इरिसेट IRISET

TCT4

OFC SYSTEMS

Indian Railways Institute of
Signal Engineering and Telecommunications
SECUNDERABAD - 500 017

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INDIAN RAILWAYS INSTITUTE OF SIGNAL ENGINEERING & TELECOMMUNICATIONS, SECUNDERABAD - 500 017

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CHAPTER-1

NEED FOR OFC AND LIGHT WAVE PROPAGATION MECHANISM

1.1 Introduction
1.2 Basic terms of Optical engineering
1.3 Advantage of OFC communication
1.4 Limitations of OFC
1.5 Applications in Signal & Telecommunications

1.1 Introduction

The demand for bandwidth on transmission networks is increasing rapidly because video and graphical rich contents are exchanged through the corporate network or the Internet. The Gigabit Ethernet became commonly used in the corporate network backbone, and 10Gbit Ethernet will be adopted in the near future. Meanwhile in the home, the demand for high-speed network becomes popular as the wide spread of broadband access, e.g. CATV, xDSL, and FTTH. The transmission medium with capability to transmit high bit rate signal is necessary to satisfy these requirements.

The telecommunication transport technologies move from copper based networks to optical fiber, from timeslot based transport to wave length based transport, from traditional circuit switching to terabit router and all optical based networks entering into a new era of optical networking.

1.2 Basic physics of OFC

1.2.1 Optical Fiber Cable

OFC have Fibers which are long, thin strands made with pure glass about the diameter of a human hair. OFC consists of Core, Cladding Buffers and Jacket as shown in figure: 1.1

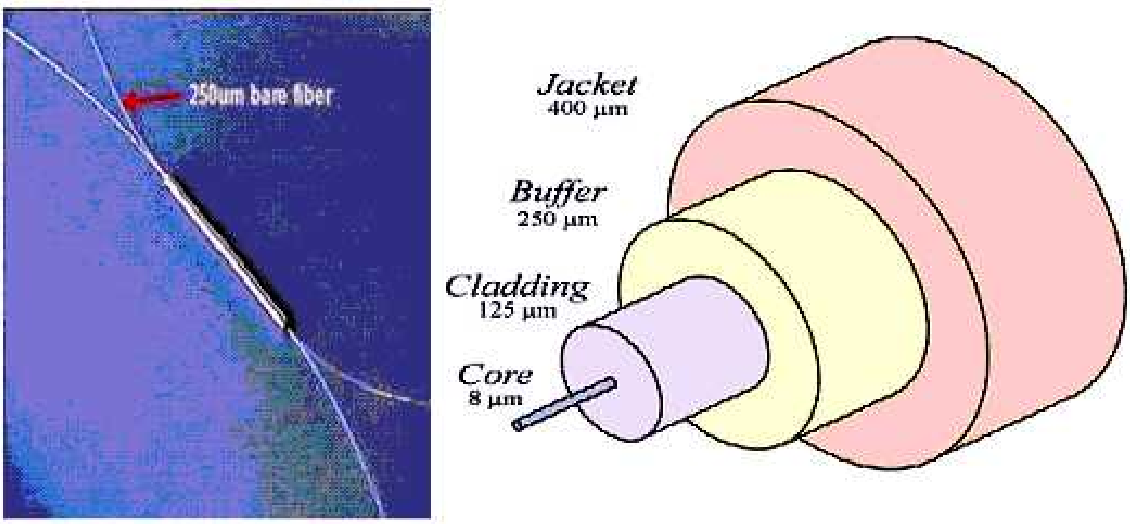


Figure 1.1 Bare Fiber and OFC cable

1.2.2 Monochromatic light, or Single Color light

Light or visible light is electromagnetic radiation of a wavelength that is visible to the human eye (about 400 – 700 nm). The word light is sometimes used to refer to the entire electromagnetic spectrum. Light is composed of elementary particles called photons. Three primary properties of light are:

- Intensity or brightness
- Frequency or wavelength and
- Polarization or direction of the wave oscillation

Light can exhibit properties of both waves and particles. This property is referred to as wave-particle duality. The study of light, known as optics.

In free space, light (of all wavelengths) travels in a straight path at a constant maximum speed. However, the speed of light changes when it travels in a medium, and this change is not the same for all media or for all wavelengths. By free space it is meant space that is free from matter (vacuum) and/or free from electromagnetic fields.

Thus, the speed of light in free space is defined by Einstein's equation:

$$\mathbf{E = mc^2}$$

Frequency, ν, speed of light in free space, c, and wavelength, λ, are interrelated by:

$$\boldsymbol{\nu = c/\lambda}$$

From the energy relationships $\mathbf{E = mc^2 = h\nu}$ and the last one, an interesting relationship is obtained, the equivalent mass of a photon

$$\mathbf{m = h\nu/c^2}$$

When light is in the vicinity of a strong electromagnetic field, it interacts with it. From this interaction and other influences, its trajectory changes direction as shown in figure: 1.2

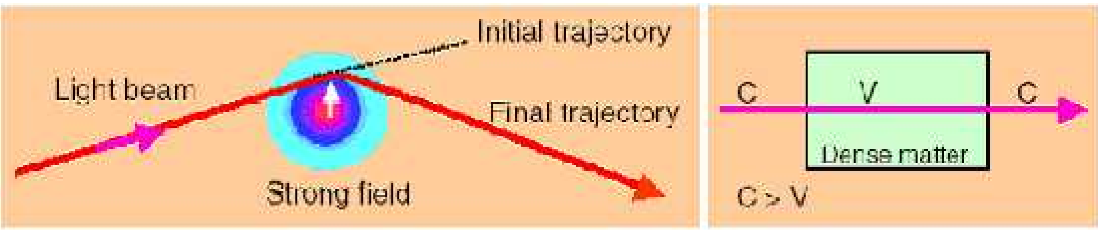


Figure 1.2 Light travels in strong field

1.2.3 Incident ray, Reflected ray and Refracted ray

An incident ray is a ray of light that strikes a surface. The angle between this ray and the perpendicular or normal to the surface is the angle of incidence.

Reflection is the change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated. Common examples include the reflection of light, sound and water waves.

The reflected ray corresponding to a given incident ray, is the ray that represents the light reflected by the surface. The angle between the surface normal and the reflected ray is known as the angle of reflection. The Law of Reflection says that for a non-scattering surface, the angle of reflection always equals the angle of incidence.

The refracted ray or transmitted ray corresponding to a given incident ray represents the light that is transmitted through the surface. The angle between this ray and the normal is known as the angle of refraction, and it is given by Snell's Law.

The figure: 1.3 shows Incident ray, Reflected ray, Refracted ray, the angle of incidence and angle of refraction.

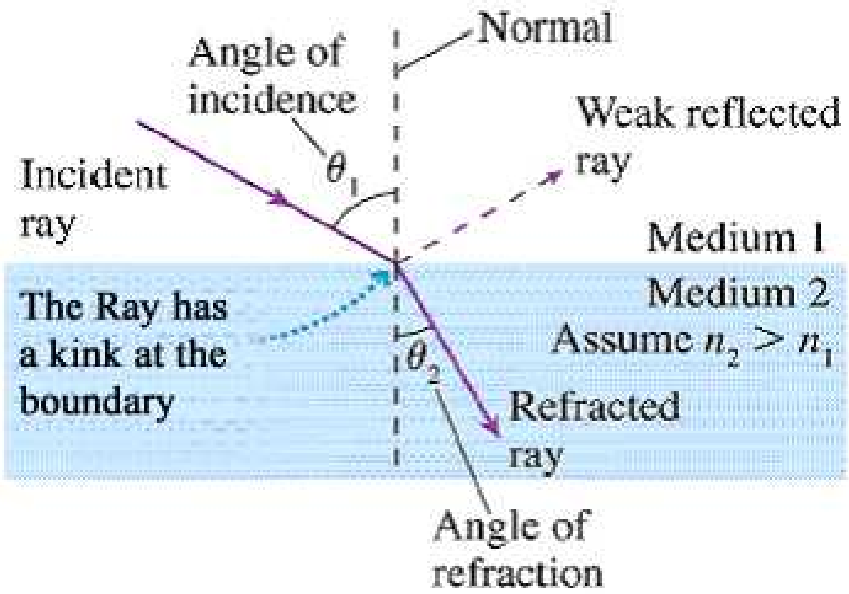


Figure 1.3 Light rays and its angles

1.2.4Refractive index

Refractive index is the speed of light in a vacuum (c =299,792.458km/second) divided by the speed of light in a material (v**)**. Refractive index measures how much a material refracts light. Refractive index of a material, abbreviated as 'n ', is defined as **'** n=c/v ' . Light travels slower in physical media than it does when transmitted through the air.

Refractive index (*n*): is a function of molecular structure of matter; optical frequency, optical intensity; determines optical propagation properties of each wavelength *(λ)* may not be distributed equally in all directions, is affected by external temperature, pressure, and fields.

Refractive index of a medium is a measure for how much the speed of light is reduced inside the medium. For example, typical glass has a refractive index of 1.5, which means that light travels at 1/1.5 = 0.67 times the speed in air or vacuum.

Two common properties of glass and other transparent materials are directly related to their refractive index. First, light rays change direction when they cross the interface from air to the material , and effect that is used in lenses and glasses. Second, light reflects partially from surfaces that have a refractive index different from that of their surroundings.

The indices of refraction of various Medias are shown in table below.

