

(I) Y coupler,
(II) T coupler,
(III) X coupler,
(IV) Star coupler and
(V) Tree coupler,

All these coupler will split the optical signal based on the power.

(I) Y Coupler

- A Y coupler resembles the letter Y. Y coupler also called optical tap coupler.
- The input signal is split into two output fibers. Sometimes, to meet users' specific applications, the power distribution ratio also can be controlled precisely.

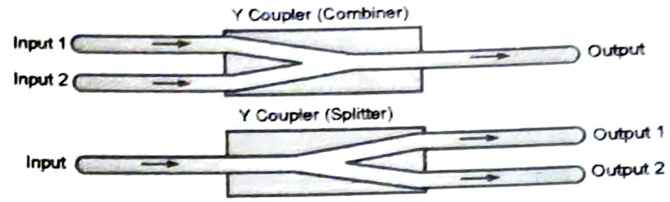

Fig. 4.2.1 : Y Coupler

(II) T Coupler

- Unlike the Y coupler, a T coupler has an uneven power distribution. The power of one output signal is greater than the other output signal.
- Popular splitting ratios include 10:90 percent and 20:80 percent. **This optical coupler is often used in small networks with less port counts.**

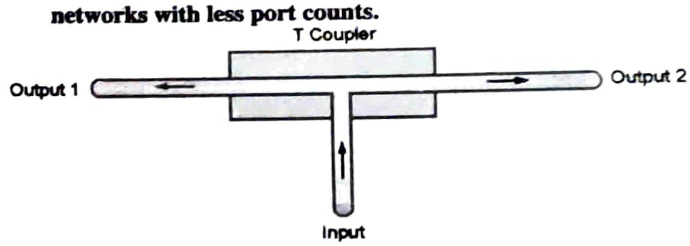

Fig. 4.2.2 : T Coupler

4.2.1 X Coupler (2x2)

- X couplers carry out the function of a splitter and a combiner in one package. The X coupler combines and divides the optical power from the two input fibers between the two output fibers.
- Another name for the X coupler is 2 x 2 coupler.

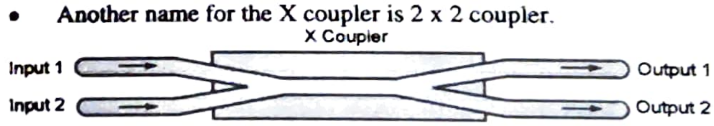

Fig. 4.2.3 : X Coupler

4.2.2 Star Coupler

- A star coupler generally has several input and output port combinations, in which the optical power is distributed from more than two input ports among several output ports.
- The number of input and output ports may or may not be equal in star couplers such as 2×4, 4×4, 8×16, etc.
- However, in all possible input and output port combinations, the distribution of power among the output ports remains equal.

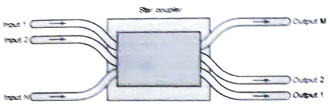

Fig. 4.2.4 : Star Coupler

Tree Coupler

- A tree coupler is also a multiport coupler. It splits optical power from one input fiber to more than two output fibers.
- A tree coupler may also be used reversely to combine the optical signal from more than two input fibers to one output fiber.

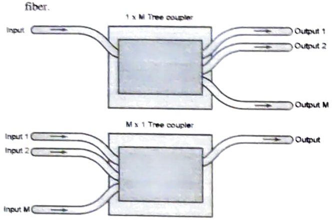

Fig. 4.2.5 : Tree Coupler

4.3 CLASSIFIED BY BANDWIDTH OR WINDOW

- Bandwidth or Window is also a factor to consider when users choose the optical coupler types. Regardless of the port types used, fiber optic couplers can be designed for single window, dual wavelength or wideband transmissions.
- Single window couplers are designed to incorporate a single wavelength within a narrow wavelength window.
- Dual-wavelength couplers have wider wavelength windows and can work with two wavelengths at a time.
- Wideband couplers can be designed to work with a single wavelength covering a wider range of wavelengths. In addition, fiber optic coupler also can be classified to single mode optical coupler and multimode optical coupler.

4.4 CLASSIFIED BY MANUFACTURING/FABRICATION

The various types of couplers are :

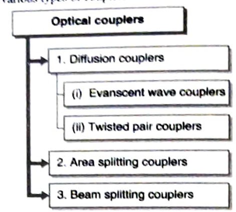

Fig. 4.4.1 : Optical Couplers

4.4.1 Diffusion couplers

The diffusion couplers are again divided into two types viz.

(i) Evascent wave coupler

- This type of couplers are as shown in Fig. 4.4.2. Here it is required to couple the data from optical fiber 1 to the optical fiber 2.
- To achieve this coupling, for a certain length the two fiber optic cables are made parallel to each other as shown in Fig. 4.4.2. This particular length is called as coupling length

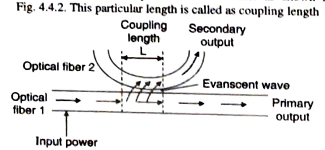

Fig. 4.4.2 : Evanscent wave coupler

- Then the optical wave called as evanescent wave enters into the second fiber optic cable. And the signal is coupled into the second optical fiber.

(ii) Twisted pair coupler (Fused Biconical Tapper Coupler, FBT)

- The schematic of twisted pair coupler is as shown in Fig. 4.4.3. In this case a pair of optical fibers is twisted and then it is fused with the heat treatment.
- Because of the fusing action the core layer of one fiber optic cable acts as cladding layer for other. Thus the coupling of data takes place.

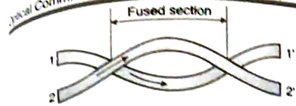

Fig. 4.4.3 : Twisted pair coupler

4.4.2 Area Splitting Coupler (Star Couplers)

- Here the optical power is divided and a part of optical power is passed to the another fiber optic cable. Thus the distribution of optical power takes place.
- The construction of star coupler is as shown in Fig. 4.4.4.. In this case a portion of several optical fibers to be coupled is fused as shown in Fig. 4.4.4.
- Then the data transmitting through one fiber optic cable gets coupled to all the remaining optical fibers. The different detectors can be connected at the output of each optical fiber.

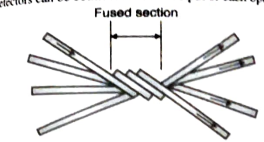

Fig. 4.4.4 : Star coupler

4.4.3 Beam Splitting Coupler

- This type of couplers are used for multiplexing operation. This coupler is as shown in Fig. 4.4.5. This consists of a partially reflecting surface. The incident light beam gets reflected partially and the data is coupled to other optical fiber.
- Sometime dichoric surfaces are used inside the optical fiber.

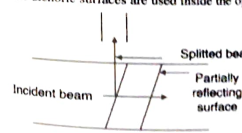

Fig. 4.4.5 : Beam splitting coupler

- This is a wavelength selective surface. So only required wavelengths of light can be coupled into another optical fiber.

4.5 VARIATION OF STAR COUPLERS

The different variations in the basic star couplers are as follows :

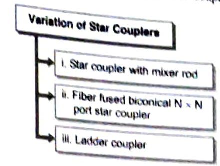

Fig. 4.5.1 : Variation of star couplers

(I) Star coupler with mixer rod

- In case of ideal couplers; output power from input is equally distributed among all fibers. The star coupler using mixer rod is shown in Fig. 4.5.2.
- The different input fiber optic cables are connected to the mixer rod and output of mixer rod is connected to various optical cables.

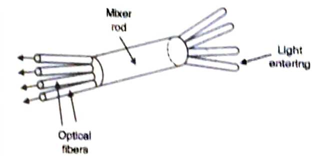

Fig. 4.5.2

- In the mixer rod ; the light is effectively mixed and distributed to many fibers connected at output of mixer rod. This technique is especially used for multimode fibers.
- The total loss in coupling is basically addition of splitting loss and excess loss. The splitting loss is given by,

$$\text{Splitting loss} = 10 \log N \text{ dB}$$

Here N = number of output fibers.

- If there is single input port and multiple output ports then excess loss is given by,

$$\text{Excess loss} = 10 \log_{10} \left[\frac{P_{in}}{\sum_{i=1}^{N} P_{out}} \right] \text{dB}$$

- The insertion loss between any two ports, say m and n is calculated using equation.

$$\text{Insertion loss between port m and n} = 10 \log \frac{P_m}{P_n} \text{ dB}$$

(ii) Fiber fused biconical N × N star coupler

- This coupler is shown in Fig. 4.5.3. This connection is shown for four input and four output ports.
- The four fibers are twisted and heated. Then it is pulled to obtain four output fibers.
- Input signal applied to any input port can be coupled to all four output ports.

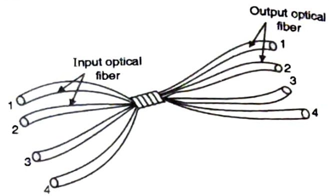

Fig. 4.5.3

(iii) Ladder coupler

- The ladder coupler is also called as N × N star coupler and it is extension of basic 2 × 2 coupler. Fig. 4.5.4 shows the ladder coupler having 8 input ports and 8 output ports. The power from each input port is divided equally among all output ports.
- The ladder coupler is used when it is required to combine many input signals and then broadcast it to many outputs. This structure provides multiport facility with low insertion loss.

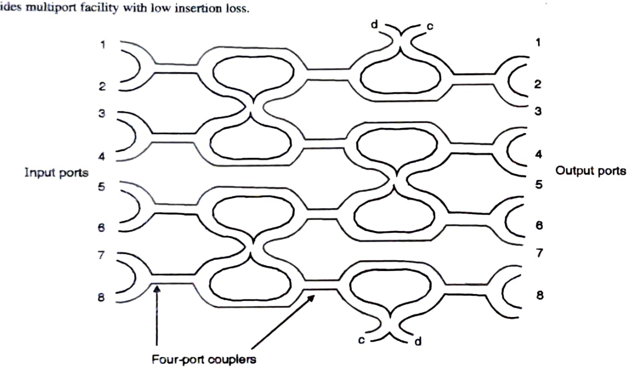

Fig. 4.5.4 : Ladder coupler

4.6 WAVELENGTH DIVISION MULTIPLEXING (WDM) COUPLERS

- Some optical couplers are wavelength dependent devices and such couplers can be used as multiplexers, as well as demultiplexers. In such couplers ; the light from different optical sources is launched into single optical cable, at a time.
- The wavelength of light from each source is different. The coupling strength is wavelength dependent as well as it is polarization dependent.
- The broadband 1310 and 1550 nm WDM couplers are designed for multiplexing and demultiplexing 1310 nm and 1550 nm wavelengths.
- Here 1310 nm signal from input port 1 is passed through the cable to output port 1. Similarly 1550 nm signal from input port 2 is also passed to output port 1.
- If these two wavelengths are combined and passing through single optical cable, then the same optical coupler can be used to separate out these wavelengths.

4.7 ISOLATORS

- In the year 1842, Michael Faraday stated that the optical isolator operation depends on the Faraday Effect. This effect refers to a fact that the polarized light plane turns when the light energy transmits through the glass that can be exposed toward a magnetic field.
- The direction of rotation mainly depends on the magnetic field as an alternative of the light transmission direction. An optical isolator is also known as an optical diode, photocoupler, an optocoupler. It is a passive magneto-optic device, and the main function of this optical component is to permit light transmission in one direction only.
- So it plays a main role while preventing unnecessary feedback to an optical oscillator namely laser cavity. The working of this component mainly depends on the Faraday's effect which is used in the main component like Faraday rotor.
- Optical isolator is a device which allows the propagation of light in one direction and blocks the propagation in another direction. Basically optical isolator allows the light to propagate in forward direction only and blocks the propagation of reflected light.
- Consider an optical system in which laser is used as light source. The laser beam coming out from the laser source, passes through optical cable and strikes on the detector at other end of optical cable.
- It may happen that, the light rays get reflected from photodetector and starts travelling towards the laser source. When such reflected light, strikes on the laser source ; it affects the laser oscillations.
- To avoid this optical isolators are placed between source and detector. Isolator allows the light only in forward direction that means from laser source to the detector but it blocks the reflected light.
- The two important parameters of isolators are as follows :
  (i) Insertion loss (ii) Isolation
- Insertion loss is the loss taking place in optical cable, when the light rays are travelling in forward direction. Insertion loss should be as low as possible. A typical value of insertion loss is 1dB.
- Isolation is the loss in reverse direction and it should be as large as possible. Typical value of isolation is 40 to 50 dB. Thus an isolator is irreversible device, that permits the passage of light only in forward direction.

4.7.1 Working of Opto Isolator

- An optical isolator includes three main components namely a
  - Faraday rotator,
  - input polarizer, &
  - an output polarizer. Shown in Fig. 4.7.1.
- The block diagram representation is shown Fig. 4.7.1. The working of this is like when light passes through the input polarizer in the forward direction & turn into polarized within the vertical plane.
- The operation modes of this isolator are classified into two types based on the different directions of light such as forward mode & backward mode.

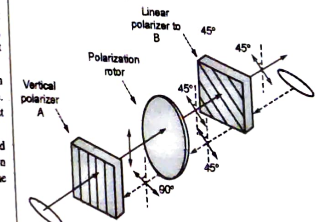

Fig. 4.7.1 : Working principle of Opto-Isolator

- The forward mode enables light enter into the input polarizer and become linearly polarized. When laser light reaches the Faraday rotator, the Faraday rotator rod will rotate by 45° polarization. Thus, the light finally leaves the output polarizer at 45° polarization. Shown in Fig. 4.7.2.

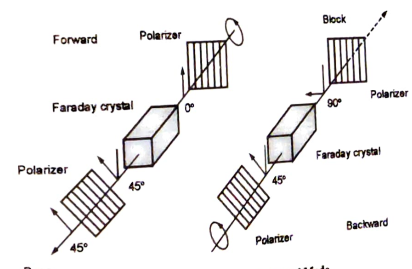

Fig. 4.7.2 : Forward and Backword Mode

- However in the backward mode, the light first enters into the output polarizer with a 45° polarization. Next, as it passes through the Faraday rotator, it continues to be rotated for another 45° in the same direction. Then the light of 90° polarization becomes vertical to the input polarizer and can not leave the isolator. As a result, the light will be either reflected or absorbed.

4.7.2 Types of Optical Isolator

(I) Polarized Optical Isolator

- Polarized optical isolator employs the polarization axis to keep light transmit in one direction. It allows light to propagate forward freely, but disallows any light to travel back.
- Also, there are dependent and independent polarized optical isolators.
- The latter is more complicated and often used in EDFA (erbium-doped fiber amplifier) optical amplifier.

(II) Composite Optical Isolator

- Composite optical isolator is actually a type of independent polarized optical isolator.
- It is used in EDFA optical amplifier which consists of many other components, such as erbium-doped fiber, wavelength-division multiplexer, pumping diode laser and so on.
- Since there are many other components in EDFA module, this type of isolator is named as composite optical isolator.

(III) Magnetic Optical Isolator

- Magnetic optical isolator is essentially the polarized optical isolator in another expression.
- It stresses the magnetic part of a Faraday rotator.
- The Faraday rotator is generally a rod made of a magnetic crystal under strong magnetic field with Faraday effect.

Applications of Optical Isolator

1. Optical isolator is used in many optical applications in corporate, industrial, and laboratory settings.
2. They are reliable devices when used in conjunction with fiber optic amplifiers, fiber optic ring lasers, fiber optic links in CATV applications, and high-speed and coherent fiber optic communication systems.
3. Single polarization fiber optic isolators are also used with laser diodes, gyroscopic systems, optical modular interfaces, and a variety of other mechanical control and testing applications.

4.8 OPTICAL CIRCULATORS

UQ. Explain the working principle of optical circulator. **(MU - Q. 1(d), May 18, 4 Marks)**

- The circular is similar to optical isolator ; the only difference is that, the circulator is having multiple ports. Optical circulator can have three ports or four ports.
- Optical circulator is used to separate out optical powers, which travels in opposite directions in an optical cable.
- The three ports optical circulator and four port optical circulators are shown in Figs. 4.8.1(a) and 4.8.1.(b) respectively.
- The arrow indicates the directions along which the light ray propagate from one port to another.

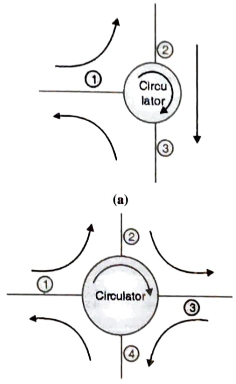

Fig. 4.8.1 : Optical Circulator

- Consider the case of three port optical circulator. If the signal enters in port ① then it comes out from port ②. Similarly, the signal entering in port ②, comes out from port ③ and the signal entering in port ③ comes out from port ①. This propagation of light rays is shown by the directions of corresponding arrows. The four port circulator, works on the same principle.
- Suppose, in three port circulator, the light enters in port ① and from port ② the light gets reflected to the circulator ; then reflected light will not enter into port ①. It will be emitted out from port ③. The circulators are basically used to perform bidirectional communication by using single optical cable. Circulators are basically non-reciprocal devices and are used to construct optical add or drop elements. It also provides add and drop functionality in optical multiplexer and optical de-multiplexer.

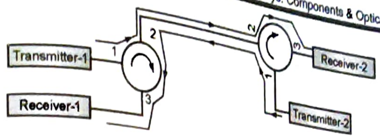

Fig. 4.8.2 : Use of Circulator

- As shown in the Fig, 4.8.2. signal from left to right is transmitted through two circulators having 3 ports and signal from right to left marked in blue is transmitted in the other direction over the same fiber optic cable.
- This forms the bidirectional link using circulators. From the fig.4.8.2.it is derived that port-1 acts as INPUT port, port-3 as OUTPUT port and port-2 as both INPUT/OUTPUT port.
- Hence transmitter-1 and 2 can transmit signal with wavelength 1550 nm on port-1 simultaneously and the same can be received on the respective other sides on port-3. Optical circulators are widely used in fiber amplification systems, WDM networks, OTDRs (optical time-domain reflectometers), covering unidirectional optical link to the bidirectional link and test and measurement instruments.

4.8.1 Difference between Circulator and Isolator

UQ. Differentiate between the optical components isolator and circulator **(MU - Q. 1(c), Dec. 16, 5 Marks)**

UQ. Compare Isolators and Circulators. **(MU - Q. 4(b), May 16, Q. 3(c), May 17, Dec. 17, 5 Marks)**

Table 4.8.1 : Comparison of circulator and isolator

Sr. No.	Parameters	Isolator	Circulator
1.	Direction	It transmits the signals in one direction only.	It transmits the signals between different ports.
2.	Port	It is two port device.	It is three or four port device.
3.	Usage	It is used to isolate two ports.	It is used to separate out optical powers, which travel in opposite direction in optical cable.
4.	Port termination	It transmits the signal in forward direction with terminating any port.	According to requirements, anyone port is terminated.
5.	Application	It is used to avoid reflected light to enter into source.	It is used to construct optical add or drop elements.

4.9 OPTICAL MUX/DEMUX

- In many applications, it is required to multiplex and demultiplex the optical signals. Basically in optical communication, the signal transmission is based on operating wavelength of incoming light.
- A multiplexer is a device which combines the different wavelengths at the input port. It produces signal on a common output port as shown in Fig. 4.9.1.

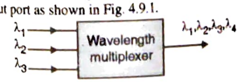

Fig. 4.9.1

- The demultiplex accepts the common wavelengths and divides into different wavelengths. That means it performs the reverse operation.
- By using a cascade connection of multiplexer and demultiplexers ; Wavelength Cross Connects (WXC) are designed.
- The Wavelength Cross connects (WXCs) are of two types namely static WXC and dynamic WXC.
- The signals of different wavelengths are transferred from input to output depending on the cross connections.