Medium	Index of Refraction
Vacuum	1.00
Air (actual)	1.0003
Air (accepted)	1.00
Water	1.33
Ethyl alcohol	1.36
Oil	1.46
Glass	1.50
Polystyrene plastic	1.59
Zircon	1.96
Diamond	2.41
Silicon	3.50

1.2.5Snell's law

In 1621, a Dutch physicist named Willebrord Snell derived the relationship between the different angles of light as it passes from one transparent medium to another. When light passes from one transparent material to another, it bends according to Snell's law which is defined as: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

Where:

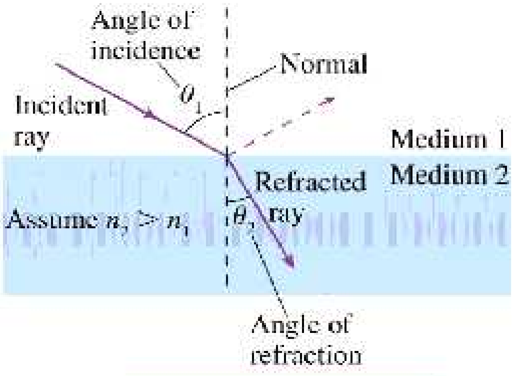
n_1 is the refractive index of the medium the light is leaving

θ_1 is the incident angle between the light beam and the normal (normal is 90° to the Interface between two materials)

n_2 is the refractive index of the material the light is entering

θ_2 is the refractive angle between the light ray and the normal

Snell's law (see figure 1.4) gives the relationship between angle of incidence and angle of refraction.



$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

Figure 1.4 Snell's law

For the case of θ_1 = 0° (i.e., a ray perpendicular to the interface) the solution is θ_2 = 0° regardless of the values of n_1 and n_2. That means a ray entering a medium perpendicular to the surface is never bent.

The above is also valid for light going from a dense (higher *n*) to a less dense (lower *n*) material; the symmetry of Snell's law shows that the same ray paths are applicable in opposite direction.

1.2.6Total internal reflection

When a light ray crosses an interface into a medium with a higher refractive index, it bends towards the normal. Conversely, light traveling cross an interface from a higher refractive index medium to a lower refractive index medium will bend away from the normal.

This has an interesting implication: at some angle, known as the critical angle θ_c, light traveling from a higher refractive index medium to a lower refractive index medium will be refracted at 90°; in other words, refracted along the interface.

If the light hits the interface at any angle larger than this critical angle, it will not pass through to the second medium at all. Instead, all of it will be reflected back into the first medium, a process known as total internal reflection (see figure 1.5)**.**

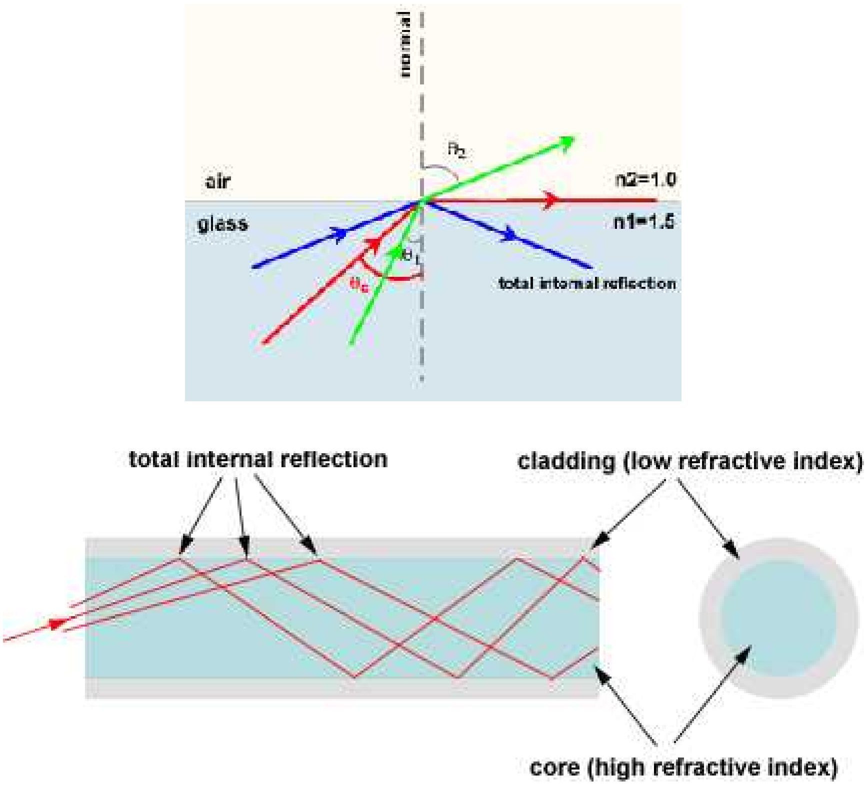


Figure 1.5 Total Internal Reflections

The critical angle can be calculated from Snell's law, putting in an angle of 90° for the angle of the refracted ray $\boldsymbol{\theta_2}$. This gives $\boldsymbol{\theta_1}$:

$$\theta_1 = \arcsin[(n_2/n_1)*\sin(\theta_2)]$$

Since, $\boldsymbol{\theta_2}$ = 90°

So, $\mathbf{sin(\theta_2)} = 1$

Then, $\boldsymbol{\theta_c = \theta_1 = \arcsin(n_2/n_1)}$

For example, with light trying to emerge from glass with n_1=1.5 into air (n_2 =1), the critical angle θ_c is arcsin(1/1.5), or 41.8°.

For any angle of incidence larger than the critical angle, Snell's law will not be able to be solved for the angle of refraction, because it will show that the refracted angle has a sine larger than 1, which is not possible. In that case all the light is totally reflected off the interface, obeying the law of reflection.

1.2.7 Optical fiber mode

An optical fiber guides light waves in distinct patterns called modes (see figure 1.6). Mode describes the distribution of light energy across the fiber. The precise patterns depend on the wavelength of light transmitted and on the variation in refractive index that shapes the core. In essence, the variations in refractive index create boundary conditions that shape how light waves travel through the fiber, like the walls of a tunnel affect how sounds echo inside.

We can take a look at large-core step-index fibers. Light rays enter the fiber at a range of angles, and rays at different angles can all stably travel down the length of the fiber as long as they hit the core-cladding interface at an angle larger than critical angle. These rays are different modes.

Fibers that carry more than one mode at a specific light wavelength are called multimode fibers. Some fibers have very small diameter core that they can carry only one mode which travels as a straight line at the center of the core. These fibers are single mode fibers. This is illustrated in the following picture.

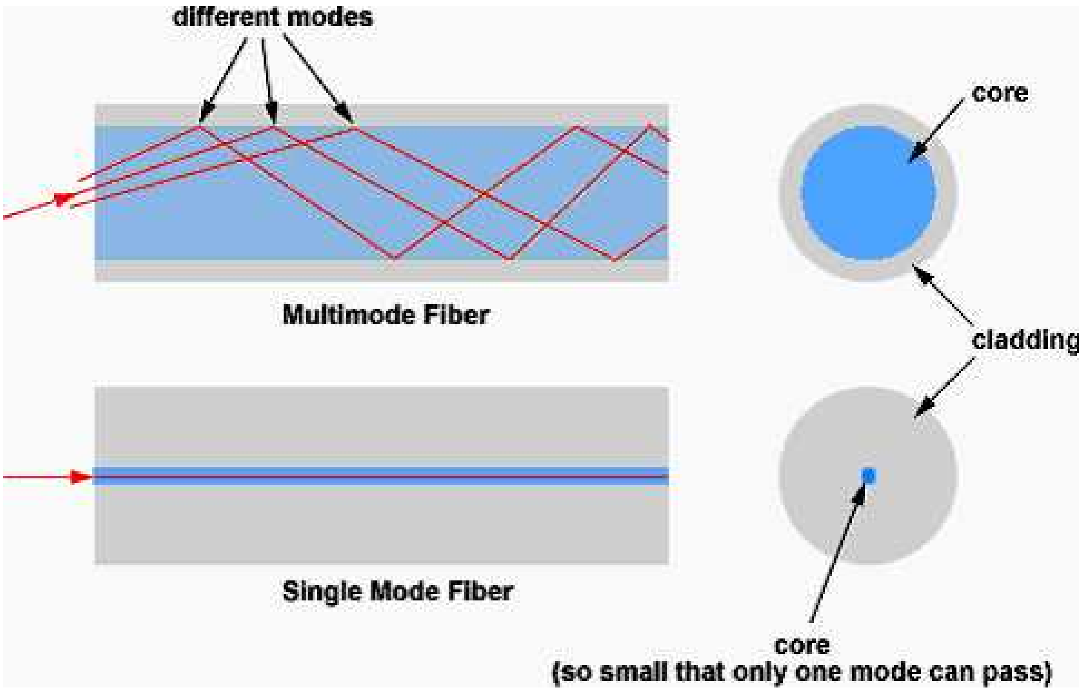


Figure 1.6 Optical fiber modes

1.2.8Optical fiber index profile

Index profile (figure 1.7) is the refractive index distribution across the core and the cladding of a fiber. Some optical fiber has a step index profile, in which the core has one uniformly distributed index and the cladding has a lower uniformly distributed index. Other optical fiber has a graded index profile, in which refractive index varies gradually as a function of radial distance from the fiber center. Graded-index profiles include power-law index profiles and parabolic index profiles. The following figure shows some common types of index profiles for single mode and multimode fibers.

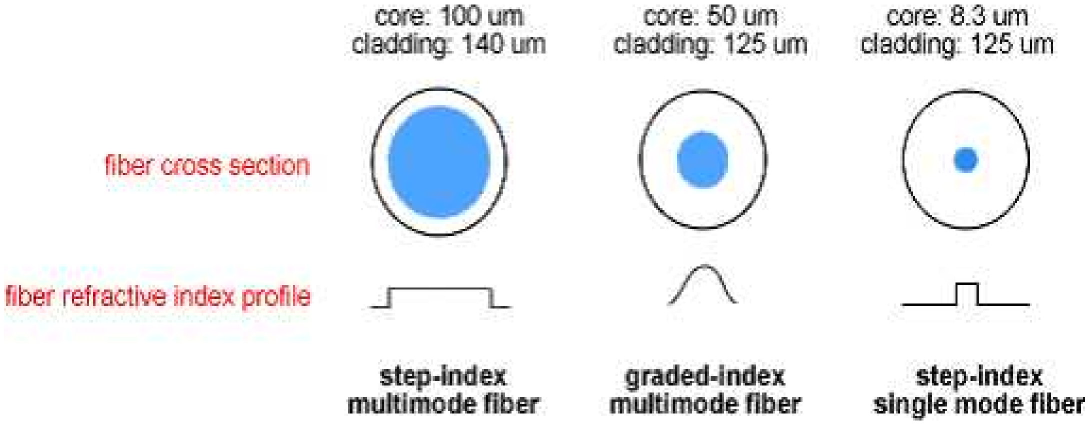


Figure 1.7 Optical fiber index profiles

1.2.9Optical fiber's Numerical aperture (NA)

Multimode optical fiber will only propagate light that enters the fiber within a certain cone, known as the acceptance cone of the fiber. The half-angle of this cone is called the acceptance angle (see figure 1.8), ***θmax***. For step-index multimode fiber, the acceptance angle is determined only by the indices of refraction:

$$NA = n\sin\theta_{max} = \sqrt{n_f^{\,2} - n_c^{\,2}}$$

Where

n is the refractive index of the medium light is traveling before entering the fiber
n_f is the refractive index of the fiber core
n_c is the refractive index of the cladding

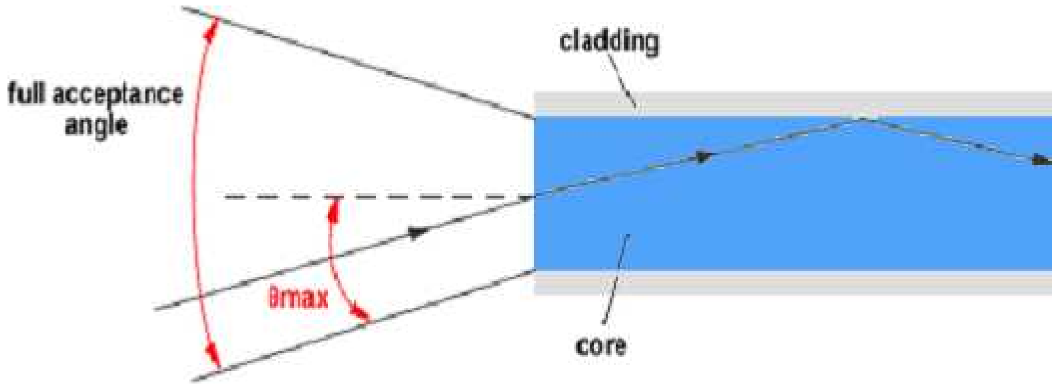


Figure 1.8 Acceptance angle

1.2.10Number of modes in a fiber

Modes are sometimes characterized by numbers. Single mode fibers carry only the lowest-order mode, assigned the number 0. Multimode fibers also carry higher-order modes. The number of modes that can propagate in a fiber depends on the fiber's numerical aperture (or acceptance angle) as well as on its core diameter and the wavelength of the light. For a step-index multimode fiber, the number of such modes, $\mathbf{N_m}$.

$$Nm = 0.5\left(\frac{\pi D \times NA}{\lambda}\right)^2$$

Where

D is the core diameter ***λ*** is the operating wavelength

NA is the numerical aperture (or acceptance angle)

1.2.11 Mode field diameter

All light do not travels through the core of the fiber, but is distributed through both the core and the cladding. The "mode field" is the distribution of light through the core and cladding (See figure 1.9) of a particular fiber. Mode-Field Diameter (MFD) defines the size of the power distribution. When coupling light into or out of a fiber, MFD is important in understanding light loss.

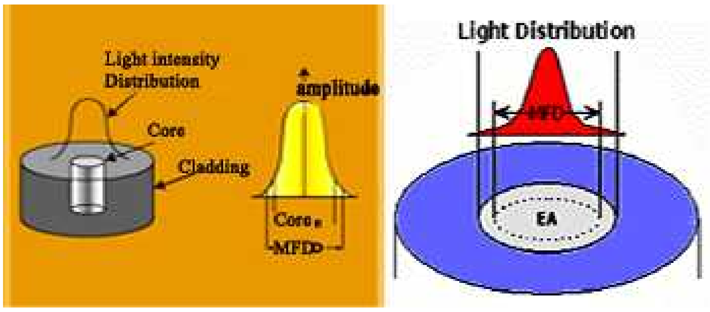


Figure 1.9 Mode field diameters

1.3Advantage of OFC communication

•More information carrying capacity

Fibers can handle much higher data rates than copper. More information can be sent in a second.

Information Carrying Capacities of various media are:

Medium / Link	Carrier	Information Capacity
Copper Cable (short distance)	1 MHz	1 Mbps (ADSL Modem)
Coaxial Cable (Repeater every 4.5 km)	100 MHz	140 Mbps (BSNL)
UHF Link	2 GHz	8 Mbps (BSNL), 2 Mbps (Rly.)
MW Link (Repeater every 40 km)	7 GHz	140 Mbps (BSNL), 34 Mbps (Rly.)
OFC	1550 nm	2.5 Gbps (STM-16 – Rly.) 10 Gbps (STM-64) 1.28 Tbps (128 Ch. DWDM) 20 Tbps (Possible)

- Free from Electromagnetic and Electrostatic interference

Being insulator no electric current flows through the fibre and due to these reason fibres neither radiate nor pick up electromagnetic radiation. So WPC CLEARANCE is not required.

- Low attenuation : 0.25 db/km at 1550 nm

Loss in twisted pair and coaxial cable increases with frequency, whereas, loss in the optical fibre cable remains flat over a wide range of frequencies (See figure: 1.10).

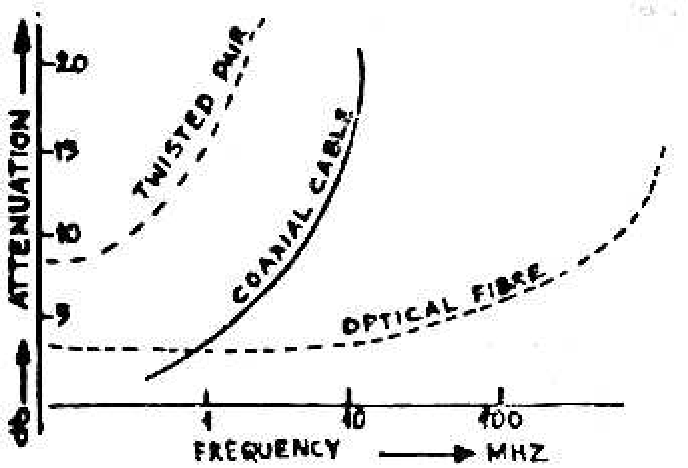


Figure 1.10 Frequency Vs Attenuation in Various Types of Cable

- Use of WDM – Switching / routing at Optical signal level
- Self healing rings under NMS control
- Small size makes fibre cable lighter in weight. So easy to handle.

  Optic fibre cable weight (approx) 500 kg / km

  Copper cable weight (approx) 1000 kg/km

- Fibres are not affected by power surges and corrosive chemicals.

The reasons are photons of light in a fibre do not affect each other as they have no electrical charge and they are not affected by stray photons outside the fibre. But in case of copper, electrons move through the cable and these are affected by each other.

- Safety

Optical fibre does not carry any electricity even if the cable is damaged or short circuited it does not cause any spark or fire hazard.

- Signal security

As the fibre does not radiate energy it cannot be detected by any nearby antenna or any other detector. The fibres are difficult to tap and therefore excellent for security.

- No cross talk

As the signal transmission is by digital modulation there is no chance of cross talk in between channels.

- Less prone to theft

  As the fibre does not have resale value in the market.

- Flexibility in system up gradation

Only by adding a few additional terminal and repeater equipments the capacity of the system can be increased, at any time once the cable is laid.

- High resistance to chemical effects and temperature variations.

1.4 Limitations of OFC

- Difficulty in Jointing (splicing)
- Highly skilled staff would be required for maintenance
- Precision and costly instruments are required
- Tapping for emergency and gate communication is difficult.
- Costly if under- utilised
- Special interface equipments required for Block working
- Accept unipolar codes i.e. return to zero codes only.

1.5 Application in Signal and Telecommunications

- Long haul circuits for administrative branch and data transmission circuits
- Short -haul circuits for linking of telephone exchanges.
- Control communication & Signalling application for fail safe transmission
- Electronic interlocking systems installations

Objective:

1.Optical fibers accept ----------------------- signals only.

a) Bipolarb) unipolarc) any polarityd) None

2.The main drawback of optical fiber as a communication medium is that ---------------------- on the fiber can be provided.

a) tappingb) no tappingc) None

3.Transmission loss of optical fiber at a wavelength of 1550 nm is about ---------------- dB/Km.

a) 2.5b) 0.25 c) 0.025d) 25

4.Transmission loss of optical fiber at a wavelength of 1310 nm is about ---------------- dB/Km.

a) 0.35b) 3.5c) 2.5d) 0.25

5.Transmission loss of optical fiber at a wavelength of 850 nm is about ------------------ dB/Km.

a) 1.5 to 2.5b) 1.5 to 3.0c) 2.5 to 3.0d) 3 to 3.5

6.In step index fiber the refractive index remains constant throughout the core and decreases to some value at the core cladding interface and again remains constant throughout the cladding. (T/F)

7.In graded index fiber the refractive index of the core varies following the parabolic rule up to the core cladding interface and then remains constant throughout the cladding. (T/F)

8.The number of modes that can propagate in fiber is a function of numerical aperture, core diameter and wavelength of light. (T/F)

9.When a light ray enters a medium at an angle of 90^0 the ray will never bent. (T/F)

Subjective:

1. What are the advantages of optical fibre cables over copper cable?
2. What is the basic principle of transmission in optical fibre cables?
3. What is difference between Refraction and Reflection?
4. Why WPC clearance is not required in case of OFC media.
5. OFC is free from Electro Magnetic & Electro Static inductions. Discuss in Brief the reasons.
6. Define Numerical Aperture and acceptance cone.