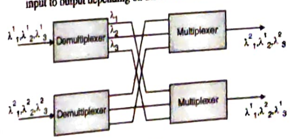

Fig. 4.9.2

- An example of wavelength cross connector is shown in Fig. 4.9.2. A static wavelength cross connect, is a device in which the cross connection are fixed ; user cannot change it according to the requirement.
- While in case of dynamic wavelength cross connect is a device in which the cross connections can be changed according to the requirements.

4.10 TUNABLE SOURCES AND FILTERS

- Basically, filter is a device which passes only the required signal and attenuates and stops all unnecessary signals.
- Optical filter is a device which allows only the required wavelength and rejects all remaining wavelengths. If in some applications, suppose the required wavelength is λ_2 and incoming signal contains the wavelengths $\lambda_1 \lambda_2$ and λ_3.
- A three port filter as shown in Fig. 4.10.1. can be used to pass to port ②.

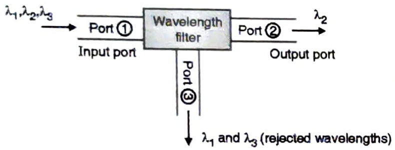

Fig. 4.10.1.Tunable source and Filter

- It allows only wavelength λ_2 and remaining wavelengths that is λ_1 and λ_3 are rejected and routed to port ③.

Some important features of optical filters are as follows

1. The loss taking place in an optical fiber from input to output is called as insertion loss. A filter should have low insertion loss.
2. The filter should not have polarization dependant loss ; because in many applications, the polarization of input signal changes with time.
3. The pass band of filter should not change, due to the change in operating temperatures.
4. When many filters are connected in cascade then every individual filter should have a flat passband.
5. There should not be mixing of signals from adjacent channels ; so the passband edges must be sharp.

4.10.1 Fabry-Perot Filters

- It is basically optical bandpass filter and it is also called as Thin Film Filter (TFF) or Fabry-perot interferometer or etalon.
- It allows only a narrow wavelength band to pass through it and remaining wavelengths are reflected.
- The basic structure of Fabry-Perot filter is shown in Fig. 4.10.2. Basically it consists of two highly reflecting mirrors and a cavity is formed between the mirrors.
- Incident light falls on the left mirror and enters into the cavity. This light passes through the cavity and strikes on the right mirror.
- Depending on the reflectivity of right mirror ; some of the light comes out of right mirror and remaining light gets reflected to the left mirror. Again the left mirror reflects this light and it comes out from the right mirror.
- If the roundtrip distance between two mirrors that means if the length of fabry perot cavity is integer multiple of wavelength of light (λ, 2λ, 3λ,... etc) then all the light rays coming out from right mirror will be in phase. Thus these light rays will be added. That means there is constructive interference of these wavelengths and so intensity will be added at the output.

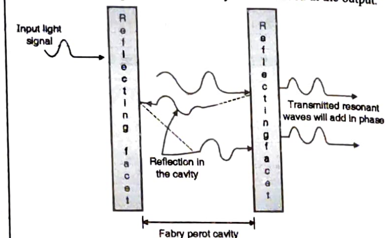

Fig. 4.10.2. basic structure of Fabry-Perot filter

- Such wavelengths are called as resonant wavelengths of the cavity. Thus only resonant wavelengths will come out of cavity and other wavelengths will be reflected.
- The power transfer function of this filter is a part of input power, which is transmitted by the cavity.
- It is given by,

$$T = \frac{\left(1 - \frac{A}{1-R}\right)^2}{\left[1 + \left(\frac{2\sqrt{R}}{1-R}\sin\left(\frac{2\pi n l}{\lambda}\right)\right)^2\right]}$$

Here
A = Absorption loss at each mirror, that means it indicates the amount of light absorbed by mirror
R = Reflectivity of mirror, that means amount of light reflected by mirror.
n = Refractive index of cavity
l = Length of cavity
λ = Wavelength of incident light

- The propagation delay from left mirror to right mirror in the cavity is denoted by τ and it is given by,

$$\tau = \frac{nl}{c};$$

Where, c = speed of light

- The number of resonant wavelengths, that can be supported by this cavity is given by ratio,

$$F = \frac{\pi\sqrt{R}}{1-R}$$

- This ratio is called as **finesse** of the filter. This structure can be tuned to generate another resonant wavelength by using following techniques.
  (i) Change the cavity length, that means distance between two mirrors (l) OR
  (ii) Change the refractive index of cavity (n).
- The one way propagation delay time (τ) is given by, $\tau = \frac{nl}{c}$, so if we change n or l, τ will be changed and filter will be tuned for other wavelength.

4.11 FIBER GRATINGS

- Basically grating means a series of grooves are formed such that a particular wavelength of light is reflected and other wavelengths are transmitted.
- These grooves can be formed inside the optical cable. It is also called as **grating are written in fibers.** The gratings are written in the fiber by making use of photosensitivity property of the fiber. Generally fiber is made using silica material. When it is dopped using germanium then it becomes photosensitive.
- When UV (ultraviolet) rays falls on this fiber then the refractive index of core layer is changed. By this way gratings can be written inside the fiber.
- Two UV beams are used to illuminate the fiber core ; then the radiation intensity varies periodically along the length of optical cable. For the low radiation intensity ; the refractive index is unchanged and when the radiation intensity is high the refractive index is increased.

4.11.1 Types of Fiber Gratings

UQ. Write short note on : Fiber Bragg grating **(MU – Q. 6(a), May 18, 5 Marks)**

UQ. What is fiber bragg gratings ? Give its applications. **(MU – Q. 1(d), Dec. 18, May 19, 5 Marks)**

UQ. Explain the concept of Fiber Bragg Grating. Give its applications. **(MU - Q. 1(d), Dec. 16, Dec. 2019, 5 Marks)**

There are two types of fiber grating namely short period grating and long period grating. The short period grating is also called as Brag grating.

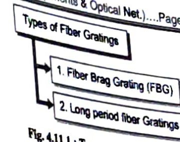

Fig. 4.11.1 : Types of Fiber Gratings

1. Fiber Brag Grating (FBG)

- It is also called as distributed brag reflector and it is constructed in the short length of optical cable. This grating has a property to reflect a particular wavelength and to pass all remaining wavelengths. This property can be achieved by making the variations in the refractive index of fiber core.
- Consider a fiber brag grating used along with a circulator as shown in Fig. 4.11.1(a).

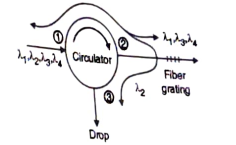

Fig. 4.11.1(a) : Fiber Brag Grating

- This is three port circulator. If input is applied to port ① then output is generated to port ② and if input is applied to port ②, then output is generated at port ③.
- Suppose the wavelengths λ_1, λ_2, λ_3 and λ_4 are applied to port ① and λ_1, λ_3, λ_4 are the required wavelengths. Basically circulator passes these all wavelengths to port ②.
- The fiber grating is placed at port ② and it is designed in such a way that ; the wavelength λ_2 gets reflected by this grating. This reflected wavelength will be routed to port ③.
- This is basically called as optical drop element because the wavelength λ_2 is dropped. After the diffraction grating ; we can connect one more circulator and wavelength λ_2 is again added. It will produce the outputs λ_1, λ_2, λ_3 and λ_4. This later part is called as optical add element. These short period grating is having a period around 0.5 μm, which is comparable to the wavelength.

2. Long Period Fiber Gratings

- As the name indicates ; the period of such grating is long. This period is much greater than wavelength. It is in terms of millimeter. These grating are fabricated using same technique as that of fiber brag grating. Now a days, these gratings are used as filters inside erbium dopped fiber amplifier.
- In case of short period fiber grating, the wavelength to be reflected is transferred (coupled) from forward mode to the backward mode. In long period fiber gratings, the required

energy is coupled from the forward mode incore layer to another forward mode is cladding layer.

- Many losses take place in the cladding modes and their energy decreases as they propagate along the fiber.
- The coupling between core mode and a particular cladding mode depends on the pitch or grating.

4.11.2 Advantages of Fiber Gratings

(i) It possess very low losses because it is basically all fiber device.
(ii) Easily coupled with other fibers.
(iii) Fiber gratings are not sensitive to polarization.
(iv) They have low temperature coefficients.
(v) Packaging is simple and cost is low.

- An Arrayed Waveguide Grating (AWG) is shown in Fig. 4.12.1.

4.12 ARRAYED WAVEGUIDE GRATING (AWG)

- Arrayed Waveguide Gratings (AWG) are also based on diffraction principles. An AWG device, sometimes called an optical waveguide router or waveguide grating router, consists of an array of curved channel waveguide with a fixed difference in the path length between adjacent channels.
- The waveguides are connected to cavities at the input and output. Basically AWG is used as a wavelength selective filter or a wavelength switch in optical network.
- AWG can be used as a multiplexer or demultiplexer in Wavelength Division Multiplexing (WDM).

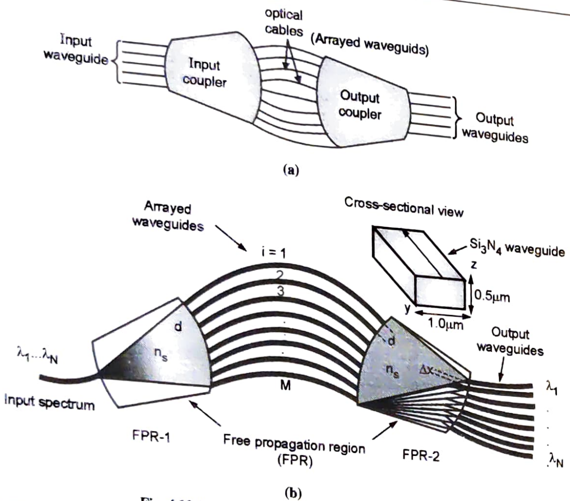

Fig. 4.12.1 : Arrayed Waveguide Gratings (AWG)

- It consists of two couplers, namely input coupler and output coupler. Let us say input coupler has 'n' input ports and 'm' output ports. While output coupler has 'm' input ports and 'n' output ports.
- These two couplers are connected by using 'm' number of optical fiber cables. These connecting cables are called as arrayed waveguides.
- All these components of AWG, namely input-output couplers along with input-output waveguides and the arrayed waveguides (optical fiber cables) ; all are fabricated on a single substrate.
- The substrate material is usually SiO_2 or silica, Indium Phosphide (InP) etc. The incoming light traverses a free space or input waveguides and enters into input coupler.
- The input coupler couples these light rays to 'm' optical fibers. These fibers are called as arrayed waveguides and these fibers are having different lengths. Due to difference in length ; every fiber produces different phase to incoming wavelength. All these signals from 'm' optical fibers are coupled to free space or output waveguides through output coupler.

- The signals passing through arrayed waveguides, interfere with the signals passing through the neighbouring arrayed waveguides. This interference can be constructive or destructive. So, depending on interference a signal of required wavelength can be obtained at the output device. When there are only two input ports and two output ports, then such AWG is called as **Mach-Zehnder Interferrometer** (MZI).

4.13 OPTICAL SWITCH

- An optical switch is a **multi-port network bridge**, which connects multiple optic fibers to each other and controls data packets routing between inputs and outputs. Some optical switches convert light to electrical data before forwarding it and converting it into a light signal again.
- Other optical switches, which are called All-optical, can route and forward the light pulses themselves without any electrical conversion. An optical switch is a device that can selectively switch light signals that run through in optical fibers or integrated optical circuits from one circuit to another.
- Optical switches can transfer light signals between different channels in communication networks. As the growing popularity of Internet and telephone, greater quantities of data managed by communication networks also expanded. Optical switching technology provides a perfect solution to fully exploit capacity of optical systems.

4.13.1 Requirement of Optical Switch

The various important characteristics of optical switch are as follows :

1. The extinction ratio of switch must be large. It is basically the ratio of optical power when the switch is ON, to the optical power when the switch is OFF.
2. Insertion loss must be small. It is the loss taking place in optical network when optical signal is routed through the switch.
3. The cross talk should be ideally zero. When using a switch, 'i' **input** is connected to 'j' output then many times the 'j' output contains. Some signals from other input channels. It is the cross talk in optical switch.
4. Optical switch should be polarization insensitive.
5. In many application, it is required that, the switch remain ON, in case of power failures. Such switches are called as latching switches.
6. There should be readout facility in the display of switch. That means by reading a display, user will come to know, whether the switch is ON or OFF.

4.13.2 Working Principles & Functions of Optical Switches

UQ. Write short note on Optical Switches **(MU - Q. 6(iv), Dec. 2019, 5 Marks)**

4.13.2 (A) Working Principles of Optical Switches

- When a light signal runs through from one computer to another in fiber optic networks, it may be required to move the signal between different fiber paths. To accomplish this, a switch is required to transfer the signal with a minimum loss. Optical switch is a technology needed.
- The optical switch we often see is operated by mechanical method which just moves fiber or other bulk optic components. But they can offer unprecedented high stability and unmatched low cost performance.
- Optical switches are mainly deployed in establishing the light path. They feature scalability and highly reliable switching capacity.

4.13.2 (B) Major Function of Optical Switches

UQ. Explain the working principle of optical switches. **(MU - Q. 1(d), May 16, 5 Marks)**

Following are the major functions that optical switches bear in optical cross networks :

1. **Protection** : Sometimes a failure of some single point can cause the whole network breaking down. And the protection switching is to protect the transmission data, which can avoid network fault before finding the failure causes.
2. **Optical add/drop multiplexing** : Optical switches must be equipped with the capability that can add or delete the wave channels `without any electronic processing. This kind of optical switches is also called wavelength selective switches.
3. **Optical spectral monitoring** : Optical spectral monitoring is a network management operations. In this process, operators receive a small portion of optically tapped signal for monitoring power level, wavelength accuracy and optical cross talk.

4.14 TYPES OF OPTICAL SWITCHES

The most common types of optical switches are as follows :

1. Opto-Mechanical optical switches
2. MEMS (Micro-Electro-Mechanical-System) Switches
3. Liquid crystal switches
4. Electro-optic switches
5. Thermo-optic switches
6. Semiconductor optical amplifier switches

4.14.1 Opto-Mechanical Optical Switches

- Opto-mechanical optical switch is an old type of switches but the most widely used one. It can produce different optical path selections out of a plurality of optical path sections that are oriented in different spatial directions. Hence opto-mechanical optical switches can be used in multi-channel optical power monitoring, optical local area networks, switching multiple laser sources or optical receivers in Ethernet networks.
- They are also very useful in optical fiber, components or systems testing and measurement, as well as applications in multi-point fiber sensor systems.
- Generally, according to the number of redirecting signals, opto-mechanical optical switches have different configurations such as **1 × 1, 1 × 2, 1 × 4, 1 × 16, etc.** In simple terms, the 1× 8 opto-mechanical optical switch module connects optical channels by redirecting an 1 incoming optical signal into a selected signal from 8 output fibers. This kind of optical switches can achieve excellent reliability, insertion loss, and cross talk.

4.14.1(A) Advantages and Disadvantages of Opto-Mechanical Optical Switches

Advantages of Opto-Mechanical Optical Switches

1. Low insertion loss
2. Low cross talk
3. Low polarization dependant loss
4. Low cost

Disadvantages of Opto-Mechanical Optical Switches

1. Less reliability
2. Number of ports are small around 8 ; so can be used only for small wavelength cross connects.

4.14.2 MEMS Optical Switches

- MEMS optical switches use a **micro-mirror to reflect a light beam**. And the direction that the light beam is reflected can be changed by adjusting the angle of the mirror, which allows the input light to be connected to any out port.
- It is a compact optical switch which connects optical channels by redirecting incoming optical signals into the selected output fibers. And the switching state is highly stable against environmental variations of temperature and vibration due to its unique design. In some degree MEMS optical switch can be considered as a subcategory of opto-mechanical switches. But it is distinguished from **opto-mechanical switches** in many aspects such as the characteristics, performance and reliability.
- The most obvious is the opto-mechanical switch has more bulk compared to other alternatives, but the MEMS switch overcomes this. Besides, MEMS optical switches also have different configurations such as **1 × 8, 1 × 12, 1 × 16**, etc.

4.14.3 Liquid Crystal Switches

- These are the solid state switches and switching action is performed using polarization effect. A voltage is applied to a liquid crystal cell and the polarization of light passing through the cell is rotated. This liquid crystal cell is combined with a polarization beam splitter and the structure acts as an optical switch.
- Basically, this type of switch is not operated as a digital switch ; that means producing only two states ON or OFF. But by controlling the voltage applied to liquid crystal cell ; the switching action can be operated like analog switching.
- That means, depending on the switching action ; attenuation of signal passing through it can be controlled. So, this type of switch can be used as variable optical alternator.

4.14.4 Electro-Optic Switches

These switches provides very fast switching actions and the switching time is around **1 nsec**. These switches are designed using any one of the following configurations :

(a) The directional coupler configuration

In this case the coupling ratio is changed by changing the applied voltage and switching action is performed.

(b) The Mach-Zehnder configuration

Here the switching action is performed by changing the relative path length between two arms.

Disadvantages of Electro-Optic Switches

(i) High insertion loss
(ii) High polarization dependant loss
(iii) More expensive

4.14.5 Thermo-Optic Switches

- These switches are basically **2 × 2 Mach-Zehnder Interferometer, fabricated on silica substrate.** The relative path difference between two arms of interferometer can be changed by changing the refractive index in one arm.
- This produces the switching of signal from one output port to another.

Disadvantages of Thermo-Optic Switches

(i) The switching action is slow because of slow thermooptic effect.
(ii) Less efficiency.

4.14.6 Semiconductor Optical Amplifier Switches

- Semiconductor Optical Amplifiers (SOA) can be used as switches by varying the bias voltage. When the bias voltage is reduced ; input signal is absorbed and it acts as 'OFF' condition.

- When the bias voltage is increased then the device amplifies input signal. So it represents 'ON' condition.

Advantages of Semiconductor Optical Amplifiers (SOA)

(i) High switching speeds.
(ii) It passes very large extinction ratios.
(iii) Using passive couplers large number of switches can be integrated.

4.15 ALL-OPTICAL SWITCH

- An all-optical switch controls the routing between multiple optic fibers without any electrical data conversion.
- All-optical switches routes the entire light signal which is coming from an optical input and forward it all to an optical output without converting or altering IP level data packets. Shown in Fig. 4.15.1.
- Because of not using electrical conversion, All-optical switches do not have latency, data corruption or timing jitter.

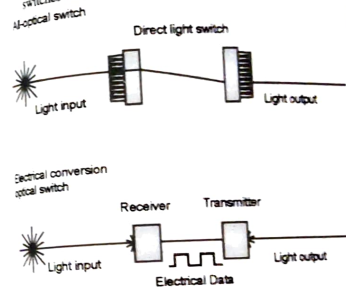

Fig. 4.15.1 : All Optical Switch

4.15.1 Features of All-optical Switch

1. All-optical switch is a circuit switch with no packet routing.
2. Does not selectively route IP packets.
3. Switches data on the fiber without conversion.
4. All-optical switch uses OOO switching.
5. OOO switching optical input, optical switch core and optical output.
6. Does not use OEO (Optical - Electrical - Optical) conversion.
7. Switches the entire light signal from one fiber to another.
8. Has no timing jitter, latency or data corruption.

4.16 WAVELENGTH CONVERTERS

- When input wavelength is changed to another wavelength without modifying the data contained in the signal ; is called as wavelength conversion.
- A device which performs this operation is called as wavelength converter. The wavelength conversion is done by using any one of the following techniques shown in Fig. 4.16.1.