CHAPTER-2

PROPAGATION MODES AND OFC CLASSIFICATONS

2.1 Propagation modes concept
2.2 Multimode fiber
2.3 Propagation through MMSI fiber
2.4 Problems and solution with MMSI fiber
2.5 Propagation through MMGI
2.6 Propagation through SMSI fiber
2.7 Important parameters of SM fiber
2.8 Cutoff wave length

2.1 Propagation modes concept

2.1.1 Mode

Mode is an available distribution of electromagnetic field in a plane transverse to the direction of light propagation. Each mode (see figure 2.1) is characterized by frequency, polarization, electric field strength, and magnetic field strength. Available patterns are derived from Maxwell's equations and boundary conditions.

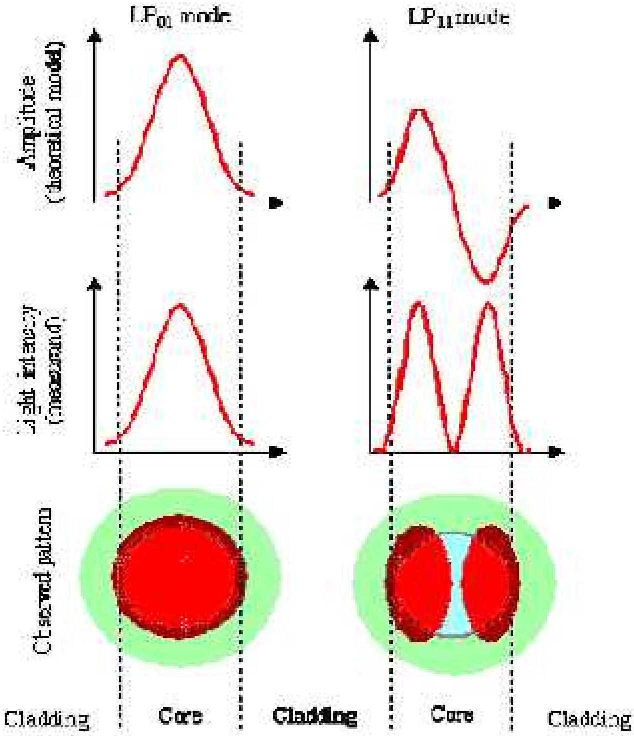


Figure 2.1 Modes in OFC

2.1.2 Linearly polarized (LP) mode

A mode for which the field components in the direction of propagation are small compared to components perpendicular to that direction. An optical fiber supports only different field patterns, called as 'Linear Polarized' or 'LP' modes (See figure 2.2). The reasons are:

- The EM wave propagating inside an optical fiber has to meet the boundary condition requirements.
- EM waves that meet the requirements will exist as stable pattern or mode.
- The light rays within propagation cone which satisfy above conditions only are transmitted.
- The power of launched light is delivered by separate modes within the fiber. Total output power is the accrual of power carried by different modes.

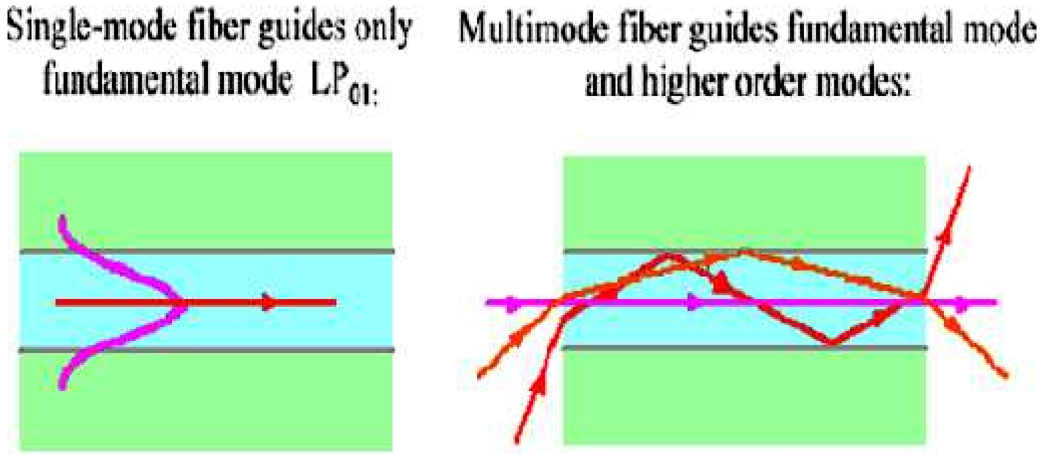


Figure: 2.2 Fundamental modes in SM and MM fiber

There are two basic types of fiber: Multimode fiber and Single-mode fiber

Multimode fiber is best designed for short transmission distances. This is suited for used in LAN systems and video surveillance. Single mode fiber is best designed for longer transmission distances. This is suitable for long distance telephony and multi channel television broadcast systems.

2.2 Multi mode fiber

Multimode fiber, the first to be manufactured and commercialized, simply refers to the fact that numerous modes or light rays are carried simultaneously through the waveguide. Modes result from the fact that light will only propagate in the fiber core at discrete angles within the cone of acceptance. MM fiber type has a much larger core diameter, compared to single-mode fiber, allowing for the larger number of modes and is easier to couple than single-mode optical fiber.

Multimode fiber further categorized as Multimode step-index and Multimode graded- Index fiber.

2.3 Propagation through MMSI fiber

Figure: 2.3 shows the principle of total internal reflection applies to multimode step-index fiber. Because the core's index of refraction is higher than the cladding's index of refraction, the light that enters at less than the critical angle is guided along the fiber.

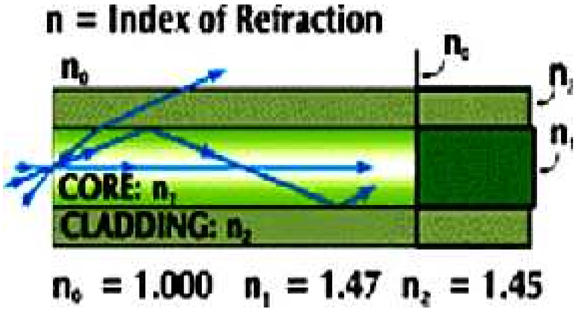


Figure: 2.3 Total Internal Reflection in Multimode Step-index fiber

Three different light waves travel down the fiber. One mode travels straight down the center of the core. A second mode travels at a steep angle and bounces back and forth by total internal reflection. The third mode exceeds the critical angle and refracts into the cladding. Naturally, it can be seen that the second mode travels a longer distance than the first mode, causing the two modes to arrive at separate times.

2.4 Problems with MMSI fiber and Solution

This disparity between arrival times of the different light rays is known as dispersion, and the result is a muddied signal at the receiving end. It is important to note that high dispersion is an unavoidable characteristic of multimode step-index fiber. The solutions are either use Graded index fiber or Single mode fiber.

2.5 Propagation through MMGI Fiber

Multimode Graded-index refers to the fact that the refractive index of the core gradually decreases farther from the center of the core. The increased refraction in the center of the core slows the speed of some light rays, allowing all the light rays to reach the receiving end at approximately the same time, reducing dispersion.

Figure: 2.4 show the Light propagation principle through multimode graded-index fiber. The core's central refractive index (n_A) is greater than that of the outer core's refractive index (n_B).

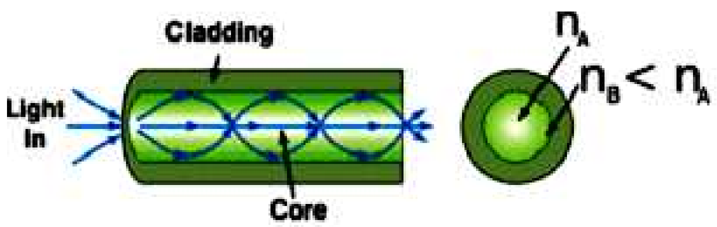


Figure: 2.4 Multimode Graded-index Fiber

It is very clear from the figure: 2.4, the light rays no longer follow straight lines; they follow a serpentine path being gradually bent back toward the center by the continuously declining refractive index. This reduces the arrival time disparity because all modes arrive at about the same time. The modes traveling in a straight line are in a higher refractive index, so they travel slower than the serpentine modes. These travel farther but move faster in the lower refractive index of the outer core region.

2.6 Propagation through SMSI fiber

Single mode fiber has a much smaller core that allows only one mode of light at a time to propagate through the core. The figure: 2.5 show the single mode fiber.

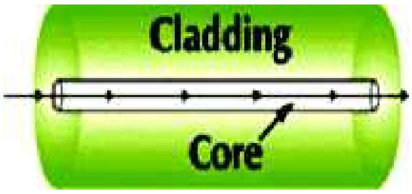


Figure 2.5 Propagation through SMSI fiber

Single-mode fiber exhibits no dispersion caused by multiple modes. Single-mode fiber also offers lower fiber attenuation than multimode fiber. Thus, more information can be transmitted per unit of time because it can retain the fidelity of each light pulse over longer distances

Like multimode fiber, early single-mode fiber was generally characterized as step-index fiber meaning the refractive index of the fiber core is a step above that of the cladding rather than graduated as it is in graded-index fiber. Modern single-mode fibers have evolved into more complex designs such as matched clad, depressed clad and other exotic structures

2.6.1 Single-mode fiber disadvantages

The smaller core diameter makes coupling light into the core more difficult. The tolerances for single-mode connectors and splices are also much more demanding.