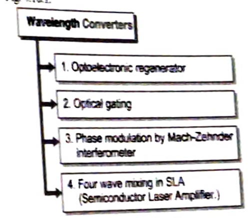

Fig. 4.16.1 : Wavelength converters

4.16.1 Optoelectronic Regenerator

- This is basically a variable input, fixed output converter. Input is an optically intensity modulated signal having a wavelength λ_{in}. Using a suitable **photodetector,** it is converted into electronic form. Then using radio frequency amplifier ; this signal is amplified and it is used to drive the laser source.
- The laser source then generates another wavelength λ_{out} which is different than λ_{in}. This is called as 1R generation and its basic block schematic is shown in Fig. 4.16.2.
- This is the basic wavelength converter, having following drawbacks :
  (i) There is presence of noise at the converter.
  (ii) The output is non-linear.
  (iii) There is effect of dispersion at the output.

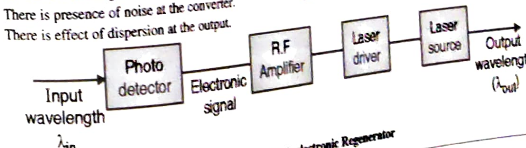

Fig. 4.16.2 : Optoelectronic Regenerator

- By connecting a logical gate at the output of RF amplifier, the signal can be reshaped ; but there will not be retiming of signal. This is called as 2R generation. Another variation is to generate the output wavelength with reshaping and retiming. This is called as 3R generation and it removes the effect of non-linearity, fiber dispersion and amplifier noise.

4.16.2 Optical Gating

- This method makes use of **optoelectronic device** whose characteristics can change in proportion to the input optical signal. A good example of such device is Semiconductor Optical Amplifier (SOA).
- According to change in the intensity of input signal ; using non-linear effects in SOA ; another unmodulated probe signal is generated at the output.
- The wavelength of this probe signal is different than that of input signal. We can use a variable input signal, but the output can be either fixed or variable. This operating principle is called as Cross-Gain Modulation (CGM).
- The **only advantage** of this method is that it is **simplest method of wavelength conversion**.

The disadvantages are as follows :

(i) Extinction ratio is small

(ii) To obtain a good variation in the gain of amplifier; input signal power must be high.

(iii) A suitable filter is required at the output to eliminate high powered signal.

(iv) A large amount of pulse distortion is produced at the output.

4.16.3 Phase Modulation by Mach-Zehnder Interferometer (MZI)

- The Mach-Zehnder modulator (MZM) is an **interferometric structure made from a material with strong electro-optic effect (such as LiNbO3, GaAs, InP)**. Applying electric fields to the arms changes optical path lengths resulting in phase modulation.
- Combining two arms with different phase modulation converts phase modulation into intensity modulation. In this method , a Semiconductor Optical Amplifier (SOA) is placed in each arm of interferometer. SOA is used in cross phase modulation mode as shown in Fig. 4.16.3.

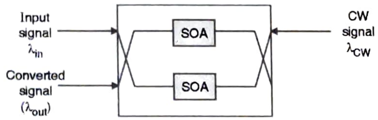

Fig. 4.16.3 : Phase Modulation by Mach-Zehnder Interferometer

- Input signal of wavelength λ_{in} and a Continuous Wave (CW) signal of wavelength λ_{CW}, are simultaneously applied as shown in Fig. 4.16.3. Input signal is used to modulate the gain of SOA and it changes the amplitude and phase of CW signal. Due to cross gain modulation ; wavelength converted signal is obtained at the output.

4.16.4 Four Wave Mixing in SLA (Semiconductor Laser Amplifier)

UQ.	Explain four waves mixing.	**(MU – Q. 4(b), Dec. 16, 8 Marks, Q. 6(c), May 18, 5 Marks)**
UQ.	Define Four Wave Mixing (FWM).	**(MU – Q. 1(d), Dec. 17, 5 Marks)**

- The term FWM refers to Four Wave Mixing. It also mentions effects of FWM and how to reduce it in optical fiber. Optical Four wave mixing is similar to **third order intermodulation distortion** seen in electronic or RF circuit.
- FWM is the short form of Four Wave Mixing. This term is given to the most common interference found in DWDM optical fiber systems. In DWDM, multiple optical signals of various different wavelengths are combined; it will form a new signal of undesired wavelength. Shown if Fig. 4.16.4.
- The Fig. 4.16.4. depicts FWM effect in two channel WDM system on low dispersion fiber cable. The FWM effect usually occurs in nonlinear optical materials e.g. photonic switch, fiber cable etc. This interaction between waves will lead to interaction between the channels.

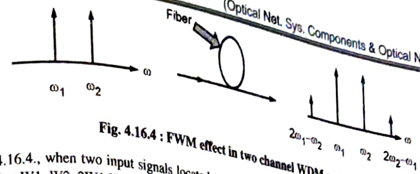

Fig. 4.16.4 : FWM effect in two channel WDM system

- As shown in Fig. 4.16.4., when two input signals located at W1 and W2 traverse fiber of length (L), it will produce outputs at four frequencies located at W1, W2, 2W1-W2 and 2W2-W1. **FWM depends on following parameters:**
  - Dispersion
  - Effective Area
  - Channel spacing
- FWM can be expressed as follows:

  FWM ~ { Power^4 / (Dispersion^2 x Effective Area^2 x Channel Spacing^4) }

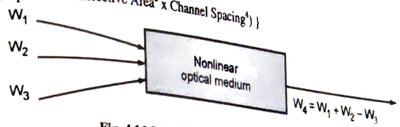

Fig. 4.16.5 : FWM – Fourth Spurious Component

- The Fig. 4.16.5 depicts generation of fourth wave when three channels are provided as input to the nonlinear fiber device or component. As shown it produces fourth component equal to w1 + w2 - w3.
- In general, when three waves at frequencies of fi, fj and fk traverse a fiber, they will generate another signal as defined by following equation.

  $F_{ijk} = f_i + f_j - f_k$, Where i, j is not equal to k
- If there are N channels, the newly generated signals are expressed as follows.

  M = (1/2)*N2 * (N-1)

  Where N = Number of input frequencies.

  M = Mixing products generated at the output.
- If there are 3 channels, this will create 9 additional signals. From this it can be observed that if N increases, M increases rapidly.

Effects of FWM-Four Wave Mixing

1. Four Wave Mixing is one of the most troublesome issue in optical domain. It produces unwanted spurious components which cause following problems.
2. Produces interference between wanted optical signals.
3. Produces additional noise which degrades the performance of the optical system.
4. Some power will be lost from wanted wavelengths to the unwanted ones.
5. As mentioned in above equation, if number of channel increases then mixing products at the output increases rapidly.

4.17 ADD-DROP MULITPLEXER

- With an explosive growth in the amount of information transmission, the optical telecommunication networks develop rapidly.
- The progress of single wavelength point-to-point transmission lines to wavelength division multiplexed optical networks has introduced a demand for wavelength selective optical add-drop multiplexer (OADM) to separate or route different wavelength channels. This paper will have an overview of the OADM.

4.17.1 OADM Technology

- The introduction of optical add drop multiplexers into optical networks allows traffic to be inserted, removed and, most importantly, bypassed. Moreover, OADM can support functions such as protection, drop/continue, loop-back and wavelength reuse of the optical channels.
- Drop and continue refer that the channel is removed at the node but allowed to pass through to the next OADM. Wavelength reuse means the dropped channel does not pass through to the next OADM, instead, a new channel of the same wavelength can be added. Fig. 4.17.1 explains OADMs work in a CWDM system.

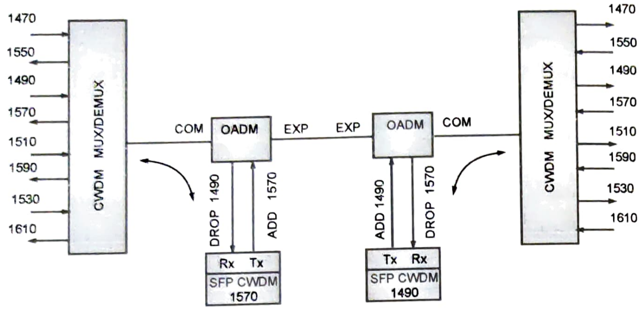

Fig. 4.17.1 : OADM Technology

Passive and Dynamic OADM

- OADM can be used in the dynamic as well as static mode. The add and drop wavelengths are fixed in the passive OADM, while in dynamic mode, the OADM can be set to any wavelength after installation.
- Passive OADM is mainly used in networks with WDM systems (**CWDM and DWDM**) or hubbed structures, where the OADM is connected to a central hub, e.g. in the metropolitan network.
- In order to utilize resources in a more efficient way, the OADM with dynamic wavelength assignment are preferred when traffic variations are comparable to network capacity. It can select any wavelength by provisioning on demand without changing its physical configuration.

4.17.1(A) Advantages and Applications of OADM Technology

Advantages of OADM Technology

(1) The most striking one is that its multiplexing happens to coincide with the minimum loss area of single mode fiber. This reduces the transmission loss of the light signal which can be transmitted relatively far distance.

(2) Additionally, it is transparent to digital signal format and data rate.

(3) Its gain saturation recovery time is long, and has a very small crosstalk between the respective channels. What's more, multiple channels of information carried over the same fiber with each using an individual wavelength.

(4) Narrow channel spacing or wavelength selection give rise to denser channels in the same wavelength range. Last but not the least, repeater or amplification sites are reduced, which results in large savings of funding.

Applications of OADM Technology

(1) OADM supports standard network topologies such as point-to-point and ring. It can be used at different points along the optical link to insert/remove or route selected channels increasing the network flexibility. This feature is particularly important in metropolitan WDM lightwave services where offices or sites can be connected by different add-drop channels, for instance in an interoffice ring.

(2) OADM is installed in a multi-wavelength fiber span, and allows a specific wavelength on the fiber to be demultiplexed (dropped) and remultiplexed (added) while enabling all other wavelengths to pass.

(3) It can provide flexibility and scalability to optical networks as it allows users to optimize the use of existing fiber by adding or dropping channels on a per-site basis, thereby maximizing fiber bandwidth.

4.18 SYNCHRONOUS OPTICAL NETWORK (SONET) AND SDH STANDARDS

- SONET is optical transmission interface. It was proposed by Bellcore laboratories and was standardised by the American National Standard Institute (ANSI).
- A compatible version, referred to as Synchronous Digital Hierarchy (SDH) has been published by ITU-T in Recommendation G. 707.

The major design goals of SONET are :

- SONET being a synchronous network requires a single clock to handle the timing synchronisation and equipment across the network. There should be standardisation of fiber optic transmission system equipments sold by different manufacturers.

- The physical specification and frame design must include mechanisms that will allow it to carry signals from incompatible tributary systems.
- SONET is a multiplexed transport mechanism and hence can be the carrier for broadband services such as ATM and B-ISDN.
- SONET is basically a Time Division Multiplexing (TDM) system.

Note : Thus SONET is a synchronous TDM system which is controlled by a master clock.

4.18.1 SONET Standards

- SONET provides standards for a number of line rates up to the maximum line rate of 10 gigabits per second (Gbps). Actual line rates approaching in the 30 gigabits per second range are possible. Base units of SONET are defined as Optical Carrier level-1, or OC-1. OC-1 supports up to 51.84 megabytes per second (Mbps).
- The next level up, OC-3, supports up to triple the bandwidth. Each level increases by multiples of four. OC-3, OC-12, OC-24, OC-48 can be used as examples.
- The set of multiples of the base rate known as "Optical Carrier levels (OCx)."
- SONET standards are specified in ANSI T1.105 and T1.117.

4.18.2 SONET vs. SDH

- **Synchronous digital hierarchy (SDH)** is the international equivalent of SONET. SONET and SDH are very similar standards made for the same reason. However, the basic unit for SDH is called the **synchronous transmission module level-1(STM-1)**, as compared to SONET's Optical Carrier level.
- SDH is an International Telecommunications Union (ITU) standard and can work with SONET line rates. However, SONET and SDH have differing structures when restructuring data. SDH frames are made out of 2,430 bytes and use Synchronous Transport Module (STM), while SONET frames are made up of 6,480 and use Synchronous Transport Signal (STS).

4.18.3 Comparison Between SONET and SDH

Table 4.18.1 : Comparison of SONET and SDH

Basis for comparison	SONET	SDH
Basic	Digital hierarchy interface	Network node interface
Developed by	ITU-T	ANSI
Deployed in	North America extensively	Europe and Japan.
Data transmission	Only synchronous	Asynchronous transfer is also possible.
Overhead	27 bytes	81 bytes

4.19 SONET DEVICES

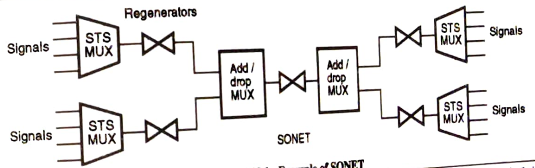

Fig. 4.19.1 : Example of SONET

There are three basic SONET devices :

1. Synchronous Transport Signal (STS) multiplexers.
2. Regenerators.
3. Add/drop multiplexers.

Fig. 4.19.1 shows an example of SONET.

Operation of SONET devices

- The STS Multiplexer/Demultiplexer is used for two purposes. It multiplexes signals from various sources into an STS i.e. Synchronous Transport Signal, or it demultiplexes an STS signal into various destination signals.
- Multiplexer and demultiplexer converts electrical signal to optical signal and optical signal back to electrical signal.
- The STS signal passes through a number of regenerators or repeaters while travelling from the source to destination. This repeaters regenerates or increase the strength of the signal.
- The regenerators are basically repeaters and are bidirectional devices. They will regenerate the STS applied to them. This will eliminate any effect of additive noise on the quality of transmission.
- The SONET regenerators function at the data link layer. The add/drop multiplexer is capable of adding signals from various sources or it can remove any signal and redirect it without demultiplexing the entire multiplexed signal.

4.20 SONET CONNECTIONS/ HIERARCHY/LAYERS

(i) Section Layer

- It is responsible for the movement of signal across a physical section. Each device of network provides section layer functions.
- A section is a single fiber run that can be terminated by a **network element (Line or Path)** or an optical regenerator. The main function of the section layer is to properly format the SONET frames, and to convert the electrical signals to optical signals.
- Section Terminating Equipment (STE) can originate, access, modify, or terminate the section header overhead. (A standard STS-1 frame is nine rows by 90 bytes. The first three bytes of each row comprise the Section and Line header overhead.)

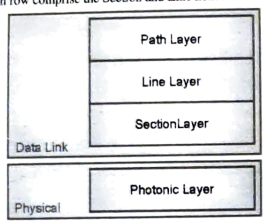

Fig. 4.20.1 : SONET includes four functional layers:

(ii) Line

- It is responsible for the movement of signal across a physical line. STS Mux/Demux and Add/Drop Mux provides Line layer functions
- Line-Terminating Equipment (LTE) originates or terminates one or more sections of a line signal. The LTE does the synchronization and multiplexing of information on SONET frames.
- Multiple lower-level SONET signals can be mixed together to form higher-level SONET signals. An Add/Drop Multiplexer (ADM) is an example of LTE.

(iii) Path

- It is responsible for the movement of signals from its optical source to its optical destination.
- STS Mux/Demux provides path layer functions.
- Path-Terminating Equipment (PTE) interfaces non-SONET equipment to the SONET network.
- At this layer, the payload is mapped and demapped into the SONET frame.
- For example, an STS PTE can assemble 25 1.544 Mbps DS1 signals and insert path overhead to form an STS-1 signal.
- This layer is concerned with end-to-end transport of data.

(iv) Photonic Layer

- It corresponds to the physical layer of the OSI model.
- It includes physical specifications for the optical fibre channel (presence of light = 1 and absence of light = 0).

4.21 SONET FRAME

- Fig. 4.21.1. shows the SONET frame. It is basically a **matrix of nine rows of 90 octets** each. Thus the total number of octets is = 810 octets. The first three columns i.e. $3 \times 9 = 27$ octets are reserved for the administration overhead.

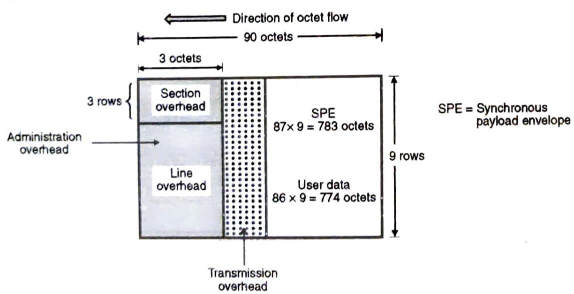

Fig. 4.21.1 : SONET frame

- The remaining frame area i.e. $87 \times 9 = 783$ octets is called as Synchronous Payload Envelope (SPE). The SPE is made of transmission overhead and user data. The administration overhead section is divided into two subsections namely section overhead and line overhead.

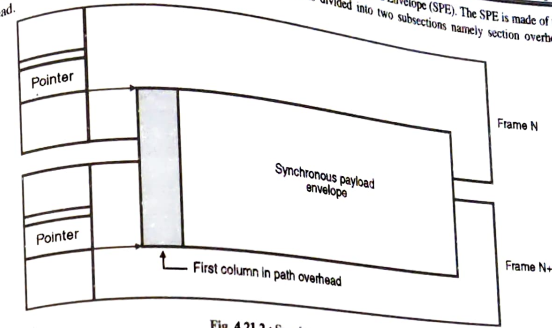

Fig. 4.21.2 : Synchronous payload envelope

- The section overhead is used to provide framing, error monitoring and management functions. It is interpreted and modified at every section termination.
- The line overhead is used to provide **synchronisation and multiplexing** for the path layer as well as protection-switching capability. It is interpreted and modified at every line termination.
- The remaining 87 columns of the frame consist of the information payload that carries the path layer information. The bit rate of the information payload for the STS-1 is given as,

$$8 \times 9 \times 87 \times 8000 = \mathbf{50.122\ Mbps}$$

- The information payload consists of one column of path overhead information. It is not necessary that the path overhead may occupy the first column but it can be any number in the 87 columns. The line overhead contains a pointer that indicates where the path overhead starts.
- The user data and the path overhead are included in the Synchronous Payload Envelope (SPE) as shown in Fig. 4.21.2.
- As shown in the Fig. 4.21.2. the SPE consists of a byte array of 87 columns by nine rows. The path overhead constitutes the first column of this array. This SPE is then inserted into the STS-1 frame. As shown in the Fig. 4.21.2. the SPE can be spread over two consecutive frames.
- The use of the pointer makes it possible to add or remove a tributary signal from the multiplexed signal. This capability gives SONET its add-drop feature.

4.22 SONET NETWORKS

- The SONET equipment in combination with the **Add-Drop Multiplexers (ADMs)** allow distant switching nodes to be connected by tributaries to form SONET networks.
- SONET networks generally have the ring topology. The network shown in Fig. 4.22.1. has a physical logical ring topology.
- Each pair of nodes is connected directly by an STS-N tributary. So the three nodes shown are logically configured in a fully connected topology.

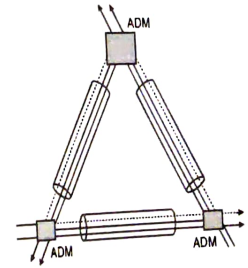

Fig. 4.22.1 : SONET ring topology

- The nodes that do not have direct physical connections can be provided with direct logical connections through the use of tributaries that are added at the source node and dropped at the destination node.
- The approach adding and dropping tributaries allows the flexibility of having arbitrary logical topologies with arbitrary

link transmission rates. The configuration can also be does using software control. To provide a fault recovery system SONET networks use two paths between any two nodes in the ring as shown in Fig. 4.22.2.

- Fig. 4.22.2 shows a two-fiber ring in which data is copied in both fibers, one travelling clockwise and the other anti-clockwise. In normal operation one fiber path is operation (Usual/clockwise) and the other path is in the protect mode (anticlockwise) when the fibers between two nodes fail are broken or the nodes the ring wraps around as shown in Fig. 4.22.3 and the traffic continues to flow.