2.7 Important parameters of SM fiber

Parameter	Description	Typical value
Attenuation	Loss of signal strength	0.35 db/km at 1310 nm 0.25 db/km at 1550 nm
Core diameter	Diameter of core	8 to 10 micro meter
Cladding diameter	Diameter of cladding	125 micro meter
Core-cladding RI ratio	Ratio of RI of core to cladding	Less than 0.37%
Cut-off wavelength	Minimal wavelength at which fiber supports only one wavelength	Greater than 1260 nm
Numerical aperture	Ability of Optical Fiber to gather light from source & guide it inside through total internal reflection	0.10 to 0.17
Mode field diameter	MM fiber carries all light energy through core as core diameter is large. But, SM fiber carries 80% light energy through core and 20% through cladding as core diameter is small.	9.3 micro meters for core diameter of 8.3 micro meters

	Mode field diameter (MFD) is the effective diameter available for propagation. MFD is dependent on wavelength – it reduces with wavelength. Shorter the wavelength, more focused the beam is and more stringent confinement of beam to core, hence less MFD. When 2 fibers are connected, not only core-cladding diameters to match but also MFDs to match	

2.8 Cutoff wave length

Cutoff wavelength is the wavelength above which a single-mode fiber supports and propagates only one mode of light. In other words, an optical fiber that is single-mode at a particular wavelength may have two or more modes at wavelengths lower than the cutoff wavelength. The effective cutoff wavelength of a fiber is dependent on the length of fiber and its deployment. The longer the fiber, the lower is the effective cutoff wavelength. The smaller the bend radius of a loop of the fiber, the lower is the effective cutoff wavelength. If a fiber is bent in a loop, the effective cutoff wavelength is lowered.

Objective:

1.Mode is an available distribution of electromagnetic field in -------------------to the direction of light propagation.

a) a plane transverseb) a plane longitudinal

c) Both transverse and longitudinal planesd) none

2.A mode for which the field components in the direction of propagation are small compared to components perpendicular to that direction is called ------------------------------

a) Circularly polarized modeb) linearly polarized mode

c) TEM moded) TM mode

3.Single mode fiber is best designed for --------------- transmission distances.

a) Longerb) shorterc) mediumd) very short

4.Multimode fiber is best designed for ------------------ transmission distances.

a) Longerb) shorterc) mediumd) very short

5.The disparity between the arrival times of different light rays at the output of a fiber while traveling through the fiber is known as dispersion. (T/F)

6.In graded index fiber dispersion is reduced due to variation of refractive index in the core of the fiber. (T/F)

7.Ratio of refractive index of core to cladding of SM fiber is less than 0.37 %. (T/F)

8.Cut-off wavelength of a SM fiber is greater than 1260 nm. (T/F)

9.The effective cut-off wavelength of a fiber is a function of the length of the fiber. (T/F)

10.The longer the fiber length, the lower is the effective cut-off wavelength. (T/F)

11.The smaller is the bending radius of the fiber; the lower is the effective cut-off wavelength. (T/F)

12.The numerical aperture of a SM fiber is about 0.10 to 0.17. (T/F)

Subjective:

1. What are the differences between multimode and single mode fibre?
2. What are the different categories in multimode fibre?
3. What are the disadvantages of Single mode fibre?
4. How dispersion is reduced in graded index fibre?
5. What is the importance of cut off wavelength?

CHAPTER-3

ATTENUATION IN OFC

3.1 Introduction to signal attenuation in fiber

Optical fiber has a number of advantages over copper. However it also suffers from degradation problems which cannot be ignored. The first of these is loss or attenuation (see figure 3.1). Attenuation is typically the result of two sub properties. They are scattering and absorption. Both of which have cumulative effects. The second is dispersion which is the spreading of the transmitted signal and is analogous to noise.

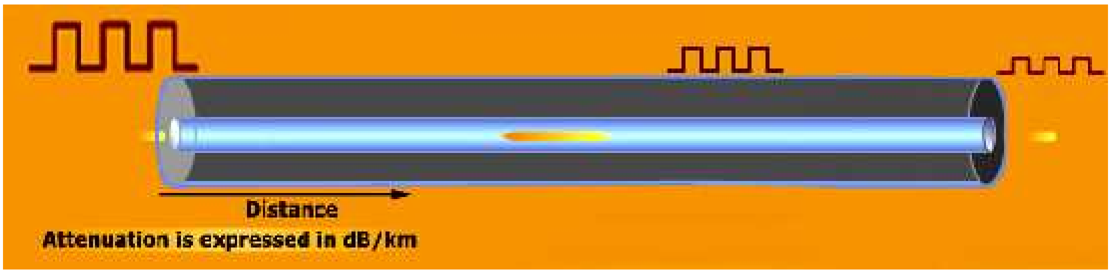


Figure 3.1 Attenuation in Fiber

3.2 Scattering

Scattering (see figure 3.2) occurs because of impurities or irregularities in the physical construction of the fiber. The well known form of scattering is Rayleigh scattering. It is caused by metal ions in the silica matrix and results in light rays being scattered in various directions.

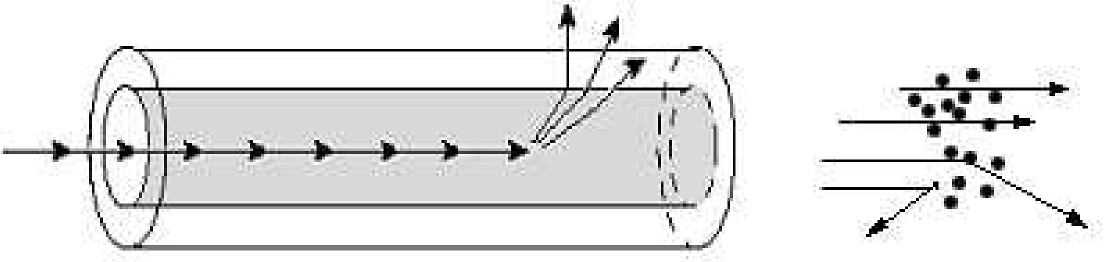


Figure 3.2 Scattering

Scattering limits the use of wavelengths below 800nm. The short wavelengths are much affected than longer wavelengths. It is because of Rayleigh scattering that the sky appears to be blue (shorter wave length). The shorter wavelengths (blue) of light are scattered more than the longer wavelengths of light.

3.3 Absorption

Absorption (see figure 3.3) results from three factors. They are hydroxyl ions (OH^-, water) in the silica, impurities in the silica and incomplete residue from the manufacturing process. These impurities tend to absorb the energy of the transmitted signal and convert it to heat, resulting in an overall weakening of the signal. The Hydroxyl absorption occurs at 1.25 and 1.39 micro. The silica itself starts to absorb energy at 1.7 micro, because of the natural resonance of the silicon dioxide.

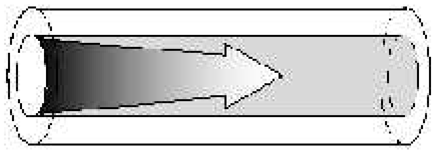


Figure 3.3 Light Absorption

3.4 Macro bending loss

Macro-bending loss (see figure 3.4) is caused by bending of the entire fiber axis. The bending radius shall not be sharper than '30d', where'd' is diameter of cable. A single bend sharper than '30d' can cause loss of 0.5dB. The fiber may break if bending is ever sharper.

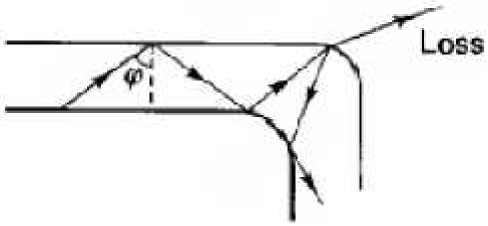


Figure: 3.4 Macro bend in fiber

3.5 Micro bending loss

Micro-bending loss (see figure 3.5) is caused by micro deformations of fiber axis which leads to failures in achieving total internal reflection conditions. Micro-bends are small-scale perturbations along the fiber axis, the amplitude of which are on the order of microns. These distortions can cause light to leak out of a fiber.

Micro-bending may be induced at very cold temperatures because the glass has a different coefficient of thermal expansion from the coating and cabling materials. At low temperatures, the coating and cable become more rigid and may contract more than the glass. Consequently, enough loads may be exerted on the glass to cause micro bends. Coating material is selected by manufacturers to minimize loss due to micro-bending. The linear thermal expansion coefficient of coating material shall be compatible with that of fiber.

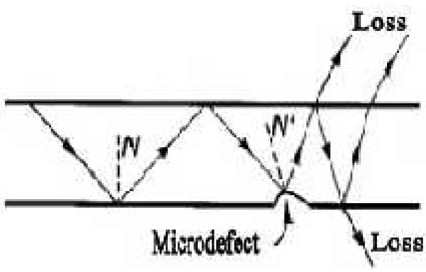


Figure: 3.5 Micro bend in fiber

3.6 Dispersion

Dispersion (see figure 3.6) is the optical term for the spreading of the transmits in the fiber. It is the bandwidth limiting phenomenon and comes in two forms: Multimode dispersion and chromatic dispersion. Chromatic dispersion is further subdivided into material dispersion and waveguide dispersion.

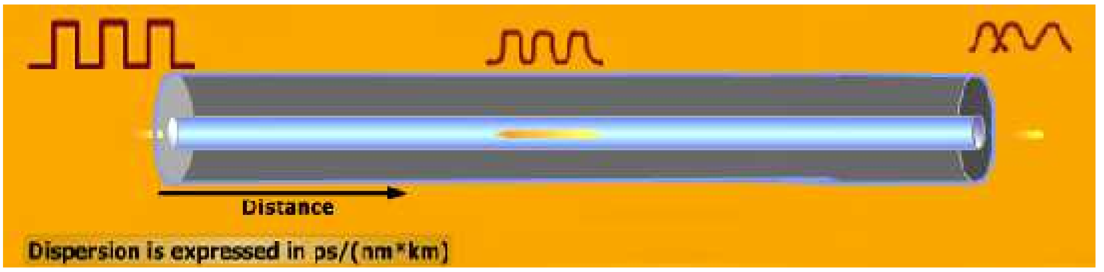


Figure 3.6 Principle of Dispersion

3.6.1 Dispersion Phenomenon in Optical fiber

Dispersion is the time distortion of an optical signal that results from the differences of time of travel for different components of that signal, typically resulting in pulse broadening. As the distance traveled by the signal is more, broadening of pulse is more.

In digital transmission, dispersion limits on the maximum data rate and the maximum distance i.e. the information-carrying capacity of a fiber link. The interference from broadened pulse in the next interval shall not lead to erroneous interpretation of received signal.

3.6.2 Types of dispersions

There are two types of dispersion. They are Inter modal dispersion and Chromatic Dispersion.

3.6.3 Inter-modal dispersion in Multi-mode step-index fiber

The disparity between arrival times of the different modes is known as inter modal dispersion. Since pulse power is delivered by separate modes which travel different distances within fiber, fractions of power arriving at the end combine to cause spreading of pulse. The solutions to modal dispersion problem are either use Graded index fiber or Single mode fiber.

3.6.4 Chromatic dispersion

Individual mode has light of different wave lengths, each traveling along fiber with different velocity and resulting in dispersion. This is called ‘Chromatic dispersion’. It has two components. They are ’ Material dispersion’ and ’Wave guide dispersion’.

The ’ Material dispersion ’ is due to disperse properties of material, results in pulse spread. The ’ Wave guide dispersion ’ results from the light waves traveling in the core and the inner cladding glasses at slightly different speeds.

Total chromatic dispersion, along with its components is plotted by wavelength (see fig 3.7) for dispersion shifted fiber.

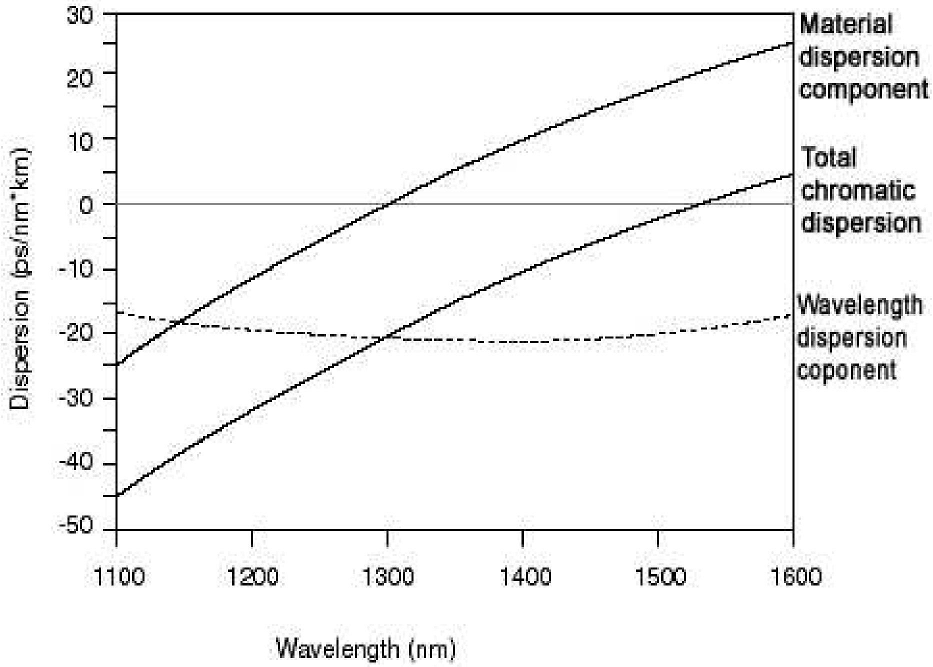


Figure 3.7 Chromatic Dispersion

3.6.5 Chromatic dispersion in MM and SM fiber

The wave guide dispersion is negligible in MM fiber. The material dispersion exists. The total dispersion in MM fiber is equal to:

$$[(\text{modal dispersion})^2 + (\text{material dispersion})^2]^{1/2}$$

There is no modal dispersion in SM fiber but chromatic dispersion exists. The dispersion varies with wavelength. The wavelength at which dispersion equals zero is called the zero-dispersion wavelength (λ_0). This is the wavelength at which fiber has its maximum information carrying capacity. The standard single mode fiber, this is in the region of 1310 nm (See figure: 3.8)

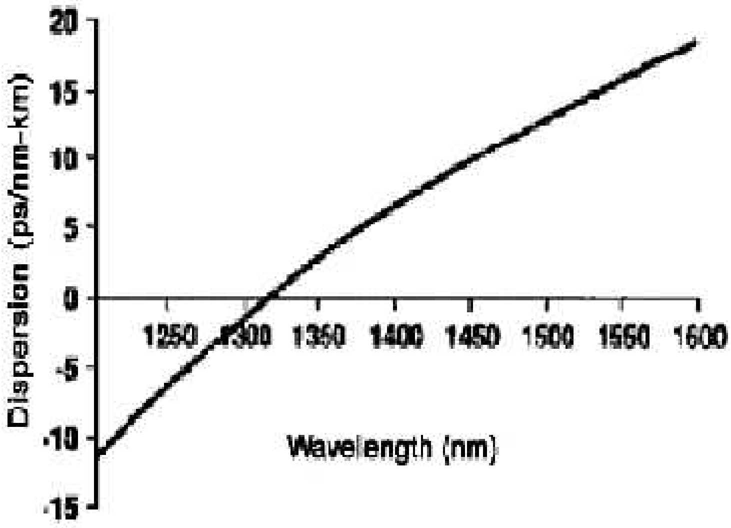


Figure: 3.8 Typical Dispersion vs. Wavelength curve

3.6.6 Polarization Mode Dispersion

Most single-mode fibers support two perpendicular polarization modes, a vertical and a horizontal. Because these polarization states are not maintained, there occurs an interaction between the pulses that results is a smearing of the signal.

Polarization mode dispersion (PMD) is caused by Oval shape of fiber as a result of the manufacturing process or from external stressors. Because stress can vary over time, PMD, unlike chromatic dispersion, is subject to change over time. PMD is generally not a problem at speeds below OC-192 (9953.28Mbps).

3.6.7 Other Nonlinear Effects

In addition to PMD, there are other nonlinear effects. Because nonlinear effects tend to manifest themselves when optical power is very high, they become important in DWDM. Linear effects such as attenuation and dispersion can be compensated, but nonlinear effects accumulate.

They are the fundamental limiting mechanisms to the amount of data that can be transmitted in optical fiber. The most important types of nonlinear effects are stimulated Brillouin scattering, stimulated Raman scattering, self-phase modulation, and four-wave mixing. In DWDM, four-wave mixing is the most critical of these types.

Four-wave mixing is caused by the nonlinear nature of the refractive index of the optical fiber. Nonlinear interactions among different DWDM channels create sidebands that can cause inter channel interference.

In figure 3.9 three frequencies interact to produce a fourth frequency, resulting in cross-talk and signal-to-noise degradation.

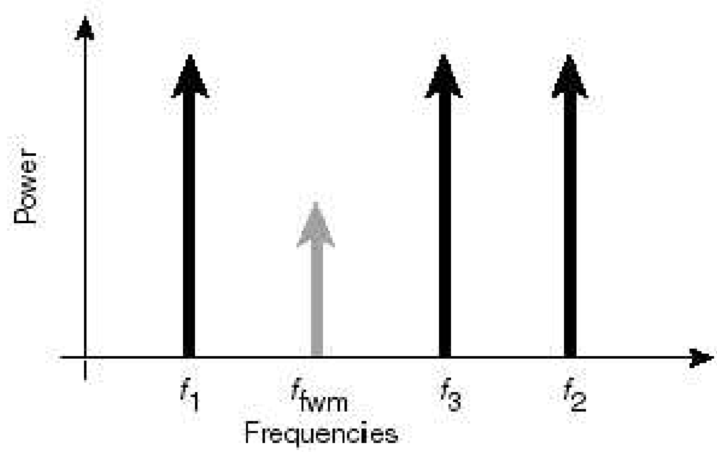


Figure 3.9 Four-wave mixing

The effect of four-wave mixing is to limit the channel capacity of a DWDM system. Four-wave mixing cannot be filtered out, either optically or electrically, and increases with the length of the fiber. Due to its propensity for four-wave-mixing, DSF is unsuitable for WDM applications. This prompted the invention of NZ-DSF, which takes advantage of the fact that a small amount of chromatic dispersion can be used to mitigate four-wave mixing.

3.7 Optical domain

Understanding where attenuation and dispersion problems occur helps optical design engineers determine the better wavelengths at which information can be transmit, taking into account distance, type of fiber and the other factors which can severely affect the integrity of the transmitted signal. The graph shown in figure 3.10 depicts the optical transmission domain, as well as the areas where problems arise. The wavelength (nm) is shown on X-axis and attenuation (dB/km) is shown on Y-axis.

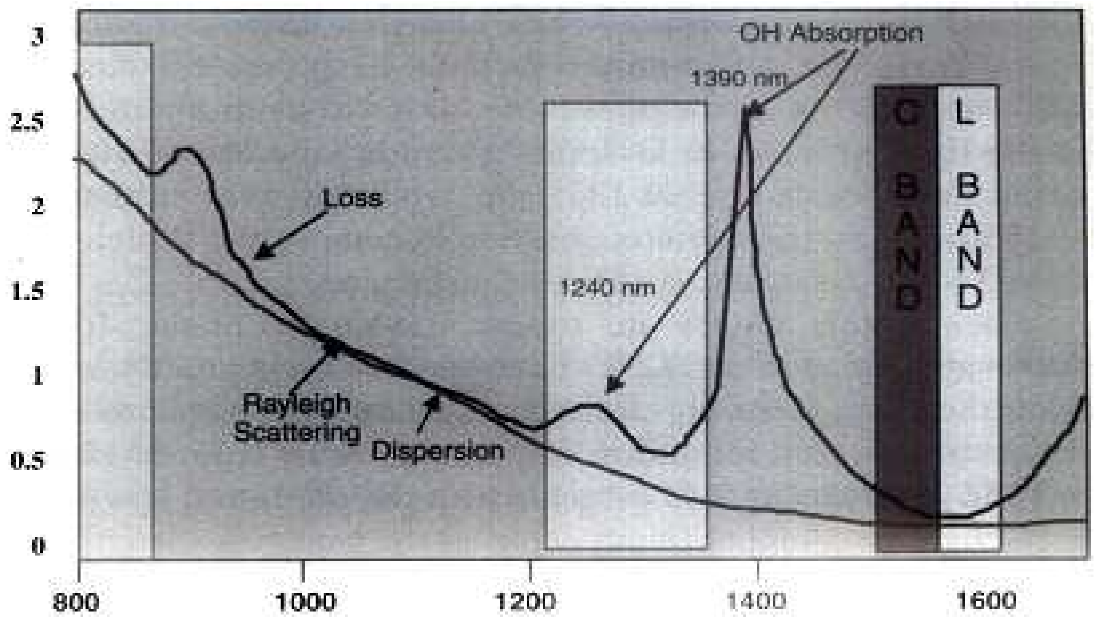


Figure 3.10 Optical Domain

There are four transmission windows appear in the figure 3.10. The first one is at around 850 nm, the second at 1310nm, third at 1550 nm and fourth at 1625 nm. The last two labeled as 'C' and 'L' band respectively.