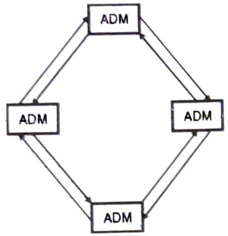

Fig. 4.22.2. : Dual ring SONET system

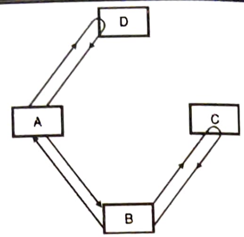

Fig. 4.22.3 : Wrapping of ring when fault occurs

- SONET ring networks can be used in local metropolitan regional area as shown in Fig. 4.22.4. As shown in the Fig. 4.22.4 the data from the user is collected by the access networks such as a telephone office.
- A number of such a telephone offices are connected in a first-tier ring network. A metropolitan area ring operating at higher rate is in turn connected the first tier-ring network formed by the telephone offices. The metropolitan area ring in turn is connected to the ring of inter exchange or regional carriers.
- Large users that cannot afford failure are connected to the access node using dual paths. To provide protection against faults, rings are inter connected by using matched inter ring gateways between the interoffice ring and the metro ring and between metro ring and the regional ring.

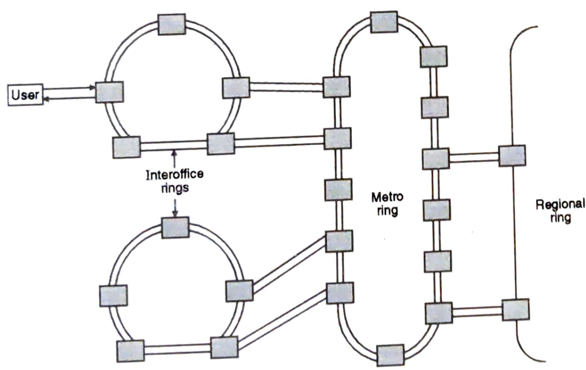

Fig. 4.22.4 : SONET network for local, metropolitan and regional networks

- The traffic flow between the rings is sent simultaneously along the primary and secondary gateway. Automated protection procedures determine whether the primary or secondary incoming traffic is directed into the ring.

4.23 BENEFITS OF SONET

There are numerous advantages associated with SONET which is why it has replaced a number of the older telecom systems and protocols. It has the capacity to set the foundation for telecom networks for years to come. Some of **the benefits of SONET are** :

1. Bandwidth availability and flexibility
2. Network reliability
3. Room to grow and morph as technological advances
4. High Efficiency
5. Reduced cost
6. Allows for the transportation of multiple forms of traffic
7. Superior connectivity between carriers
8. Can transmit data over long distances
9. Standard optical interference
10. Remote capabilities

4.24 APPLICATIONS OF SONET

1. SONET can be used as carrier for ISDN and B.ISDN
2. SONET can be used as carrier for ATM cells.
3. SONET can be used for applications which provide bandwidth on demand
4. SONET can be used for cable TV networks.
5. SONET can be used to replace networking protocols such as Switched Multimegabit Data Service (SMDS) or Fiber Distributed Data Interface (FDDI).
6. SONET can be used to replace the existing T-1 or T-3 lines.

4.25 ARCHITECTURE OF OPTICAL TRANSPORT NETWORKS (OTNS) (ANALOG AND DIGITAL BROADBAND)

- Optical Transport Network (OTN) is basically designed for transportation of IP and Ethernet over optical cables.
- OTN—or Optical Transport Network—is a telecommunications industry standard protocol— defined in various ITU Recommendations, such as G.709 and G.798— that provides an efficient way to transport, switch, and multiplex different services onto high-capacity wavelengths across the optical network.
- Today, network providers rely on OTN-enabled technology in their optical networks to gain benefits that include increased resiliency, simplified operations, enhanced Service-Level Agreements (SLA), extended reach with Forward Error Correction (FEC), and the ability to efficiently maximize wavelength fill as well as guaranteed end-to-end service delivery.

4.25.1 Features of Optical Transport Network (OTN)

Following are the important feature of OTN

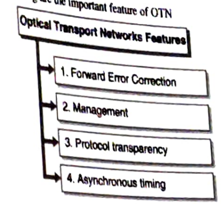

Fig. 4.25.1 : Optical transport network features

1. Forward Error Correction (FEC)

- OTNs are generally used for data transmission over longer distances. In such case, addition of noise in the optical signal is a major issue. To minimize the errors; Forward Error Correction (FEC) technique is used.
- OTNs makes use of Reed-Solomon (RS) code of the size (255, 239) for FEC. In the block of 255 bytes, 16 redundant bytes are present; which are used for error correction. This technique can detect errors up to 16 bytes and it can correct errors up to 8 bytes.
- The different block are interleaved; so that error correction capability can be increased.

2. Management

- The signals at different levels can be monitored using SONET/SDH.
- The different functions that can be managed are, signal identification at different levels, bit error rate measurement etc. If there is a connection between two sets of network then every network monitors the other network by using its own set of signals.

3. Protocol transparency

- Optical transport network provides operations, administration and management services to the clients.These network can transmit all types of data connections like IP, Ethernet.
- These network can transport entire SONET/SDH frame.
- The line rates of OTN are 7% higher than SONET/SDH line rate.

4. Asynchronous timing

- These network, transforms the client signals into OTN frames asynchronously. This is because, the clock signal which is used for generation of OTN frames is a free running oscillator. So, there is mismatch between the speed of OTN frames and client signals.
- This mismatch can be avoided if clock is driven by the client signal.

4.25.2 Architecture of OTN

- The different layers of OTN architecture are shown in Fig. 4.25.2. The layers are divided into two groups, namely optical layer and electronic layer. Optical layers consists of :
  - (i) **Optical Transmission Section (OTS)**
  - (ii) **Optical Multiplexed Section (OMS)**
  - (iii) **Optical Channel (OCh)**
- Optical Transmission Section (OTS) provides the information of different function required to transmit optical data through fiber optic cable.
- The OMS layer is used to manage the fiber connections between optical multiplexers and switches. The OMS layer basically provides the means of networking for multiwave length signal.
- Optical Channel (OCh) layer is used to transmit the information from user. Optical channel Transport Unit layer (OTU) adds the Forward Error Correction (FEC) to the network elements. This layer allows carrier operators; so the required number of optical devices and switches are reduced. The OTU layer is similar to the section layer of SONET/SDH.
- Optical channel Data Unit (ODU) layer provides the connection protection. This layer performs similar function as that of line and path layers of SONET/SDH. This layer also provides monitoring functions, like monitoring of **Bit Error Rate (BER) performance**.

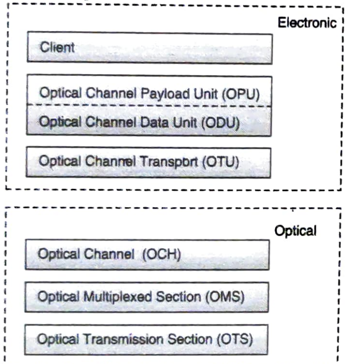

Fig. 4.25.2 : Layered Structure of OTN architecture

- Optical channel Payload Unit (OPU) is a sublayer of OPU. This layer provides the access to payload information of SONET/SDH. This layer also adapts the clients signal to OTN frame.
- Depending on the availability of the network connection; optical transport network can be reconfigured. It is called as Automatically Switched Optical Network (ASON). Depending upon the request (ASON) is capable of switching optical network automatically.

4.26 PROTECTION SCHEMES IN SONET/SDH

- The different types of protection schemes are available in SONET or SDH. In case of SONET, path layer and link layers are associated with the protection schemes. And SDH network makes use of channel layer and multiplexed layers for the protection.
- Similar types of protection schemes are used both for SONET and SDH. The different types of protection schemes are as follows :

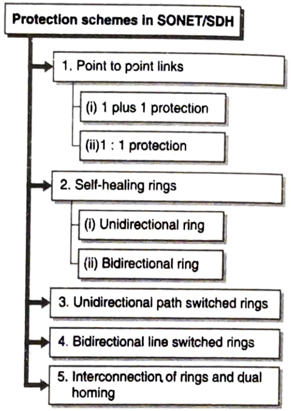

Fig. 4.26.1 : Protection schemes in SONET

4.26.1 Point to Point Links

- As the name indicates; this technique is applicable for providing a network protection in case of point to point communications.
- The two major types of point to point link protections are :

(I) 1 plus 1 protection

- This type of protection scheme is shown in Fig. 4.26.2..

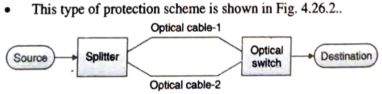

Fig. 4.26.2 : 1 plus 1 protection

- Usually, in optical communication, one fiber optic link is used to transmit the data. But for protection purpose, one more optical cable is connected in parallel with working cable.

- The incoming data from source is applied to the splitter, which splits the same data on both fibers. In case of **unidirection data transmission**; the destination is connected to one of the fibers. But if there is failure in that cable then, using optical switch, the destination gets connected to another fiber cable.
- In case of bidirectional data transmission, two cables are connected between source and destination. So, for the protection purpose, two more optical cables are used.

(II) 1 : 1 protection

- As the name indicates, one protecting cable is used for one main optical cable, that means like 1 plus 1 protection, there are two optical cables between source and destination. But in this case, the data transmission takes place only through one fixed cable. It is called as working cable.
- If there is a failure then only the communication takes place using another optical cable, called as protecting cable.
- The 1 : 1 protection scheme is shown in Fig. 4.26.3.. The more generalized form is 1 : N protection as shown in Fig. 4.26.4. In case of 1 : N protection; N working fibers, share a common protecting cable.

4.26.1(A) Advantages and Disadvantages of 1 : 1 Protection

Advantages of 1 : 1 protection

The two main advantages of 1 : 1 protection over 1 : N protection are as follows :

(i) Initially data transmission is through working cable only; so another cable (protecting cable) is unused. Under normal circumstances, low priority data can be transmitted through protecting cable.

In case of failure, this data can be erased and protecting cable gets connected for main data transmission.

(ii) 1 : 1 protection can be extended as 1 : N protection and a common protecting cable can be shared.

Disadvantages of 1 : 1 protection

APS protocol is required for data transmission between source and destination, so this protection scheme is slow compared to 1 plus 1 protection.

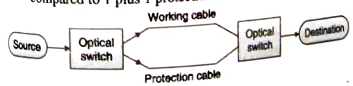

Fig. 4.26.3 : 1 : 1 protection scheme

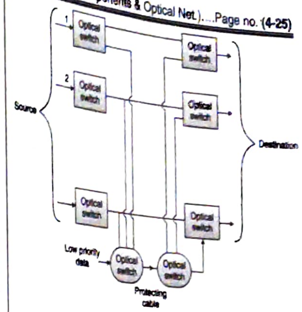

Fig. 4.26.4 : 1 : N protection

4.26.2 Self-healing Rings

Due to simplicity, ring networks are commonly used in optical communication. In this case, the protections are provided using SONET/SDH and Add or Drop Multiplexers (ADMs).

The protecting rings are called as self healing rings. Because such ring structure automatically detects the failure and transfer the data traffic in another route.

Two types of such self healing ring structures are used :

(I) Unidirectional ring

- In this case the working traffic is carried away in clockwise direction and protection is provided in anticlockwise direction.
- The working connection is shown by solid line and the protection connection is shown by dotted line in Fig. 4.26.5. Here the working connection from node ① to node ② is in clockwise direction; similarly the working connection from node ② to node ① is also clockwise using another fiber.
- The protecting fibers are connected in anticlockwise directions. Likewise all the nodes are connected in a ring topology.

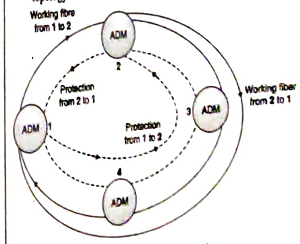

Fig. 4.26.5 : Unidirectional ring

(ii) Bidirectional ring

- In this case, the bidirectional data transmission takes place as shown in Fig. 4.26.6.

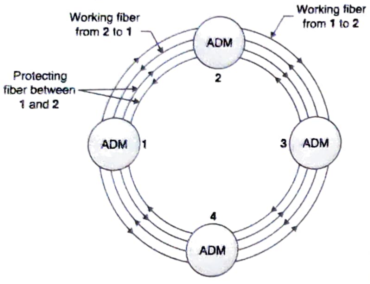

Fig. 4.26.6 : Bidirectional ring

- The working fiber from node ① to node ② is connected in clockwise direction. While the working fiber from node ② to node ① is in anticlockwise direction.
- Similarly the protecting fibers are also bidirectional. It is a four fiber bidirectional line switched ring structure, which contains two working fibers and two protection fibers.

4.26.3 Unidirectional Path Switched Rings

- It is similar to one plus one protection scheme. Here the traffic is carried away simultaneously on working fiber in clockwise direction and the protection fiber in anticlockwise direction.
- Consider the communication between nodes ① and ②. Initially node ②, checks the better connection on both fibers, working fiber as well as protection fiber.
- Suppose, node ⑧ finds the better data transmission along working fiber, then the communication is done using that fiber.
- In case of failure; switching takes place and now node ② will receive the data using protection fiber. For each connection, the protection is performed in the path layer.

4.26.4 Bidirectional Line Switched Rings

- It is basically a four fiber network in which two working fibers and two protection fibers are used. Two types of protection schemes are used namely span switching and ring switching.
- In span switching, if there is a failure of working fiber then the traffic is routed on protection fiber on the same link.
- In case of ring switching; during the failure, the traffic is routed around the ring through the protecting link and it follows another path.

4.26.5 Interconnection of Rings and Dual Homing

- In case of bigger optical networks; one ring is not sufficient. The different rings are interconnected to each other.
- The simple type of interconnection is the connections of drop sides of ADM, on different rings. That means connection of two rings in a back to back fashion. But if the failure of any one ADM occurs then the entire interconnection is failed.
- This problem is avoided using a dual homing technique. Here two hub nodes are used between the rings to be interconnected. In case of failure, the connections can be transferred from one hub node to another.

4.27 NETWORK ARCHITECTURE OVERVIEW (BROADCAST NETWORKS)

- The general architecture of access network is shown in Fig. 4.27.1. Basically access network consists of frame network and distributed network.
- The major elements of access network are hub, **Remote Node (RN) and Network Interface Units (NIUs)**. The common examples, where access network is used, are telephone company and cable company. In case of telephone exchange, hub is a central office and in case of cable company it is head end.

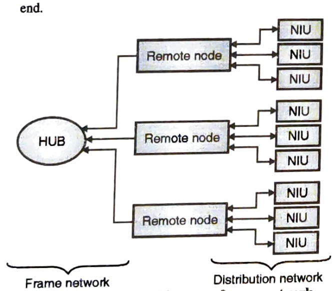

Fig. 4.27.1 : general architecture of access network

- Every hub is connected to many Remote Nodes (RNs) and then different Network Interface Units (NIUs) are connected to RNs. The network connecting hub and RNs is called as frame network and the network connecting RNs and NIUs is called as distribution network. In case of telephone exchange NIUs are located at subscribers location. The communication between hub and NIUs takes place through RNs.

The distribution network is of two types namely broadcast network and switched network.

- A common example of broadcast networking is cable television and a common example of switched networking is telephone network. In broadcast network, RNs accepts the data from hub and it broadcasts the data to all NIUs. Broadcast network is cheaper and all NIUs are identical.
- In case of switched networks; RN distributes the different data to all NIUs. So, data security is provided. It is easier to find the fault location in switched network, compared to broadcast networks.
- According to the type of feeder network; that means according to the type of connection between hub and RNs, **access networks are classified into two types as follows :**
  (i) The feeder network assigns a specific frequency band for each NIU and each NIO operates using different frequency range.
  Due to a dedicated bandwidth; a certain quality of service is assured for each NIV.
  (ii) The total available bandwidth is shared by all NIUs. That means, the feeder network assigns entire available bandwidth for each NIU on the time division multiplexing basis.
- The drawback of sharing entire bandwidth is that, each NIU contains optical components that are capable of supporting entire bandwidth.
- The telephone network provides a dedicated bandwidth to each user and cable network allows all users to share a common available bandwidth.

4.27.1 Telephone Access Network

- It is a switched network which provides a **separate frequency band for each NIU**. It consists of a twisted pair copper cable. Due to the twisting of two wires, **crosstalk** is reduced.
- Individual twisted pairs are connected between the central office and individual user as shown in Fig. 4.27.2. Each NIU operates on its dedicated **bandwidth of 4 kHz** and it makes use of switching network.

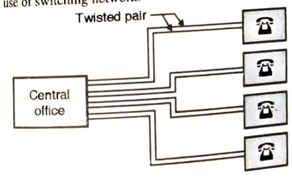

Fig. 4.27.2

4.27.2 Cable Network

- It is a broadcast network and each user share a total available bandwidth. It is also called as hybrid fiber co-axial network. As shown in Fig. 4.27.3; the head end and remote nodes are connected using optical fiber.
- The head end is similar to the central office of telephone network and it broadcasts the signal to Remote Nodes (RNs) through optical cable. Then from remote nodes; the signals are transmitted to individual home television, through co-axial cable.
- Usually the cable bandwidth is in the range 50 MHz to 550 MHz and each remote node serves between 500 homes. It is an example of unidirectional communication and the switching is not provided. Thus it requires simple management compared to the telephone access network.

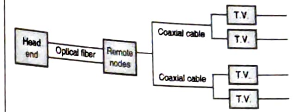

Fig. 4.27.3 : Hybrid fiber co-axial network

4.28 OPTICAL ROUTER

- A fiber router, or fiber optic router, is a router that is specifically equipped to support fiber Internet. Fiber offers a super fast Internet connection and does so by sending pulses of infrared light through an optical fiber cable.
- A fiber optic router is able to get all of the fiber optic speed through to your network, whereas a non-fiber router isn't equipped for that. If you have fiber Internet installed in your home, you need a good wireless router to support it.
- A fiber optic router has specific features to harness the lightning-fast speeds of fiber optic networks (Fiber-To-The-Home or FTTH) from your ISP.
- Router or modem does not directly connect to the fiber optic cable, but rather, it connects to an Optical Network Terminal (ONT) that converts the fiber optic signals into Ethernet.
- A cable modem router (sometimes called a gateway) is different than ONT in few ways. For one, a cable modem router is a single device. An ONT and fiber router connection is made up of two separate devices. Second, a cable modem router works with coaxial cabling that exists in your home already, so no additional cable installation. An ONT must connect with a fiber router, and also requires you to have fiber cabling installed in your home.

4.29 OPTICAL AMPLIFIERS

UQ. What are optical amplifiers ? Explain different types of front end amplifiers.
(MU - Q. 4(a), Dec. 15, 7 Marks, Q. 3(b), Dec. 18, 10 Marks)

- As the name indicates; optical amplifiers are used to amplify the optical signal. In case of optical amplifier; it is not necessary to convert optical signal into electrical and then provide the amplification.

- Optical amplifiers performs amplification without any conversion. Optical amplifiers are placed throughout the optical length; to provide amplification.
- Optical amplifiers are bidirectional and optical multiplexing is also possible. That means optical amplifier accepts many signal of different wavelength and provides amplification.
- Broadly there are two types of optical amplifiers, namely semiconductor optical amplifier and Raman amplifiers.
- Semiconductor optical amplifiers are small in size and provides amplification by using stimulated emission; which is similar to laser.
- Raman amplifier makes use of Raman scattering principle to obtain optically amplified signal.

(i) Erbium Dopped Fiber Amplifiers (EDFA)
(ii) Semiconductor Optical Amplifier (SOA)
(iii) Raman Amplifiers
(iv) Wideband Fiber Amplifiers

4.29.1 Erbium Dopped Fiber Amplifiers (EDFA)

UQ. Explain EDFA amplifier. Mention its advantages. **(MU - Q. 4(b), Dec. 17, 8 Marks)**

UQ. What is optical amplifier ? **(MU - Q. 1(e), May 18, 4 Marks)**

UQ. Explain working principle of EDFA with diagram. **(MU - Q. 4(a), Dec. 2019, 10 Marks)**

- Such optical amplifiers make use of erbium ions (E_r^{3+}) in the core layer of optical cable.
- Input optical signal, which is to be amplified is mixed with high powered beam of light. This is called as pump light. This mixing is done using wavelength selective couplers. Both the signals, namely input signal to be amplified and high powered beam of light are having different wavelengths. This signal is then passed through the optical cable containing eribium ions.
- The erbium ions, absorb energy and get excited to higher energy levels. When the photons of pump light strikes the erbium atoms; the erbium atoms give optical energy to the striking photons. This optical energy given by erbium atoms is in the form of photons and these new photos are in phase. So, optical amplification takes place and amplified light travels in the forward direction. In order to avoid back reflections; optical insulator is placed at the output.

4.29.1(A) Energy Level Diagram of E_r^{3+} ions

- The energy level diagram and transition process of E_r^{3+} ions in silica is shown in Fig. 4.29.1. Erbium atoms in the silica are E_r^{3+} ions, which are basically electrons.
- This erbium ions are raised to higher energy levels by using a pumping light. The different transition states are shown in Fig. 4.29.1.

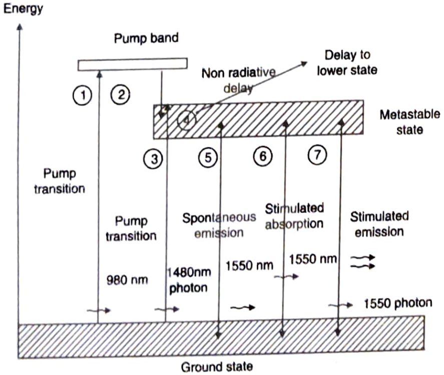

Fig. 4.29.1 : Energy Level Diagram

Transition 1 : It represents the pump transition and in this case 980 nm photons emitting laser is used for pumping. Due to absorption of incoming energy; erbium ions are excited from ground state to the pump level.

Transition 2 : Due to mechanical vibrations in optical cable; there is quick decay of excited ions from pump level to the metastable state. This is non radiative decay.

Transition 3 : The applied wavelength is 1480 nm. Due to absorption of this energy; erbium ions are excited from ground state to the metastable state.

Transition 4 : It represents the decay to the lower state of same metastable band.

Transition 5 : Some of the ions from metastable state falls back to the ground state due to spontaneous emission.

Transition 6 : The ions in the ground state absorps external photons and get excited to metastable state.

Transition 7 : Due to stimulated emission; new photons of same energy and polarization is created around 1530 nm.

4.29.2 Semiconductor Optical Amplifier (SOA)

- In case of lasers; amplification of light takes place, when the light beam causes many reflections between two end faces. In case of Semiconductor Optical Amplifier (SOA); the amplification action takes place without many reflections.
- SOA is basically InGaAsP laser diode, which is operating below the threshold point. By changing the composition of InGaAsP material; the gain of amplifier can be varied.
- It is like a **Travelling Wave (TW) amplifier**, where many reflections do not take place in an optical cavity. In SOA; using properties of semiconductor material; the required gain is obtained in one pass of light ray in an optical cavity.
- The construction of SOA is similar to the laser diode. But in case of laser diode; the reflectivities of end faces are around 0.3. Because of this many reflections take place.
- In case of SOA, the reflectivities of end faces are kept very low; so that the reflections are avoided. To lower down the reflectivities of end faces about 10^{-4}; the end faces are dopped using silicon oxide or silicon nitride. To obtain the required gain; external charge carriers are injected, similar to the laser diode. As the length of structure is increased; the gain of SOA is also increased. By changing the composition of InGaAsP material; the maximum gain in SOA is obtained around the wavelength 1200 nm and 1700 nm.

4.29.3 Raman Amplifiers

- This optical amplifier works on the principle called as **Stimulated Raman Scattering (SRS)**. When an atom is in ground state and it absorbs, the photon having a particular energy level. But when the atom falls back from excited state to the ground state; it emits the photon having different energy.
- Due to the difference in these energy levels; the vibration of optical cable takes place. The SRS effect occurs, whenever there is interaction between optical energy field and vibrational modes of cable. There are two types of Raman amplifiers; namely distributed Raman amplifier and lumped Raman amplifier.
- In distributed Raman amplifier, the pump wavelength and signal wavelength are multiplexed in optical cable. Here the transmission fiber is used as a gain medium. In lamped Raman amplifier; the interaction between signal and pump level is increased by using non-linear fiber having small core.
- The gain in this amplification is called as Raman gain and it depends on the factors like fiber length, fiber attenuation and the core diameter. By using low loss fibers; Raman gain can be increased. Raman gain can also be increased by decreasing the core diameter of optical cable.

4.29.4 Wideband Fiber Amplifiers

- For an amplification over a wide range of wavelength, combination of fiber amplifiers are used. It is called as wideband or hybrid fiber amplifiers.
- The combination of different amplifiers can be done by using any one of the following configurations :
  (i) **Serial**
  (ii) **Parallel**
  (iii) **Series and parallel together.**
- Basically this combination is used to handle large number of WDM channels simultaneously. To obtain the gain in 'C' and 'L' bands, two EDFA are connected in series as shown in Fig. 4.29.2.

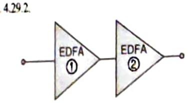

Fig. 4.29.2 : Two EDFA are connected in series

- In parallel combination, shown in Fig. 4.29.3.; the demultiplexer is used to divide incoming signal into two wavelength bands (C and L).
- These two bands are applied to the corresponding optical amplifiers. At the output of each optical amplifier; **Gain Flattening Filter (GFF)** is used to equalize the gains. These two spectral bands are then combined using wideband multiplexer.
- Sometimes it is required to use both series and parallel combination together. It is called as hybrid combination.

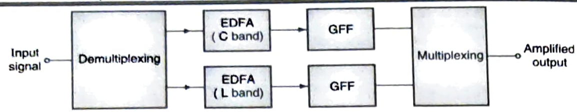

Fig. 4.29.3 : Parallel Combination

4.30 ATTENUATORS

- In case of DWDM; every channel makes are of amplifiers. The amplification done by each channel must be same. So in some channels, it is required to attenuate the signals.
- The signal attenuation is also required at the photodiode receiver; in order to prevent the saturation of photodetector. Variable optical attenuators are the dynamic attenuators. These attenuators are used to reduce amplitude of incoming signal, without disturbing other parameters of light rays.

Important characteristics of variable signal attenuators are as follows :

(i) Attenuation should not be dependent on polarization.
(ii) Wavelength of light should not cause any effect on amount of attenuation.
(iii) Attenuator should have low insertion loss.

- **The different techniques used in variable attenuators are as follows :**
  (i) **Mechanical method :** It has low dynamic range and slow response time.
  (ii) **Thermo optic method :** Has high dynamic range. The response is slow and it needs cooling arrangements.
  (iii) **MEMS method :** More accurate and it makes use of integrated circuits.

4.31 WDM TECHNOLOGY

- WDM is a technology that enables various optical signals to be transmitted by a single fiber. Its principle is essentially the same as **Frequency Division Multiplexing (FDM)**. That is, several signals are transmitted using different carriers, occupying non-overlapping parts of a frequency spectrum.
- In case of WDM, the spectrum band used is in the region of **1300 or 1550 nm**, which are two wavelength windows at which optical fibers have very low signal loss. Initially, each window was used to transmit a single digital signal. With the advance of optical components, such as **Distributed Feedback (DFB) lasers, Erbium-doped Fiber Amplifiers (EDFAs), and photo-detectors,** it was soon realized that each transmitting window could in fact be used by several optical signals, each occupying a small traction of the total wavelength window available.
- In fact, the number of optical signals multiplexed within a window is limited only by the precision of these components. With the current technology, over 100 optical channels can be multiplexed into a single fiber. The technology was then named dense WDM (DWDM).

4.31.1 Operating Principle of WDM

MU - Dec. 2009, Dec. 2012, May 2014, Dec. 2015

- This schematic of wavelength division multiplexing is as shown in Fig. 4.31.1. Here a number of light sources are used. Each light source emits the light of different wavelength. As an example three light sources emits the three wavelengths of light as shown in Fig. 4.31.1. Optical multiplexer is used at the input side to multiplex these signals.

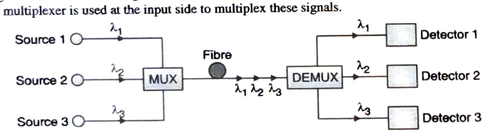

Fig. 4.31.1 : Wavelength division multiplexing

- Now this multiplexed signal is transmitted by using optical fiber. The detector is not capable of separating these signals. So a demultiplexer is used at the output side to differentiate the signals of equal amplitude. An improved version of this type of multiplexing is the bidirectional wavelength division multiplexing. The schematic of this type is as shown in Fig. 4.31.2.

- Here for the light sources 1 and 2 the first device (MUX / DEMUX1) as multiplexer and the second device (MUX / DEMUX2) acts as demultiplexer. Thus the signals gets transferred from sources 1 and 2 to the detectors 1 and 2. Now while transferring the signals from sources 3 and 4 to detectors 3 and 4 the reverse case takes place. Thus a **bidirectional data transmission** is done.

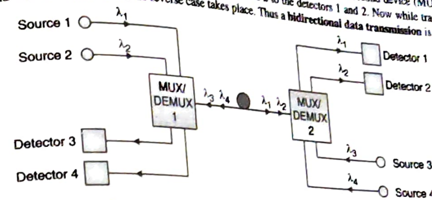

Fig. 4.31.2 : Bidirectional wavelength division multiplexing

4.32 WDM NETWORK ELEMENTS AND ARCHITECTURE

UQ. What is WDM ? Explain the architecture of WDM with network component. **(MU – Q. 5(a), May 16, 10 Marks)**

UQ. Write short note on : WDM network element and architecture. **(MU – Q. 6(iv), Dec. 16, 5 Marks)**

UQ. WDM network and architecture. **(MU – Q. 6(b), May 18, 5 Marks)**

- The general architecture of wavelength routing mesh network is shown in Fig. 4.32.1. The different WDM network elements like Optical Line Terminals (OLT), Optical Add Drop Multiplexer (OADM), Optical Cross Connects (OXC) etc. are shown in the architecture.

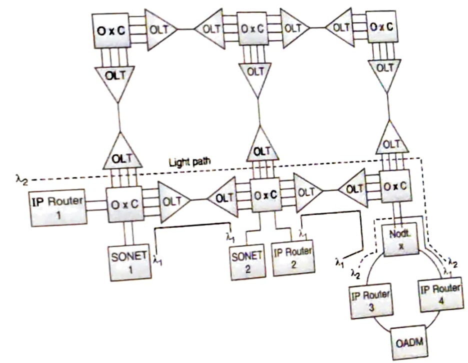

Fig. 4.32.1 : General Architecture of wavelength routing mesh network

- Optical amplifiers are not shown in Fig. 4.32.1; but they can be separately connected, according to the requirements or optical amplifiers can be inbuilt in OLT, OADM or OXC. The users such as SONET boxes and IP routers are connected using different light paths as shown in Fig. 4.32.1. In a light path, at some places, it is required to change the wavelength of operation. For this wavelength converters are used. In Fig. 4.32.1, operating wavelength λ_1 is shown by a solid line and wavelength λ_2 is shown by dotted line.

4.32.1 WDM Network Elements

The various WDM elements are as follows :

1. Optical Line Terminals (OLTs)

- Optical line terminals are used at either ends of point to point communication link. OLT consists of a transponders and wavelength multiplexers and demultiplexers.
- Transponder is also called as adaptation device and it is used as an interface between clients (IP router, SONET etc.) and optical link.
- The commonly used interface is the SONET/SDH Short Reach (SR) interface.
- Transponder accepts the signal from the clients and converts it into the form which is suitable for transmission in the optical network. Similarly in the reverse direction, it converts the signal from optical network, in the form suitable for clients.
- The signal output from transponder is multiplexed with other signals of different wavelength, using wavelength multiplexer. In some cases, optical amplifiers are used to boost these signals. At the other end, using demultiplexer, the signal of required wavelength is extracted.
- The output of OLT is also terminated on Optical Supervisory Channel (OSC). The OSCs operate on different wavelength than actual traffic.
- The OSC signals are used to monitor the performance of optical amplifiers, as well as to perform some other management functions.

2. Optical Add/Drop Multiplexers (OADMs)

- In some applications, it is required to add some wavelengths or to drop some wavelengths; depending on the requirements.
- To perform these tasks OADMs are used. The commonly used architectures of OADMs are as follows :

(i) Parallel
(ii) Modular version of parallel
(iii) Serial
(iv) Band drop.

(i) Parallel

- The parallel architecture of OADM is shown in Fig. 4.32.2.

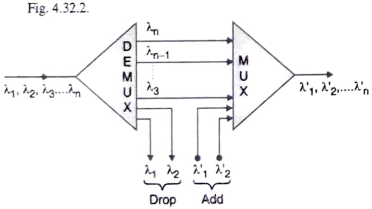

Fig. 4.32.2 : Parallel architecture of OADM

- Initially all incoming channels are demultiplexed to generate separate output wavelengths λ_1, λ_2 ....
- Some of the wavelengths are dropped at this stage and other wavelengths channels are passed forward to the multiplexer.
- At the multiplexer, some other wavelength channels (λ'_1, λ'_2 etc.) can also be added.

(ii) Modular version of parallel

- In this case, the demultiplexing as well as multiplexing is done in two stages. The first stage in demultiplexing separates the wavelength channels into different bands.
- For example, if there are 16 wavelength channels then four bands are formed; each band has 4 channels. A particular band of wavelengths can be dropped or added; remaining wavelengths are directly passed. A modular version of parallel architecture is shown in Fig. 4.32.3.

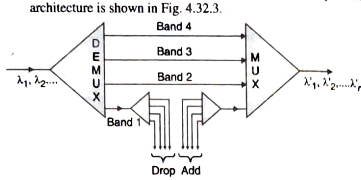

Fig. 4.32.3 : Parallel architecture

(iii) Serial

- This architecture can drop or add a single channel at a time. It is also called as S (– OADMs).
- If it is required to add or drop multiple channels at a time then, a number of such architectures are connected in series. This architecture is shown in Fig. 4.32.4.

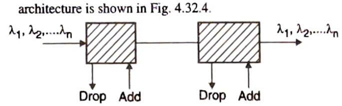

Fig. 4.32.4 : Serial Architecture

(iv) Band drop

- As the name indicates; this architecture is used to drop or add a band of wavelengths. It is shown in Fig. 4.32.5.
- From the total set of channels; a fixed group of channels is added or dropped. The dropped channels are again demultiplexed, to separate out into different wavelengths.
- The added band of channels is combined with couplers and added to existing channels.

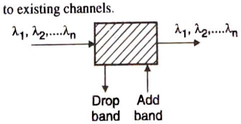

Fig. 4.32.5 : Drop or add

3. Optical Cross Connects (OXC)

- Whenever there is large amount of traffic at any node in optical network or there are many optical nodes in the complex network then optical cross connects are used to smooth out the operations.
- OXCs work along with OLTs, SONET/SDH, OADMs etc. In a larger networks, OXCs are used to provide extra light paths automatically. As well as OXCs can be used to reconfigure the existing light paths. In case of fiber cut or failure of optical element; OXC is used to detect such things and then to provide an alternate light path.
- The test equipments can be connected to the test ports, where the signals which are passing through OXCs can be monitored.
- OXCs can also be used to switch the optical signals from one port to another port and it also provides the wavelength conversion, if required.
- OXCs contain multiplexing capabilities to switch the traffic internally.

4.32.2 Important Features of WDM Architecture

- The WDM architecture is shown in Fig. 4.32.6. Some important features of this architecture are as follows :

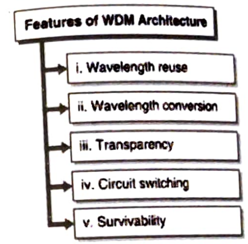

Fig. 4.32.6 : Feature of WDM Architecture

(i) Wavelength reuse

- In this architecture, the term light path represents the path from source to definition along which optical signal passes.
- For a number of light paths, we can use the same wavelength, until the paths overlap. As shown in Fig. 4.32.6, light path from SONET ① to SONET ② makes use of wavelength λ_1.

Similarly a light path from IP router ② to IP router ③ makes use of same wavelength λ_1. Thus the network can support large number of light paths, using a limited wavelengths.

(ii) Wavelength conversion

- Whenever there is overlapping of light paths then a wavelength conversion is required.
- Consider the light path from IP router ③ to IP router ④ through the node X. Here for light path from IP router ③ to node X; operating wavelength is λ_2 and for the same path, from node X to IP router ④, the wavelength is λ_1.
- Thus the wavelength conversion is done at node X. Sometimes, the wavelength conversion is required at the boundaries of the network. This is required to convert the outside wavelength into a specific wavelength, necessary to perform the data transmission inside the network.

(iii) Transparency

- As shown in the architecture, various light paths are connected between different sources and destinations.
- The light paths can be between two SONETs or it can be between two routers.
- Every light path can carry the data at different rates and different light paths make use of different protocols. Thus the protocol is insensitive to the light paths.

(iv) Circuit switching

- Optical layers provide a light path between different destination.
- The circuit switching in optical network is similar to the circuit switching in electronic networks. For example, in case of telephone networks, new connections can be setup and can be taken down according to the requirements.
- Likewise 5f in case of optical networks; the circuits can be setup or taken down; according to the requirement of applications. But the packet switching is not provided in the optical layer.

(v) Survivability

This architecture detects the failure and in such cases the light paths are routed through different paths.

4.32.3 Types of WDM

There are two main types of WDM technologies used today :

(I) Coarse Wavelength Division Multiplexing (CWDM)
(II) Dense Wavelength Division Multiplexing (DWDM).

(I) *Coarse Wavelength Division Multiplexing (CWDM)*

- CWDM allows up to 18 channels to be transported over a single dark fiber, while DWDM supports more than 200 channels.
- Both technologies are independent of protocol, meaning that any mix of data, storage, voice or video can be used on the different wavelength channels.
- In fiber terms, the main difference between CWDM and DWDM technologies lies in how the transmission channels are spaced along the electromagnetic spectrum.

(II) *Dense Wavelength Division Multiplexing (DWDM).*

- WDM technology uses infrared light, which lies beyond the spectrum of visible light.
- It can use wavelengths between **1260nm and 1670nm**. Most fibers are optimized for the two regions 1310nm and 1550nm, which allow for effective "**windows**" for optical networking.

4.33 COARSE WAVELENGTH DIVISION MULTIPLEXING (CWDM)

- CWDM is a technology that allows up to 18 channels to be connected over a dark fiber pair.
- Two wavelength regions are most commonly associated with CWDM, 1310nm and 1550nm. The 1550nm region is more popular because it has a lower loss in the fiber (meaning the signal can travel farther).
- CWDM is a convenient and low-cost solution for distances up to 70km. But between 40km and its maximum distance of 70km CWDM tends to be limited to 8 channels due to a phenomena called the water peak of the fiber (more about this further down).
- CWDM signals cannot be amplified, making the 70km estimate an absolute maximum.