The 850 nm wavelength at which the original LED technology operated. The second window, at 1310 nm has low dispersion. The 1550 nm called as ' C-band ' is ideal wavelength for long haul communication systems.

The network engineers can avoid transmitting signal at 1000 nm where Rayleigh scattering, 1240 and 1390 nm where hydroxyl absorption by water occurs to avoid high degree of loss.

Optical fibers also can be manufactured to have low dispersion wavelength in the 1550nm region, which is also the point where silica-based fibers have inherently minimal attenuation. These fibers are referred to as dispersion-shifted fibers and are used in long-distance applications with high bit rates. For applications utilizing multiple wavelengths, it is undesirable to have the zero dispersion point within the operating wavelength range.

Objective:

1. Scattering and absorption of light signal cause ----------------------.
   a) Total internal reflection b) attenuation c) gain to the signal d) None

2. Impurities and irregularities in the physical construction of optical fiber causes --------------------------------.
   a) Scattering b) absorption c) total internal reflection

3. Rayleigh's scattering is due to ---------------- present in the silica matrix.
   a) Water vapors b) metal ions c) OH ions

4. Scattering limits the use of wavelengths below ----------- nm in optical fiber.
   a) 1310 b) 1550 c) 800 d) 650

5. The hydroxyl ions and impurities present in the silica are the reasons for --------------------- of light signals.
   a) Bending b) scattering c) absorption

6. Bending of the entire fiber axis causes macro-bending loss. (T/F)

7. The coefficient of thermal expansion of glass is different from that of the coating and cabling materials. (T/F)

8. The difference in coefficient of thermal expansion of glass, coating and cabling materials cause micro-bends in the fiber. (T/F)

9. Material dispersion is present when the fiber is operated at a wavelength of 1550 nm. (T/F)

10. Modal dispersion is almost zero in SMSI fiber. (T/F)

11. Chromatic dispersion is the only dispersion present in single mode fiber. (T/F)

12. Four-wave mixing is caused by the nonlinear nature of the refractive index of the optical fiber. (T/F)

13. The effect of four-wave mixing is to limit the channel capacity of the fiber. (T/F)

Subjective:

1. Why a signal is attenuated in OFC?
2. What is difference between the scattering and absorption?
3. Explain in brief dispersion phenomenon and list out types?
4. How many transmission windows are available in Optical domain? List out.

CHAPTER-4

FIBER STANDARDS & CONSTRUCTIONAL FEATURES

4.1 Optical fiber cable classification
4.2 Standards and commercial fibers
4.3 OFC Technical requirements
4.4 Construction details of OFC

4.1 Optical fiber cable classification

Classification Based upon fiber types in a cable may be categorized as three types. They are:

4.1.1Single Mode Fiber Optic Cable

Designs of single-mode fiber have evolved over several decades. The three principle types and their ITU-T specifications are:

- Non dispersion-shifted fiber (NDSF) G.652

The initially deployed type used for 1310 nm. This fiber has high dispersion at 1550 nm, hence not suitable for 1550 nm systems. To solve the shortcoming of NDSF fiber, fiber manufacturers developed dispersion-shifted fiber (DSF).

- Dispersion-shifted fiber (DSF) G.653

This has moved the zero-dispersion point to the 1550 nm region

- Non zero-dispersion-shifted fibers (NZ-DSF) G.655

Though DSF worked extremely well with a single 1550 nm wavelength, it exhibits serious nonlinearities when multiple, closely-spaced wavelengths in the 1550 nm were transmitted in DWDM systems.

To address the problem of nonlinearities, non zero-dispersion-shifted fibers (NZ-DSF) were designed by manufacturers. The fiber is available in both positive and negative dispersion varieties and is rapidly becoming the fiber of choice in new fiber deployment.

4.1.2 Multimode Fiber Optic Cable

All fibers in the cable are multimode cables.

4.1.3 Hybrid/Composite Cable

Both single mode and multimode fibers are packaged in one cable, such as 4 multimode fibers and 4 single mode fibers in a single cable.

Classification based upon application may be categorized as four types. They are:

4.1.4 Indoor Cables

A single cable structure with a single fiber (see figure 4.1). Simplex cable varieties include 1.6mm & 3mm jacket sizes. Fire safety is the number one factor in selecting indoor cables, particularly those that run through plenum spaces. Indoor cables must pass the flame-retardant and smoke-inhibitor ratings.

Figure: 4.1 Indoor Optic Cable

4.1.4 Duplex Fiber Optic Cable

Duplex-zip (see figure 4.2). This cable contains two optical fibers in a single cable structure. Light is not coupled between the two fibers; typically one fiber is used to transmit signals in one direction and the other receives.

Figure: 4.2 Duplex Fiber Optic cable

4.1.5 Distribution Fiber Cables

This compact building cable consists of individual 900µm buffered fiber (see figure 4.3), is smaller in size and costs less than breakout cable. Connectors may be installed directly on 900µm buffered fiber at breakout box location.

Figure 4.3 Distribution fiber cable

4.1.6 Breakout Fiber Cables

Breakout cables (see figure 4.4) are also called fan-out cables. In tight buffered cables each fiber is only a 900um tight buffered fiber, but in breakout cables every fiber is a sub cable by itself. Each fiber has a 2~3mm jacket, then outer jacket covers these sub cables, aramid yarn and ripcord inside. This design allows users to divide the cable to serve users with individual fibers, without the need for patch panel. Breakout cable enables the quick installation of connectors onto – 2.00 mm robust jacketed fiber.

Figure 4.4 Break fiber optic cables

4.1.7 Ribbon Fiber Cables

Ribbon fiber cables (see figure 4.5) Consists of up to 12 fibers contained side by side within a single jacket. Often used for network applications and data centers.

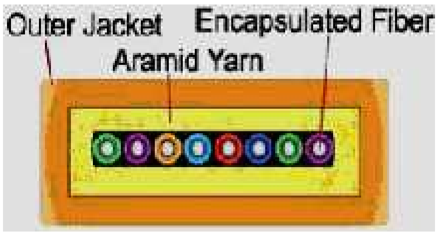


Figure: 4.5 Ribbon Fiber Optic cable

4.1.8 LSZH Fiber Cables

Low Smoke Zero Halogen (see figure 4.6) cables are offered as an alternative for halogen-free applications. Less toxic and slower to ignite, they are a good choice for many internal installations. They are available as simplex, duplex and 1.6mm designs. This cable may be run through risers directly to a convenient network or splicing closet for interconnection.

Figure 4.6 LSZH cable

4.1.9 Outdoor Fiber Cable

Indoor/outdoor rated tight buffered cables have riser and plenum rated versions. These cables are flexible, easy to handle and simple to install. Since they do not use gel, the connectors can be terminated directly onto the 900um fiber without difficult-to-use kits. This provides an easy and overall less expensive installation.

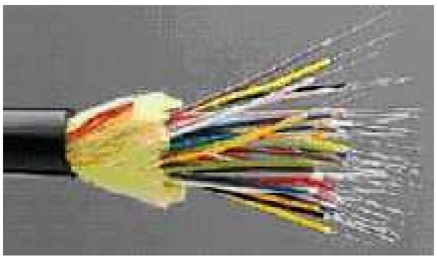


Figure: 4.7 Indoor/Outdoor Tight Buffered Fiber Optic cable

4.1.10 Outdoor Loose Tube Fiber Optic Cables

Tube encloses multiple coated fibers (see figure 4.8) that are surrounded by a gel compound that protects the cable from moisture and outside environments. Cable is restricted for indoor use, typically allowing not exceeding 50 feet.

Moisture resistance and temperature tolerance are the major factors when choosing materials for outdoor environment cables. They also need to be ultraviolet (UV) resistant.

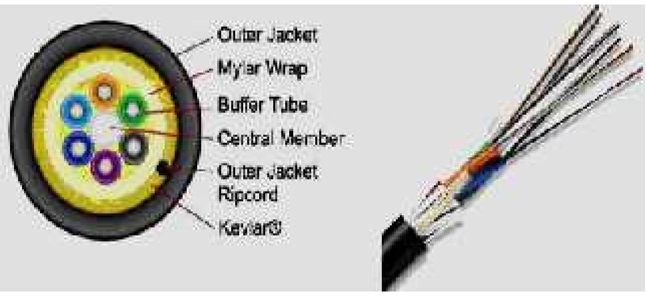


Figure: 4.8 Indoor/Outdoor Tight Buffered Fiber Optic cable

4.1.11 Indoor/Outdoor Dry Loose Tube Fiber Optic Cable

This cable is suitable for both indoor and outdoor applications. One advantage of this cable is that it eliminates the need for a splice or connector at the point where the cable transitions takes place between an outdoor and indoor environment.