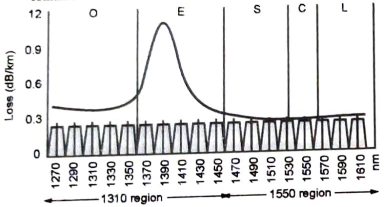

Fig. 4.33.1 : CWDM *Coarse Wavelength Division Multiplexing*

4.34 DENSE WAVELENGTH DIVISION MULTIPLEXING (DWDM)

In the Dense Wavelength Division Multiplexing(DWDM), the **channels** which are used to carry different wavelengths are very close (**dense**) to each other.

4.34.1 What is the Necessity of DWDM ?

- In case of optical communication, **attenuation and dispersion** are the major problems. It limits the practical speed and the distance of communication.
- Using **Erbium Dopped Fiber Amplifier** (**EDFA**), the problem of attenuation of signal can be recovered. However, due to the bandwidth effect always a compromise is required between transmission distance and the bandwidth.
- So, **repeaters** are used, after a certain distance, all along the length of optical cable. This increases the total cost of system. DWDM increases the bandwidth of systems, without using the repeaters.
- EDFA are commonly operated in the range of **wavelengths 1525 nm to 1565 nm** and DWDM are used in the band of **1550 nm**. So, DWDM increases the capabilities of EDFA.
- In order to implement **100 Gbps networks**; there is a requirement of faster physical layer technology. The normal optical networks are not capable of supporting this bandwidth for more than **500 meters** distance. The DWDM increases the bandwidth and it supports for more transmission distance.

4.34.2 Principle of Operation of DWDM

- The DWDM, divides the light travelling through optical cable into different wavelengths. Each wavelength is called as **lambdas**.
- DWDM takes **input optical signal** and divides it into different wavelengths (colors). All these wavelengths are transmitted through the same optical cable.
- DWDM selects the wavelength in certain band. It is around **1550 nm** and it is called as **operating window** of DWDM. Thus, DWDM increases the capabilities of existing optical networks without extra cabling. Thus, using DWDM the different signals can travel in parallel as if, they travel in a dedicated lanes, where each lane is independent.

4.34.3 DWDM System Structure

(i) Laser transmitters
(ii) Receivers
(iii) EDFA
(iv) OADM
(v) DWDM MUX
(vi) DWDM DEMUX

The DWDM system structure consists of following components :

(i) **Laser transmitters :** The different laser sources transmitting laser beams at **accurate wavelengths**. Each laser source, transmits different wavelength and all wavelengths from individual laser sources are closely spaced.

(ii) **Receivers :** These are **optical detectors**, which receives the signal and transmit them into demultiplexers.

(iii) **Eribium dopped fiber amplifier (EDFA) :** It is **eribium dopped fiber amplifier**. It is a silica based optical fiber and it is dopped with eribium. Basically EDFA acts as a **repeater** and it is used to amplify incoming optical signal.

(iv) **OADM :** These are the components receiving an **optically multiplexed signal** and can add or drop a certain wavelength.

(v) **DWDM MUX :** It is DWDM multiplexer, which receives many optical signals of different wavelengths; and transmits them on a single optical cable.

(vi) **DWDM DEMUX**

- It receives all the signals on a single cable and transmit each wavelength on different cables. The DWDM system structure is shown in Fig. 4.34.1.

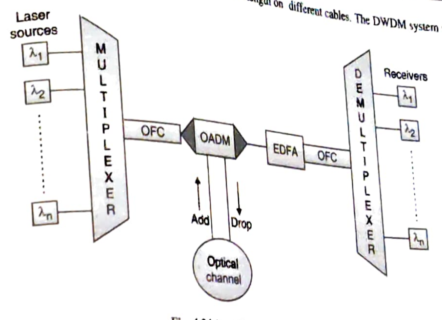

Fig. 4.34.1 : DWDM system structure

- The laser sources, transmit different wavelengths. All these wavelengths are applied to the multiplexer. The different fibers carry these wavelengths to the multiplexer. The multiplexers, combine all these wavelength and transmit it on a single **Optical Fiber Cable** (**OFC**).
- OADM can take certain wavelengths of its channel or add certain wavelength from other optical channel. It can also drops certain wavelength from main optical cable to other optical channels.
- EDFA is used to amplify the signals. The output of EDFA is connected to demultiplexer which separates out the different wavelengths.

4.34.4 DWDM Network

UQ. What is DWDM ? Mention its advantages and disadvantages. **(MU – Q. 2(c), Dec. 17, 5 Marks)**

The DWDM network makes use of **mesh, star or ring** topologies. There are two types of DWDM network as follows :

(i) **Single hop networks :** In this case each data stream has same wavelength from source to destination.

(ii) **Multiple hop networks :** Whenever there is an overlapping of **network paths** (**light paths**) the reuse of wavelength is done. Each node has a limited number of wavelengths, so at intermediate nodes, electronic switching of packets is required.

4.34.4(A) Advantages of DWDM

(i) DWDM increases the bandwidth capacity of the channel.
(ii) Using DWDM, it is possible to use signals with different data rates and different formats.
(iii) A large amount of information can be transmitted simultaneously.
(iv) DWDM can handle higher data rates.
(v) Every wavelength is independent of others
(vi) Optical amplifier can act on all wavelengths, providing cost savings over a single amplifier per fiber.
(vii) The capability to support 160 wavelengths means that over 1Tbps of traffic can be used.
(ix) Each wavelength can be a different traffic type such as SONET, gigabit, Ethernet or IP can be operated at different speeds.
(x) This provides Bandwidth and protocol flexibility with payload efficiency.

4.34.4(B) Disadvantages of DWDM

(i) Some fiber plants are not suitable for DWDM Vendor Inter-operability issues exist
(ii) DWDM systems can be extremely difficult to troubleshoot, manage and provision.
(iii) Service providers typically run SONET over DWDM to utilize SONETS's network management capabilities but DWDM equipment's need to be managed.
(iv) Not cost effective for low channel numbers
(v) Complex technology requires
(vi) More space and More power
(vii) Startup cost more than equivalent CWDM
(viii) High accuracy laser and wave filter

4.35 WAVELENGTH ROUTED NETWORKS

- Consider interconnection of three nodes as shown in Fig. 4.35.1. Here for the interconnection two wavelength channels λ_1 and λ_2 are used.

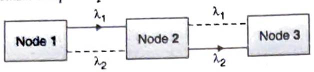

Fig. 4.35.1

- In Fig. 4.35.1, **solid line** represents the available wavelengths and **dotted line** represents, the wavelengths which are in use.
- Thus available wavelength between node ① and node ② is λ_1 and available wavelength between node ② and node ③ is λ_2.
- If we want to transfer the data from node ① to node ③ then a single wavelength channel is not available. In such cases **wavelength routing technique** is used.
- Suppose for the data transmission between node ① and node ②, we will use wavelength channel λ_1. At node ②, the incoming wavelength is λ_2; it is converted to λ_1 at the output port of node ② and then using wavelength λ_1; the data transmission takes place between node ② and node ③. Such networks are called as **wavelength convertible networks.**

4.35.1 Types of Wavelength Convertible Architectures

There are three main types of wavelength convertible architectures as follows,

1. Full wavelength converters
2. Wavelength converter shared per link.
3. Wavelength converter shared per node.

1. Full wavelength converters

- It is also called as **rededicated wavelength converter**. Its architecture is shown in Fig. 4.35.2. Incoming wavelength is applied to the demultiplexer and then to the optical switch. The optical switch directs the signal to a particular channel.
- A Wavelength Converter (WC) is connected separately to each channel; so output of each channel is converted separately into different wavelength.
- For example, output of channel 1 is λ_a, it is converted into another wavelength λ_b using WC. After the wavelength conversion; each new wavelength is connected to the multiplexer.
- According to the requirement; any new channel can be locally added and for this, wavelength conversion is not provided.

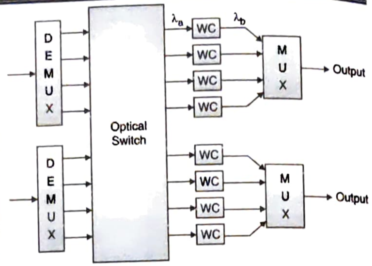

Fig. 4.35.2 : rededicated wavelength converter

2. Wavelength conversion shared per link

- Adding the wavelength conversion block at each channel is not cost effective. The more cost effective method is to apply the wavelength conversion on shared basis.
- This type of architecture is shown in Fig. 4.35.3. It makes use of Wavelength Conversion Band (WCB). The WCB contains number of wavelength converter blocks connected to each other.
- Only the required channel output is passed through WCB. Suppose it is required to convert outputs of channels ③ and ④ then, only these two outputs are applied to WCB. The other output channels are directly connected to the multiplexer.

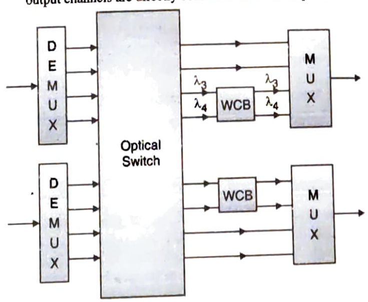

Fig. 4.35.3 : Wavelength conversion shared per link

3. Wavelength conversion shared per node

- It is similar to the wavelength conversion shared per link; but in this case two optical switches are used. Similar to the earlier case; the output of channel-3 which is λ_3 is passed through WCB and wavelength conversion is done.
- This output of WCB is connected to an optical switch ②; which performs the switching action in order to connect the output of WCB to the required node of optical network. This architecture is shown in Fig. 4.35.4.

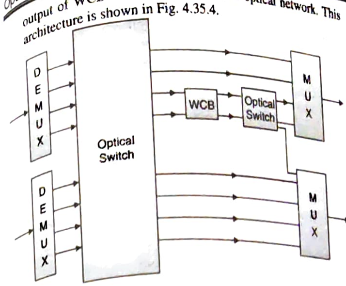

Fig. 4.35.4 : Architecture of Wavelength conversion shared per node

4.36 WDM ACCESS NETWORKS

- Multiple-access networks offer a **random bidirectional access** to each subscriber. Each user can receive and transmit information to any other user of the network at all times.
- Telephone networks provide one example; they are known as subscriber **loop, local loop, or access networks**.
- Another example is provided by the Internet used for connecting multiple computers. Both the local-loop and computer networks were using electrical techniques to provide bidirectional access through **circuit or packet switching**.
- The main **limitation of such techniques** is that each node on the network must be capable of processing the entire network traffic. Since it is difficult to achieve electronic processing speeds in excess of **10 Gb/s**, such networks are inherently limited by the electronics.
- The use of WDM permits a novel approach in which the channel wavelength itself can be used for **switching, routing, or distributing** each channel to its destination, resulting in an all-optical network. Since wavelength is used for multiple access, such a WDM approach is referred to as ***wavelength-division multiple access*** (WDMA).

4.36.1 Classification of WDMA networks

Broadly speaking, WDMA networks can be classified into two categories, called

- single-hop and
- multihop all-optical networks.

(A) Single-hop network

- Every node is directly connected to all other nodes in a single-hop network, resulting in a fully connected network.
- In contrast, multihop networks are only partially connected such that an optical signal sent by one node may require several hops through intermediate nodes before reaching its destination. In each category, transmitters and receivers can have their operating frequencies either fixed or tunable.

(B) Multihop all-optical networks

- Several architectures can be used for all-optical multihop networks. Hypercube architecture provides one example—it has been used for interconnecting multiple processors in a supercomputer.
- Another example of a multihop WDM network is provided by the ***shuffle network*** or its bidirectional equivalent—the **Banyan network**.

4.36.2 Lambdanet with N nodes

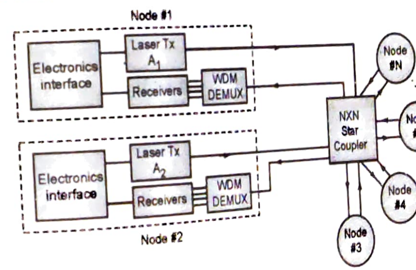

Fig. 4.36.1 : Schematic of the Lambdanet with N nodes

- Fig.4.36.1 shows an example of the single-hop WDM network based on the use of a *broadcast star*. This network, called the *Lambdanet*, is an example of the *broadcast-and-select* network.

- The new feature of the Lambdanet is that each node is equipped with one transmitter emitting at a unique wavelength and N receivers operating at the N wavelengths, where N is the number of nodes.
- The output of all transmitters is combined in a passive star and distributed to all receivers equally. Each node receives the entire traffic flowing across the network.
- A tunable optical filter can be used to select the desired channel. In the case of the Lambdanet, each node uses a bank of receivers in place of a tunable filter.
- This feature creates a nonblocking network whose capacity and connectivity can be reconfigured electronically depending on the application.
- The network is also transparent to the bit rate or the modulation format. Different users can transmit data at different bit rates with different modulation formats. The flexibility of the Lambdanet makes it suitable for many applications.

Drawback of Lambdanet

1. The number of users is limited by the number of available wavelengths. Moreover, each node requires many receivers (equal to the number of nodes), resulting in a considerable investment in hardware costs.
2. A tunable receiver can reduce the cost and complexity of the Lambdanet. This is the approach adopted for the ***Rainbow network***.
3. This network can support up to **32 nodes**, each of which can transmit 1-Gb/s signals over **10-20 km**. It makes use of a central passive star (see Fig.4.36.1.) together with the high-performance parallel interface for connecting multiple computers.
4. A tunable optical filter is used to select the unique wavelength associated with each node. The main shortcoming of the Rainbow network is that tuning of receivers is a relatively slow process, making it difficult to use packet switching. The Starnet provides an example of the WDM network that uses packet switching.
5. It can transmit data at bit rates of up to **1.25 Gb/s per node** over a **10-km** diameter while maintaining an SNR close to 24 dB.

4.37 WDM METRO NETWORKS

1. Metro access network
2. Metro interoffice network

- The metro network can be broken up into two parts :
  - The first part is the metro access network and extends from the carrier's central office to the carrier's customer locations, serving to collect traffic from them into the carrier's network.
  - The second part of this network is the metro interoffice network—the part of the network between carrier central offices.
- The access network today typically consists of rings a few kilometers to a few tens of kilometers in diameter, and traffic is primarily hubbed into the central office.
- The interoffice network tends to be several to a few tens of kilometers between sites, and traffic tends to be more distributed. Because of the shorter spans involved, the case for WDM links is less compelling in metro networks. The other alternatives, namely, using multiple fibers or using higher-speed TDM, are quite viable in many situations.
- Metro carriers need to provide a variety of different types of connections to their customers. The service mix includes leased private-line services and statistical multiplexing types of services such as **IP, Ethernet, Gigabit Ethernet, and Fibre Channel.**
- In many cases, this service mix is supported by having a set of overlay networks, each dedicated to supporting a different service. These overlay networks are ideally realized using a single infrastructure. Because of its transparent nature, a WDM network provides a better infrastructure than most others, such as **SONET/SDH**, for this purpose. Another factor is that the traffic distribution changes much more rapidly in metro networks than in long-haul networks.
- This drives the need to be able to rearrange network capacity quickly and efficiently as needed. Reconfigurable WDM networks allow capacity to be provided as needed in an efficient manner.
- A big driver for WDM deployment in metro networks has been the need for large enterprises to interconnect their data centers. These data centers are separated by several kilometers to a few tens of kilometers. All transactions are mirrored at both sites. This allows the enterprise to recover quickly from a disaster when one of the centers fails. There may be other reasons to have separate data centers, such as lower real estate costs at one location than at the other. Peripheral equipment such as disk farms can be placed at the cheaper site. The bandwidth requirement for such applications is large.
- The large mainframes at these data centers need to be interconnected by several hundred channels, each up to several gigabits per second.
- Typically, these data centers tend to be located in dense metropolitan areas where most of the installed fiber is already in use. Moreover, these networks use a large variety of protocols and bit rates. These two factors make WDM an attractive option for these types of networks.
- These networks are sometimes called **storage-area networks**. This is the primary application for most of the WDM networks deployed in metro networks today.
- Because of the nature of the traffic and a large amount of pass through traffic in these networks, a strong case can be made for deploying WDM rings with optical add/drop multiplexers instead of higher-speed TDM rings.
- **Despite the shorter spans for metro networks, optical amplifiers may still be needed, for several reasons:**
  1. Although spans are short, in many cases the fiber in the ground is old, has many connectors in its path, and thus has relatively high loss. For example, a **10 km** metro link may have a loss as high as **10 dB**.

2. The loss is not just due to spans a large component of the loss comes from the loss of optical add/drop multiplexers, each of which can add several decibels of loss.
3. Finally, protection requirements drive the need for alternate spans that may be much longer (for example, around a ring) than the working spans.

4.38 WDM IN THE LONG HAUL

- In 1995, long-haul carriers in the United States started deploying point-to-point WDM transmission systems to upgrade the capacity of their networks while leveraging their existing fiber infrastructures.
- Since then, WDM has also taken the long-haul market by storm. WDM technology allows to cope with ever-increasing capacity requirements while postponing the exhaustion of fiber and increasing the flexibility for capacity upgrade.
- The most prevailing driver, however, is the cost advantage of the WDM solution compared to competing solutions, such as **Space Division Multiplexing (SDM) or enhanced Time Division Multiplexing (TDM)** to upgrade the network capacity.
- The **"open"** WDM solution, illustrated in the following figure makes use of transponders in **WDM terminal multiplexers (TMs)** and inline optical amplifiers that are shared by multiple wavelength channels.
- The transponder is in essence a **3R opto-electro-optic (O/E/O)** converter, that converts a **G.957** standard compliant optical signal into an appropriate wavelength channel (and vice versa) while repowering, reshaping and retiming the signal electrically.
- The SDM solution uses multiple fiber pairs in parallel, each equipped with SDH regenerators instead of multiple wavelengths sharing the same inline optical amplifier.
- Upgrading to higher **TDM rates (e.g., from 2.5 Gb/s STM-16 to 10 Gb/s STM-64)** is only a short-lived solution since transmission impairments such as dispersion do not scale well with increasing TDM rates, especially on standard single-mode fiber.

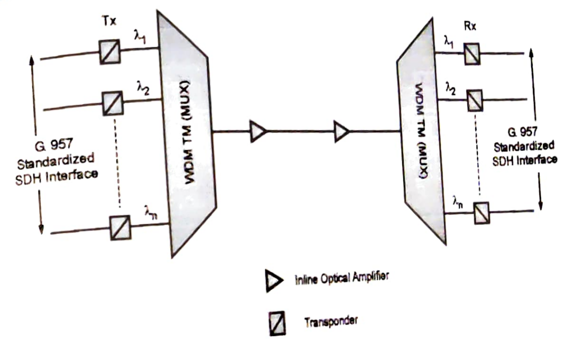

Fig. 4.38.1 : Long Haul Network

- A case study has demonstrated that long haul point-to-point WDM systems are clearly a more cost-effective solution than SDM, even for as low as three channels of STM-16. The above figure illustrates two link cost comparisons for the initial core of a transport network consisting of **5000 fiber km** with an average distance of **300 kms** between two access cities.
- Note that the 100 percent cost reference point in the above figure corresponds to the cost of deploying one STM-16 channel, including fiber cost. Two conclusions can be derived from the above fig.4.38.1.As shown in the Fig. 4.38.2, if only transmission and regeneration equipment costs are considered (i.e., SDH regenerators in the SDM case and WDM TMs with transponders with inline optical amplifiers in the WDM case), the initial link cost of using WDM technology is more than double that of SDH.

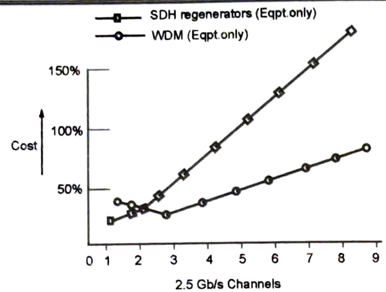

Fig. 4.38.2 : Cost versus Channel in SDM regenerator and WDM

- However, WDM solution is more cost-effective for the deployment of three channels and more in the network, because of the shared use of the inline optical amplifier. As shown in the fig.4.38.3., if in addition to the above consideration, the fiber cost is also considered, the cost advantage of WDM case becomes even more evident and is amplified as the number of channels increase. WDM solution is more cost-effective for the deployment of three channels and more in the network.

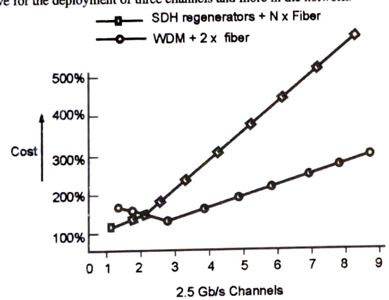

Fig. 4.38.3 : Cost versus Channel in SDM regenerator and WDM for the deployment of three channels and more in the network

4.39 WDM IN THE SHORT HAUL

- Regenerators are not necessary and optical impairments have less impact because of the limited distances in the short haul networks, hence the benefits of WDM are less clear than those of SDM or enhanced TDM solutions. However, fiber exhaustion and low-cost optical components are now driving WDM in the metropolitan area.
- The short-haul application is related to the inter-connection of **multiple Points of Presence (POPs)** within the same city. Let us consider an example. The Fig. 4.39.1 shows that the transport network has at least two POPs per city, where the customers can interconnect. With dual node interconnection techniques, such as drop and continue, customer networks can be interconnected with the transport network via two different POPs.
- This results in a very secure architecture that can even survive POP failures without any traffic impact. Thus, the traffic flow between two POPs in a city consists of not only traffic that passes through the city, but also of traffic that is terminated in the city and protected using **Drop and Continue**. These increased **intra-city capacity** requirements have led to the deployment of WDM in the short-haul section of a transport network.

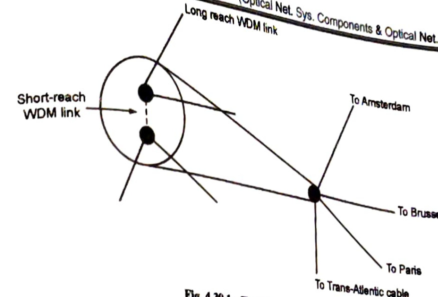

Fig. 4.39.1 : Short Haul Network

- The main reason WDM is preferred over SDM is because fibers in a city have to be leased from a third party or a fiber optic network has to be built. Leasing or building city fiber is not only an expensive process, it is also a less flexible approach to upgrade capacity. In a dynamic environment, where traffic distributions and volumes evolve rapidly, the amount of fiber to be leased or built is hard to predict in advance. Therefore, using WDM **technology** has clear flexibility advantages because the wavelength channels can be activated in a very short time.
- Although specific **short-haul WDM** systems are available in the world, it is advantageous to use the same type of WDM system for its long-haul network. While short-haul WDM systems are less expensive than their long-haul counterparts and due to their low-cost optical components can be used, they lead to a heterogeneous network, which is not preferred for several reasons.
- First, using two different systems leads to an increased operational and management cost. For instance, a heterogeneous network requires more spare equipment parts than a homogeneous network. Second, the interworking between two different systems might pose problems. For instance, a bottleneck can occur because short-haul WDM systems typically support fewer wavelengths than **long-haul WDM systems.**

4.40 WDM + EDFA SYSTEMS

MU - Dec. 2011, Dec. 2012, Dec. 2013, May 2014, May 2015, Dec. 2015

- In between transmitter and receiver; to boost the power of signal, different amplifiers are required as shown in Fig. 4.40.1.

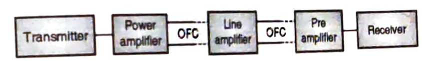

Fig. 4.40.1 :WDM +EDFA system

- Depending upon the distance between transmitter and receiver, losses takes place in the system etc; it is required to boost the power of transmitter.
- The power amplifiers are required to increase the transmitted power. These amplifiers should have maximum output power.
- When the signal is passing through optical cable; different losses are taking place inside the cable. To compensate these losses, line amplifiers are used.
- Line amplifiers are high gain and it produces the maximum possible output power. In order to increase the sensitivity; preamplifiers are used before the optical receiver. It is designed to have maximum gain and it introduces minimum noise in the signal.
- The **Erbium Dopped Fiber Amplifier (EDFA)** is most commonly used optical amplifier in majority application.
- EDFA amplifiers can amplify many WDM channels simultaneously. But, for longer distance communication, Raman amplifiers are connected in cascade with EDFA.

Limitations of optical amplifiers

(i) During amplification process, noise is introduced in the signal.

(ii) The gain of amplifier is directly proportional to input power. For high input powers, the amplifier tends to saturate and the gain of amplifier is reduced. It produces the transients in optical signals.

(iii) In case of EDFA; a constant gain is not provided to all channels. Some of the channels get less gain compared to others.

4.41 DATA CENTER NETWORKS AND ELASTIC NETWORK

4.41.1 Data Center Networks

- A data center is a facility that centralizes an organization's shared IT operations and equipment for the purposes of storing, processing, and disseminating data and applications.
- Consider a data center with **1,024 racks**, with each rack containing 20 servers, with each server containing 16 processor cores, **64 GB** of memory, and 48 TB of storage. If these servers are interconnected with a high-performance **data center network (DCN)**, the resulting cluster will be a supercomputer having 327,680 cores, 1.31 PB of memory, and 983 PB of storage. Such supercomputers are routinely used by companies such as Google, Microsoft, Facebook, Yahoo!, Amazon.com, eBay, and others, to provide modern web and mobile applications such as social networking, search, maps, video streaming, e-commerce, and multi player gaming.
- Deeper integration of optical communications technologies, namely optical transmission and optical switching, into DCNs, can substantially improve performance, cost, and energy efficiency, thereby making possible to run applications that previously were too demanding for current net-work technologies.
- DCNs should be constructed using select optical communications technologies to overcome the cost, power, performance, and scalability problems of traditional electronic packet switched (EPS)DCNs. Modern data center networks with their vast scale and bandwidth requirements are necessarily optical networks.
- Only optical communication technology has demonstrated capacities of **10 Gb/s, 40 Gb/s, and higher**, over distances of more than 10 m. However, traditional data center network architectures limit the use of optics to the physical cables only, requiring **wasteful electrical-optical-electrical conversions** between every pair of switches.
- A typical datacenter contains tens of thousands of identical servers arranged into one or more clusters as shown in Fig. 4.41.1. A cluster consists of multiple racks, each with 20-40 servers connected to a rack switch.
- Clusters are further networked through layers of cluster aggregation switches, which are then connected to datacenter routers. The datacenter routers connect to the rest of the Internet through Internet points of presence (POPs), where traffic flows from datacenter networks to end users and vice versa.

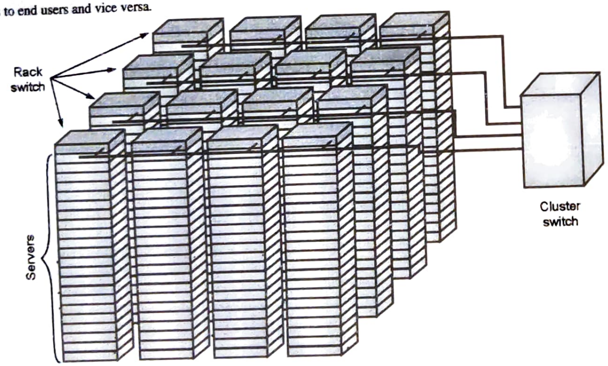

Fig. 4.41.1 : Typical View of Data Center Cluster

- Long haul WDM systems provide the connectivity between datacenters and population centers in different metro areas.
- Metro WDM transport links are used to interconnect datacenters and POPs located within the same metro area.

(a) Optical Technologies for Intra-Datacenter Applications

Within a datacenter, optical technologies are used to interconnect vast number of identical servers and switches.

- Cloud computing takes the advantage of distributed computation power from **massive parallel CPUs** in warehouse scale-datacenters
- In order to make efficient use of the distributed CPU farm, it is important to provide a flattened network with rich connectivity among all the servers so that application layer software can easily assign parallel jobs to arbitrary servers without concerning server location and communication overheads.

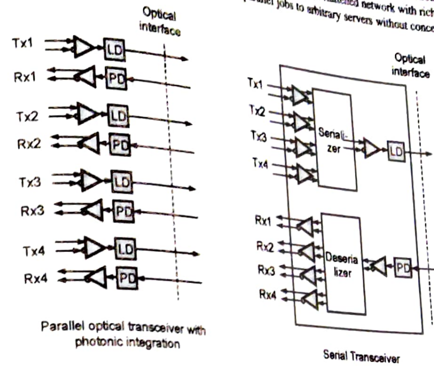

Fig. 4.41.2 : Parallel vs. Serial Optical Transceiver

- Higher connectivity also leads to **higher fault tolerance to individual link failures**. Ideally, a fully meshed, completely non-blocking switch fabric with very low latency between any two servers is desirable.
- In reality, servers are interconnected through layers of cluster switches comprised of massive identical switching equipment. **Intra-datacenter** interconnects can be achieved in different topologies. Commonly seen interconnect architectures for cluster computing include **torus, hypercube, fat-tree and flattened butterfly**.
- Irrespective of what architecture is chosen, eventually, the port density on cluster switches will limit the number of servers that can be connected to a cluster.
- Unlike in long-haul networks where fiber is scare and the figures of merit are spectral efficiency and bit-rate distance product, the intra-datacenter environment is fiber-rich with interconnection distances spanning from a few meters to a few kilo-meters. Here the figures of merit are really **power-space efficiency** and **bit-rate-port-count product**. Photonic integration of parallel transceivers using parallel ribbon fibers helps to improve transceiver footprints and port count.
- Potential technologies for achieving such goals include high-density photonic integrated circuits (PIC), integrated low-power optical vector modulators and optical demodulators for multi-level and/or phase-intensity modulations, electronic dispersion compensation and equalization techniques, etc.

(b) Optical Networks for Inter-Data centre

- Communications Usually, datacenter facilities are located in remote rural areas near power stations to reduce the operation costs related to space and power. These mega datacenters are connected to the outside world and among themselves using ultra-long-haul WDM optical transport networks.
- Long-haul fiber resources are scarce, expensive and time consuming to acquire or construct. To maximize the utilization of precious long-haul transmission fibers, such networks need to provide high spectral efficiency.
- Compared to traditional teleco networks which need frequent intermediate add/drops, mega datacenters are relatively sparsely located with large distances in between. Optical layer add/drop flexibility is not the most important concern.
- Most of the traffic between mega datacenters is machine generated with huge volume. Therefore, spectral efficiency, capacity, and **ultra-long reach (6000km+)** is important.
- Inter-datacenter long haul optical networks must minimize the number of regenerators in the field. Regenerators cause significant Op-Ex penalty. Sometimes, there simply may not be any space and power available between remotely located mega datacenters for regeneration purposes.
- The common requirement between long-haul carrier networks and inter datacenter optical networks is smooth upgradability

4.41.2 Elastic Networks(EONs)

- Advanced optical communication network technologies such as **Dense Wavelength Division Multiplexing (DWDM)** can provide bandwidth up to **1Tbps**, but these networks are not efficient in handling heterogeneous and variable traffic demands. In order to serve this huge and heterogeneous traffic efficiently there is a need for next generation optical networks.
- **Elastic Optical Networks (EONs)** can provide a long-term solution to handle this exponentially increasing data traffic efficiently and economically.
- EONs are OFDM-based spectrum efficient, flexible and adaptive networks, equipped flexible trans- receiver with adaptable network elements have been proposed recently as an improvement over traditional networks. They provide an alternative to single carrier modulation technique as the data stream divided and multiplexed onto multiple consecutive low rate subcarriers and hence increase the symbol duration and provides a higher data rate .

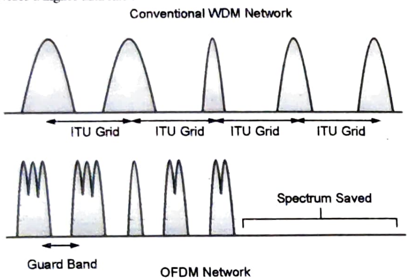

Fig. 4.41.3 : Spectrum Allocation OFDM network and Conventional WDM Network along the Frequency domain

- Unlike WDM systems, the use of OFDM allows subcarriers of the same light-path to overlap, thereby leading to high spectrum efficiency as shown in Fig. 4.41.3 above. The term elastic in EONs refers to three key properties of the optical networks :
  - Flexible optical spectrum
  - Bandwidth variable Transponder (BVT)
  - BV-WXC.
- The architecture of an EON is shown in Fig. 4.41.4 given below.

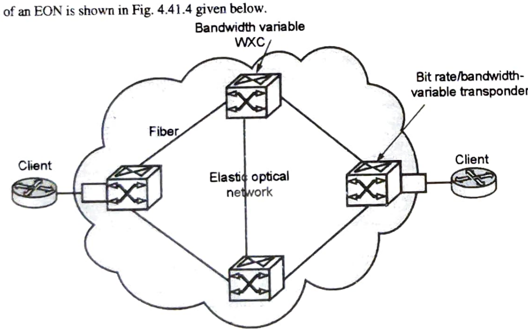

Fig. 4.41.4 : Architecture of EON

- OFDM together with **BVT(Bandwidth variable Transponder)** and BV-WXC made the way for the elastic allocation of spectral resources.
- BVT generates optical signal with optimum spectrum usage and various subcarriers channels are combined into a single super-channel using OFDM and transported as an individual OFDM channel makes these networks more efficient .

4.41.2(A) Characteristics of (EONs)

In EONs the central frequency of each channel has a finer granularity that enables expansion and contraction of optical paths. Hence, these networks provide several unique characteristics that are as follows :

(A) Flexible Bandwidth

- EONs support flexible granularity and supports fractional data rates and variable traffics by enabling the concept of sub-wavelength, super wavelength.
- Fig. 4.41.5 shows bandwidth segmentation in which a **100 Gbps bandwidth** is segmented into **sub-wavelengths of 50 Gbps, 20Gbps, and 30 Gbps** respectively by using appropriate configuration of BV-WXC and BVT at each node of the optical path allocates appropriate spectrum bandwidth and provides efficient use of network resources. Similarly, EONs enables bandwidth aggregation feature to create a super-wavelength optical path as depicted in Fig. 4.41.5, in which three separate 100 Gbps bandwidths are multiplexed using OFDM creating a 300 Gbps super-channel for efficient spectrum utilization.

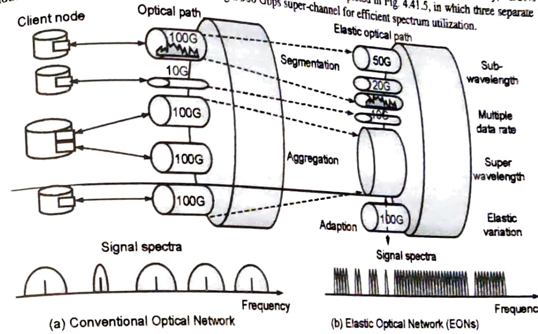

Fig. 4.41.5 : Spectrum Assignment over (a) conventional optical networks with Rigid Frequency grid (b) EONs [16]

B) Multiple data rate accommodation

As shown in Fig. 4.41.5, EONs supports multiple data rates and have the ability to provide high spectrum efficiency through flexible spectrum allocation and improves spectrum utilization over WDM networks in optical bandwidth is wasted due to frequency spacing for guards bands even for low bit rate signals.

Enhanced Spectral efficiency

The use of OFDM in EONs enables efficient use of spectral resources as because of **orthogonality**, adjacent subcarriers may overlap in the spectrum without causing ISI and adaptable data rates, scalable path lengths and thus increases the overall system capacity by supporting spectrum reuse.

Energy saving

- EONs have a unique property to save power consumption as it turns off unused OFDM subcarriers while traffic demand is less and thus provides energy-efficient operations.
- EONs although brings not only opportunities but also poses several new challenges to avail benefits from these opportunities such as the application of Routing and Wavelength Assignment (RWA) techniques in EONs creates several challenges due to the introduced novel spectrum flexibility.

- The spectrum continuity constraint in WDM networks has to be replaced with wavelength continuity constraint of RWA. In order to accommodate OFDM subcarriers, the non-overlapping spectrum constraint in WDM networks will be changed into single wavelength assignment constraint of RWA and the subcarriers should be assigned consecutively in order to exploit the spectrum efficiency brought by orthogonal adjacent subcarriers.

4.42 DWDM, WDM AND SONET

4.42.1 Differentiate DWDM, WDM and SONET

UQ. Differentiate DWDM, WDM and SONET. **(MU – Q. 1(a), Dec. 15, 5 Marks)**

Sr. No.	DWDM	WDM	SONET
1.	DWDM means Dense Wavelength Division Multiplexing	WDM means Wavelength Division Multiplexing	SONET means Synchronous Optical Network
2.	Dense WDM is WDM utilizing closely spaced Channel	Here Number of Light sources are used, each emits different wavelength	SONET of Optical transmission interface
3.	DWDM assigns incoming optical signal to specific frequencies multiplexes them for transport over single fiber	Optical multiplexer is used at the input side to multiplex there signal	SONET aggregates a number of optical signals into a single higher bit rate signal for transmission over a single fiber using a single wavelength
4.	Multiple channel of information carried over the same fiber,each using an individual wavelength	All signal arrive at the same time,instead of being distributed across time slot	Time Division Multiplexing (TDM) or Statistical TDM is used
5.	DWDM increases the bandwidth of systems, without using repeaters	Improve the capability of optical cable in carrying data by Multiplexing many channels of wavelength	SONET/SDH are technologies that are used as a buffer (interfacing) layer for higher layers
6.	Channel spacing is small 200GHz and Small	Channel spacing reduced to 1.6nm or less	SONET/SDH can carried over WDM , but not vice versa
7.	Allows new optical network topologies, for high speed metropolitan rings	Cost effective ways of increasing capacity without replacing fiber	Access the huge capability of optical transmission system(Optical Fiber)
8.	DWDM is qualified for system Z only	1310nm laser is used in Conjunction with 1550nm Laser	IP packets can be configured to flow over SONET
9.	Band used are C and L	Band used are O and L	STS-1 with fixed Size frames(810 bytes)
10.	Cost per channel is High	Cost per channel is Low	Synchronous Frame structure at a speed of 51.840Mbps
11.	Hundreds of Channels possible	Number of Channels delivered are 2	With SONET it is easy to isolate one channel from a multiplexed circuit
12.	Best application is Long Haul	Passive Optical Network(PON)	Ethernet cabling or Public telephone network

4.43 SONET ARCHITECTURE

UQ. Write a short note on : SONET / SDH. **(MU – Q. 5(b), May 17, Q. 6(a), Dec. 17, 10 Marks)**

UQ. Explain SONET architecture in detail. **(MU – Q. 4(c), May 16, Q. 5(a), May 18, 10 Marks, Dec. 15, 5 Marks, Q. 4(b), Dec. 18, May 19, 10 Marks)**

UQ. What are the elements of SONET/SDH infrastructure ? **(MU – Q. 1(c), May 16, 5 Marks)**

UQ. Draw architecture of SONET/SDH and explain in brief. **(MU – Q. 2(b), Dec. 16, 10 Marks)**

Architecture of SONET consists

1. SONET devices
2. Connections and
3. Signals,

1. SONET Devices

Fig. 4.43.1 shows a simple link using SONET devices. SONET transmission relies on three basic devices:

- STS multiplexers/demultiplexers,
- re-generators,
- add/drop multiplexers and terminals.

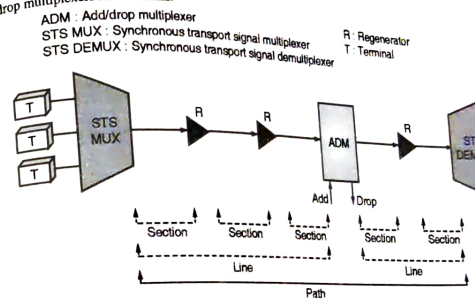

Fig. 4.43.1 : Simple link using SONET devices

- **STS Multiplexer/Demultiplexer :** STS multiplexers/demultiplexers mark the beginning points and endpoints of a SONET link. They provide the interface between an electrical tributary network and the optical network. An STS multiplexer multiplexes signals from multiple electrical sources and creates the corresponding OC signal. An STS demultiplexer demultiplexes an optical OC signal into corresponding electric signals.
- **Regenerator :** Regenerators extend the length of the links. A regenerator is a repeater, that takes a received optical signal (OC-n), demodulates it into the corresponding electric signal (STS-n), regenerates the electric signal, and finally modulates the electric signal into its correspondent OC-n signal. A SONET regenerator replaces some of the existing overhead information with new information.
- **Add/drop Multiplexer :** Add/drop multiplexers allow insertion and extraction of signals. An add/drop multiplexer (ADM) can add STSs coming from different sources into a given path or can remove a desired signal from a path and redirect it without demultiplexing the entire signal. Instead of relying on timing and bit positions, add/drop multiplexers use overhead information such as addresses and pointers to identify individual streams.
- In the simple configuration shown by Fig. 4.43.1, a number of incoming electronic signals are fed into an STS multiplexer, where they are combined into a single optical signal.
- The optical signal is transmitted to a regenerator, where it is recreated without the noise it has picked up in transit. The regenerated signals from a number of sources are then fed into an add/drop multiplexer. The add/drop multiplexer reorganizes these signals, if necessary, and sends them out as directed by information in the data frames. These remultiplexed signals are sent to another regenerator and from there to the receiving STS demultiplexer, where they are returned to a format usable by the receiving links.
- **Terminals :** A terminal is a device that uses the services of a SONET network. For example, in the Internet, a terminal can be a router that needs to send packets to another router at the other side of a SONET network.

2. Connections

- **Sections** : A section is the optical link connecting two neighboring devices: multiplexer to multiplexer, multiplexer to regenerator, or regenerator to regenerator.
- **Lines** : A line is the portion of the network between two multiplexers: STS multiplexer to add/ drop multiplexer, two add/drop multiplexers, or two STS multiplexers.
- **Paths** : A path is the end-to-end portion of the network between two STS multiplexers. In a simple SONET of two STS multiplexers linked directly to each other, the section, line, and path are the same.
- **Path-terminating equipment (PTE)** : Typically the user interface at the CPE.
- **Line-terminating equipment (LTE)** : Typically a terminal, switch, add/drop multiplexer, or cross-connect.
- **Section-terminating equipment (STE)** : Primarily a regenerator.

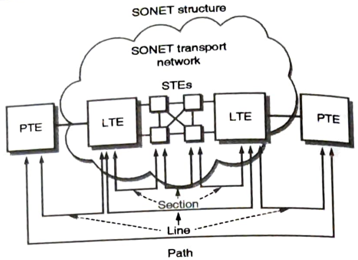

Fig. 4.43.2 : SONET Structure

3. Signals

- SONET defines a hierarchy of electrical signaling levels called synchronous transport signals (STSs). Each STS level (STS-1 to STS-192) supports a certain data rate, specified in megabits per second.
- The corresponding optical signals are called optical carriers (OCs). SDH specifies a similar system called a synchronous transport module (STM).

4.44 FRAME OF SONET

UQ. Draw the frame of SONET and determine its basic rate. **(MU – Q. 4(b), Dec. 18, May 19, 10 Marks)**

SONET uses a basic transmission rate of STS–1 that is equivalent to 51.84 Mbps. Higher-level signals are integer multiples of the base rate.

For example, STS–3 is three times the rate of STS–1 (3 x 51.84 = 155.52 Mbps). An STS–12 rate would be 12 x 51.84 = 622.08 Mbps. SONET is based on the STS-1 frame. STS-1 Frame Format is shown in Fig. 4.44.1.

- STS-1 consists of 810 octets
- STS-1 frame transmitted every 125 us: thus a transmission rate of 51.84 Mbps.

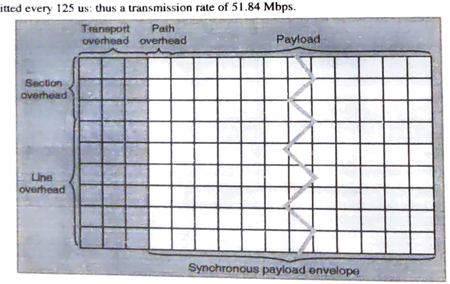

Fig. 4.44.1 contd...

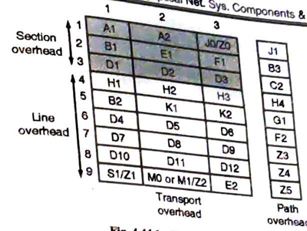

Fig. 4.44.1 : Frame Format

Section Overhead

- **Framing bytes (A1, A2)** : These two bytes indicate the beginning of an STS-1 frame. These are used for framing and synchronization. These Bytes are also called as Alignment Bytes
- **Section trace (J0)/section growth (Z0)** : This is also known as Identification Byte. It carries a unique identifier for STS1 frame. This byte is necessary when multiple STS1 frames are multiplied to create higher rate STS. Information in this byte allows the various signals to de-multiplex easily.
- **Parity byte (B1)** : This is a for bit-interleaved parity (even parity), BIP used to check for transmission errors over a regenerator section. Its value is calculated over all bits of the previous STS–N frame after scrambling then placed in the B1 byte of STS–1 before scrambling. Therefore, this byte is defined only for STS–1 number 1 of an STS–N signal
- **Orderwire byte (E1)** : This byte is allocated to be used as a local orderwire channel for voice communication between regenerators, hubs, and remote terminal locations.
- **User channel byte (F1)** : This byte is set aside for the users' purposes. It terminates at all section-terminating equipment within a line. It can be read and written to at each section-terminating equipment in that line.
- **Data communications channel (DCC) bytes or Management byte (D1, D2, D3)** : Together, these 3 bytes form a 192–kbps message channel providing a message-based channel for OAM&P between pieces of section-terminating equipment. The channel is used from a central location for alarms, control, monitoring, administration, and other communication needs. It is available for internally generated, externally generated, or manufacturer-specific messages.

Line Overhead

- **Pointers and Pointer Action (H1, H2, H3)** : These are used to point to the payload (SPE). They provide flags to indicate about changes to payload location and provide location for the data.
- **Line Parity (B2)** : B2 Octet is used for bit error rate estimation.
- **Automatic Protection Switching (APS) channel (K1,K2)** : These two octets are used for APS signalling between line level entities. APS stands for Automatic Protection Switching.
- **Line Data Communications Channel (D4-D12)** : D4 to D12 octets form communication channel to send administrative messages. Used for line data communication and consider as single 576kbps message based channel. Used for maintenance, control, monitoring, administration, alarms as well as communication need between line terminating entities.
- **Synchronization messaging (S1)** : It is used for transporting synchronization status messages and defined for STS-1 of the STS-N signal. Bits 5 to 8 are used for this purpose.
- **STS-1 REI(M0)** : This octet sends no. of errors detected by B octets back to the transmitter. This helps in knowing line status as well as receiver status.
- **STS-N REI (M1)** : The function is same as listed in M0 above.
- **OrderWire (E2)** : The function is same as listed above for E1.

PATH OVERHEAD

- **Path Trace (J1)** : It helps two ends to verify the connection status (live or not) and check whether it is connected with right terminations. It is used to transmit STS path Access point identifier repetitively, Hence path receiving terminal can verify its continued connection with intended transmitter. 64 byte frame is used for the purpose.
- **Path BIP-8(B3)** : It is used by the receiver for BER estimation. It is calculated over all the bits of previous STS SPE before the scrambling process.

- **STS Path Signal Label (C2) :** This indicates type of traffic carried in the payload part of the SDH frame.
- **Path Status (G1) :** It is used to convey path terminating status/performance back to the transmitter (Originating STS PTE). PTE stands for Path Terminating Equipment.
- **Path user channel (F2) :** It is used for user communication similar to F1 octet in transport overhead.
- **Multi-frame indicator (H4) :** It provides generalized multi-frame indicator for the payloads. The first purpose of this indicator is for VT structured payload. The second purpose is for support of virtual concatenation of STS-1 SPEs.
- **Growth octets (Z3,Z4,Z5) :** Reserved for future use.

4.45 FRONT END AMPLIFIERS IN OPTICAL COMMUNICATION

UQ. Explain Front End Amplifiers in optical communication. **(MU - Q. 4(c), May 17, 5 Marks)**

Optical amplifiers

- In between transmitter and receiver; to boost the power of signal, different amplifiers are required.
- A general representation of a fiber amplifier is shown in Fig. 4.45.1.

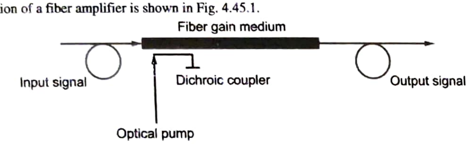

Fig. 4.45.1 : Schematic of a fiber amplifier

i. The gain medium normally comprises a length of single-mode fiber connected to a dichroic coupler which provides low insertion loss at both signal and pump wavelengths.
ii. Excitation occurs through optical pumping from a high-power solid-state or semiconductor laser which is combined with the optical input signal within the coupler. The amplified optical signal is therefore emitted from the other end of the gain medium.
iii. Optical amplifiers are placed at intervals along a fiber link to provide linear amplification of the transmitted optical signal.
iv. The optical amplifier, in principle, provides a much simpler solution in that it is a single in-line component which can be used for any kind of modulation at virtually any transmission rate.
v. The Erbium Dopped Fiber Amplifier (EDFA) is most commonly used optical amplifiers in majority application.
vi. The basic amplifier configurations that are used in optical fiber communication are front end amplifiers. Different categories of front end amplifiers are as follows:

(a) Low impedance front-end amplifier
(b) High impedance front-end amplifier
(c) Trans impedance front-end amplifier

(a) Low-impedance front-end amplifier

i. Three basic amplifier configurations are frequently used in optical fiber communication receivers.
ii. The simplest, and perhaps the most common, is the voltage amplifier with an effective input resistance R_a as shown in Fig. 4.45.2.
iii. In order to make suitable design choices, it is necessary to consider both bandwidth and noise.
iv. However, in most practical receivers the detector is loaded with a bias resistor R_b and an amplifier (see Fig. 4.45.2).
v. The bandwidth is determined by the passive impedance which appears across the detector terminals which is taken as R_L in the bandwidth relationship.

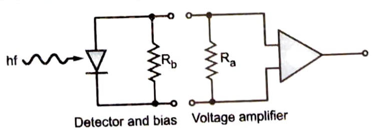

Fig. 4.45.2 : Low-impedance front-end optical fiber receiver with voltage amplifier

vi. However, R_L may be modified to incorporate the parallel resistance of the detector bias resistor R_b and the amplifier input resistance R_a. The modified total load resistance R_{TL} is therefore given by:

$$RTL = (R_b R_a)/(R_b + R_a)$$

To achieve an optimum bandwidth both R_b and R_a must be minimized.

(b) High-impedance (integrating) front-end amplifier

i. The second configuration consists of a high input impedance amplifier together with a large detector bias resistor in order to reduce the effect of thermal noise.
ii. However, this structure tends to give a degraded frequency response as the bandwidth relationship is not maintained for wideband operation.
iii. The detector output is effectively integrated over a large time constant and must be restored by differentiation.
iv. This may be performed by the correct equalization at a later stage as illustrated in Fig. 4.45.3.
v. Therefore the high-impedance (integrating) front-end structure gives a significant improvement in sensitivity over the low-impedance front-end design, but it creates a heavy demand for equalization and has problems of limited dynamic range (the ratio of maximum to minimum input signals).

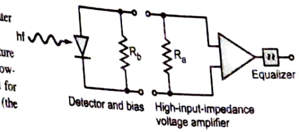

Fig. 4.45.3 : High-impedance integrating front-end optical fiber receiver with equalized voltage amplifier

(c) The Trans impedance front-end amplifier

i. This configuration largely overcomes the drawbacks of the high-impedance front end by utilizing a low-noise, high-input-impedance amplifier with negative feedback.
ii. The device therefore operates as a current mode amplifier where the high input impedance is reduced by negative feedback.
iii. An equivalent circuit for an optical fiber receiver incorporating a transimpedance front-end structure is shown in Fig. 4.45.4.

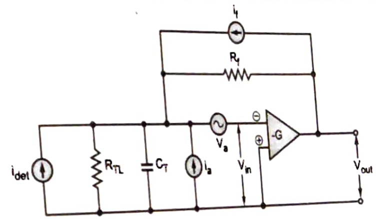

Fig. 4.45.4 : An equivalent circuit for the optical fiber receiver incorporating a transimpedance preamplifier

iv. In this equivalent circuit the parallel resistances and capacitances are combined into RTL and CT respectively. The open loop current to voltage transfer function HOL (ω) for this transimpedance configuration corresponds to the transfer function for the two structures.

4.46 DIFFERENTIATE DWDM AND WDM TECHNIQUES

UQ. How DWDM is different from WDM? **(MU - Q. 5(c), Dec. 16, 4 Marks)**

Sr. No.	WDM	DWDM
1.	WDM uses a number of light sources, each emits the light of different wavelength.	DWDM is WDM utilizing closely spaced channels.
2.	In this, Optical multiplexer is used at the input side to multiplex these signals.	In this, DWDM assigns the incoming optical signals to specific frequencies multiplexes them for transport over a single fiber.

Sr. No.	WDM	DWDM
3.	All the signals arrive at the same time, instead of being distributed across time slots.	In this, multiple channels of information carried over the same fiber, each using an individual wavelength.
4.	It improve the capability of optical cable in carrying data by multiplexing many channel of wavelengths.	It increases the bandwidth of systems, without using repeaters.
5.	The channel spacing is reduced to 1.6 nm or less.	The channel spacing is small 200GHZ.
6.	The band used are O (Original) and C (Conventional).	The band used are C (Conventional) and L (Long).
7.	It cost per channel is low.	It cost per channel is high.
8.	The number of channels delivered are 2.	There is hundreds of channels is possible.
9.	The best application is PON.	The best application is Long-haul.
10.	In WDM, 1310nm laser used which is combined with 1550nm lasers.	Only system Z is qualified to be used in DWDM.
11.	**Advantages** (i) Extreme security (ii) It offers more bandwidth. (iii) There is possibility of transmission in full duplex mode. (iv) A simpler reconfiguration (v) This strategy might work best because it is straightforward to implement.	**Advantages** (i) Increasing scalability (ii) Allows multiple logical topologies to be used instead of a single physical MAN (iii) DWDM system with higher fibre capacity and longer span length (iv) Amplify your resilience (v) New services will be offered (vi) Easier network growth (vii) System with the highest capacity possible is able to conserve switched bandwidth
12.	**Disadvantages** (i) Tuning of wavelengths is difficult (ii) Bandwidth is not efficiently utilized. (iii) The system becomes more expensive as optical components are added. (iv) When using WDM, lightwave transmission is only possible in a two-point circuit. (v) The OLT (Optical Line Termination) must have a transmitter array with one transmitter for each ONU (Optical Network Unit), so scalability is an issue. A problem could arise if a new ONU is added unless the transmitter has been provisioned beforehand. Each ONU needs to have a laser with a certain wavelength. (vi) Problems with a cascaded topology	**Disadvantages** (i) Complex technology (ii) High precision wave filters and lasers (iii) Not economical given the small channel numbers (iv) Requires more space and power

4.47 ADVANTAGES OF OTN OVER SONET

UQ. Explain the advantages of OTN over SONET. **(MU – Q. 1(a), Dec. 18, May 19, 5 Marks)**

- The OTN architecture concept was developed by the ITU-T initially a decade ago, to build upon the Synchronous Digital Hierarchy (SDH) and Dense Wavelength-Division Multiplexing (DWDM) experience and provide bit rate efficiency, resiliency and management at high capacity. OTN therefore looks a lot like Synchronous Optical Networking (SONET) / SDH in structure, with less overhead and more management features.
- It is a common misconception that OTN is just SDH with a few insignificant changes. Although the multiplexing structure and terminology look the same, the changes in OTN have a great impact on its use in, for example, a multi-vendor, multi-domain environment. OTN was created to be a carrier technology, which is why emphasis was put on enhancing transparency, reach, scalability and monitoring of signals carried over large distances and through several administrative and vendor domains.

The advantages of OTN compared to SDH are mainly related to the introduction of the following changes:

OTN network combines the advantages of optical transmission and electrical processing to provide end-to-end, transparent pipe connections, increased spectral efficiency, and large-capacity transmission capabilities for long-haul transmissions.

Better scalability

The old transport technologies like SONET/SDH were created to carry voice circuits, which is why the granularity was very dense – down to 1.5 Mb/s. OTN is designed to carry a payload of greater bulk, which is why the granularity is coarser and the multiplexing structure less complicated.

Better Forward Error Correction

OTN has increased the number of bytes reserved for Forward Error Correction (FEC), allowing a theoretical improvement of the Signal-to-Noise Ratio (SNR) by 6.2 dB. This improvement can be used to enhance the optical systems in the following areas:

- **Increase** the reach of optical systems by increasing span length or increasing the number of spans.
- **Increase** the number of channels in the optical systems, as the required power theoretical has been lowered 6.2 dB, thus also reducing the non- linear effects, which are dependent on the total power in the system.
- **The increased** power budget can ease the introduction of transparent optical network elements, which can't be introduced without a penalty. These elements include Optical Add-Drop Multiplexers (OADMs), Photonic Cross Connects (PXCs), splitters, etc., which are fundamental for the evolution from point-to-point optical networks to meshed ones.
- **The FEC** part of OTN has been utilised on the line side of DWDM transponders for at least the last 5 years, allowing a significant increase in reach/capacity.

Transparent Client Signals

In OTN the Optical Channel Payload Unit-k (OPUk) container is defined to include the entire SONET/SDH and Ethernet signal, including associated overhead bytes, which is why no modification of the overhead is required when transporting through OTN. This allows the end user to view exactly what was transmitted at the far end and decreases the complexity of troubleshooting as transport and client protocols aren't the same technology.

- **Standard Hierarchy :** OTN standards include a standard multiplexing hierarchy, defining exactly how the lower-rate signals ascend into the higher-rate payloads. This allows the WDM platform to shift lower-rate services within 10Gbps, 40Gbps, or 100Gbps wavelengths, without the need for external wavelength demultiplexing and manual interconnects.
- **Transport Capacity Expansion :** OTN networks provide the underlying high-capacity infrastructure for core interoffice, metropolitan interoffice, and broadband business-access networks. Carriers deploy OTN to support the greatest number of services on the least amount of infrastructure.
- **Reduced Cost :** With multiple clients transported on a single wavelength and their specific requirements preserved, OTN network reduces the overall cost of transport and ensures efficient bandwidth utilization.
- Transport Flexibility : Network operators can employ the technologies needed to support current transport demands, while also enabling future adoption of new technologies as business needs dictate. It can easily scale to ring networks, end to end networks and mesh networks.
- **Timing Transparency :** Timing transparency is important for offering wholesale services for third-party providers. The transparency of OTN enables the networks to carry any service, including Ethernet, storage, digital video, as well as SONET/SDH without interfering with the client timing.

Chapter Ends...

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