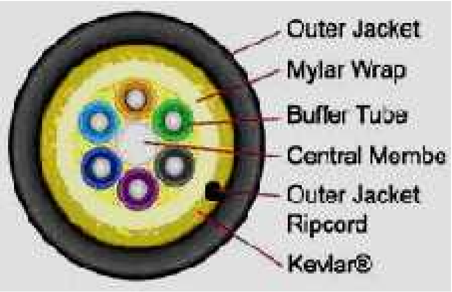


Figure: 4.9 Indoor/Outdoor Dry Loose Tube Fiber Optic cable

4.1.12Figure 8 Fiber Optic Cables (Aerial/Self-Supporting Fiber Cables)

Figure 8 (aerial/self-supporting) fiber cables are designed to be hanged on poles and most can also be installed in underground ducts. They have internal stress members of steel of steel or Aramid yarn that protect fibers from stress.

Aerial cables (see figure 4.10) must endure extreme temperature ranges from sunlight heat to freezing snow. They also must survive high wind loading.

Aerial cable provides ease of installation and reduces time and cost. Figure 8 cable can easily be separated between the fiber and the messenger. Temperature range -55 to +85°C.

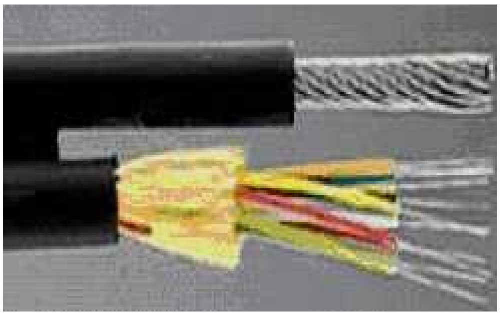


Figure: 4.10 Aerial Fiber Optic cable

4.1.13 Direct-buried (Armored Fiber Optic Cable)

Armored cables (see figure 4.11) are similar to outdoor cables but include an outer armor layer for mechanical protection and to prevent damage. They can be installed in ducts or aerially or directly buried underground. Armor is surrounded by a polyethylene jacket.

Armored cable can be used for rodent protection in direct burial if required. This cable is non-gel filled and can also be used in aerial applications. The armor can be removed leaving the inner cable suitable for any indoor/outdoor use. Temperature rating -40 to +85°C.

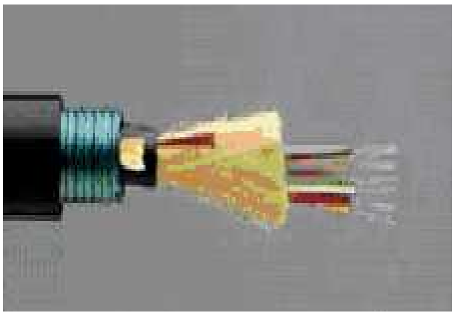


Figure: 4.11 Armored Fiber Optic cable

4.1.14Submarine Fiber Optic Cable (Undersea Fiber Optic Cable)

Submarine cables (see figure 4.12) are used in fresh or salt water. To protect them from damage by fishing trawlers and boat anchors they have elaborately designed structures and armors. Long distance submarine cables are especially complex designed.

Figure: 4.12 Submarine Fiber Optic cable

4.2 Standards and commercial fibers

The physical dimensions of core and cladding have been standardized to ensure compatibility among splices and connectors.

4.2.1 The international standards for SM fiber are:

Cladding diameter : 125 microns (micro meter)
Cladding + coating : 245 microns (micro meter)
Core diameter : 8 to 10 micro meter

4.2.3 The International standards for MM fiber are:

Cladding diameter : 125 microns (micro meter)
Cladding + coating : 245 microns (micro meter)
Core diameter : 50 to 62.5 micro meters

The figure: 4.13 shows the SM and MM Core and cladding diameters.

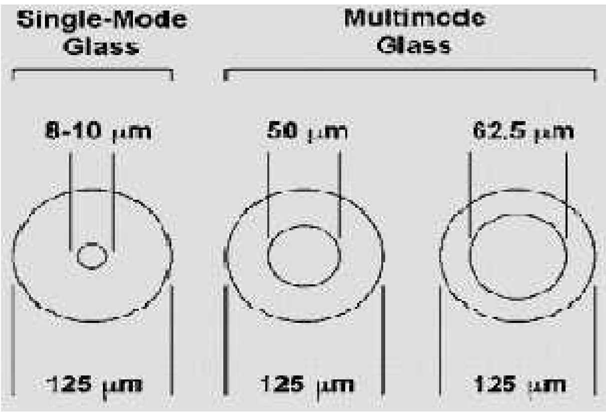


Figure 4.13 Core and Cladding diameter

4.2.4 The following table shows the different types of cables ITU-T recommendations and their applications.

S.No	Type	ITU–T Rec	Description	Indoor/ Outdoor	Application
1	MM50	G.651	Multi Mode Fiber with 50 micro m. of Core dia	Outdoor	Short-Reach Optical Transmission for LAN in Offices and Premises
2	MM62.5	G.651	Multi Mode Fiber with 62.5 micro m. of Core dia	Outdoor	Short-Reach Optical Transmission for LAN in Offices and Premises
3	MM10G	G.651	Multi Mode Fiber with 50 micro m. of Core dia	Outdoor	10Gigabit Ethernet Optical Transmission for LAN in Offices and Premises
4	SM	G.652B	Single-Mode Fiber	Outdoor	Large-Capacity & Low-Loss Transmission in 1550nm Windows
5	LWP	G.652D	Low-Water-Peak Single-Mode Fiber	Outdoor	WDM Optical Transmission for Metropolitan Networks
6	SR15	G.652B	Bending-Insensitive Small Bending Proof and High Reliability Single-Mode Fiber	Indoor	Optical cord and cable for FTTH / LAN / Premises

7	SR15E	G.652D	Bending-Insensitive Small Bending Proof and High Reliability Low-Water-Peak Single-Mode Fiber	Outdoor	Long-Distance Optical Transmission in 1550nm Windows
8	DS	G.653	Dispersion-Shifted Single-Mode Fiber	Outdoor	Long-Distance Optical Transmission in 1550nm Windows
9	LA	G.655	Large-Effective-Area NZ-DSF	Outdoor	Long-Distance DWDM Optical Transmission in the C-&L-Bands
10	SS	G.656	Small-Dispersion-Slope NZ-DSF	Outdoor	Long-Distance DWDM Optical Transmission in the C-&L-Bands
11	ULA	G.655	Ultra Large-Effective-Area NZ-DSF	Outdoor	Long-Distance DWDM Optical Transmission Utilizing the S-, C- & L-Bands
12	USS	G.656	Ultra Small-Dispersion-Slope NZ-DSF	Outdoor	DWDM Optical Transmission Utilizing the S-, C- & L-Bands for Metro Networks

4.3 Construction of Optical Fiber Cable

4.3.1 The main parts of an optical fiber cable are shown in figure: 4.14 in a cross section of armored loose tube optic fiber cable:

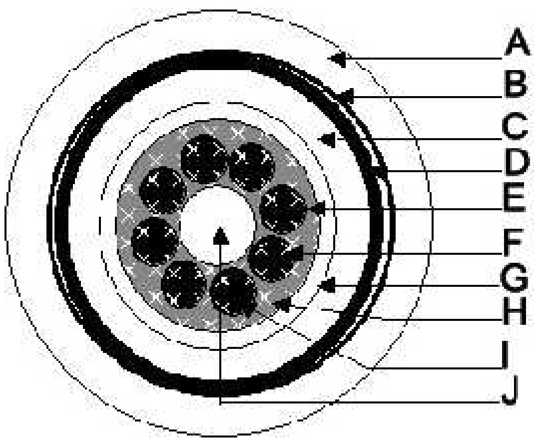


Figure: 4.14 parts of optic fiber cable

Legends:

A HDPE outer jacket 2.0 mm thickness minimum
B Corrugated stainless steel armour (.6mm mini.)
C Inner PE Sheath of 1.00 mm mini thickness
D Secondary coating tube nylon/PBTP of 2.5 mm
E Primary coated fiber of 125 micro mm max dia
F Central strength member of FRP to comply with 2w of specification
G Wrapping aramid yarn
H Water blocking jelly thixotropic
I Water blocking thixotropic jelly
J Rip card mini. two

- **Core**

Core is a central portion of the cable, in form of very thin tube size (approximately 8 um) made up of glass and carries light signals from transmitter to receiver.

- **Cladding**

It surrounds core cylindrically and is having lower refractive index as compared to the core.

- **Buffers**

a. Primary coating: Acrylate, silicon rubber or lecquer is applied as primary coating. It works as mechanical protection

b. Secondary coating: An additional buffer (secondary coating) is also added during manufacturing process. These are of three types, such as loose buffer, tight buffer and open channel.

- **Loose buffer**

More than one fiber can be inserted in a single plastic tube. The dia of the tube is several times than fiber dia (after primary coating). This arrangement protects fiber from mechanical forces. It also eliminates micro bending of fiber. Its loose tube is usually filled with jelly for protection from moisture and at curve fiber moves frictionless from one end to another.

- **Tight buffer**

In this case plastic coating is directly applied over the primary coating. This arrangement provides better crush and impact resistance but it may produce micro bends due to stresses. Such types are also affected due to temperature variations, plastic expansion & contraction which are different from glass. These are mainly used as indoor cables such as jumper cords, pigtail & patch cords.

- **Open channel**

In this type of cables, fibers are located in groove form in the central strength member. In this type fibers are free to move within the cable to avoid tensile stress like loose tube fibers. Fibers are protected from moisture by filling the cable with jelly or similar compound.

- **Strength Member**

Optical fibers are stranded helically around the strength member. Strength member holds the cable with low strain and provides mechanical strength. Strength member provided is normally of the following types:

- Steel wires
- Plastic material
- Textile fibers
- Fiber glass epoxy rods
- Fillers

Fillers are employed to maintain spacing of coated fibers and insulated conductors if any, to provide cushioning to the fibers and to give shape to the cable. Typical materials are PVC, Polythene, low-density cellulose paper, spun bonded polyester. The cable core is generally filled with a blocking or filling compound to prevent moisture entry i.e. to provide circularity.

- **Core Wrap**

This is in the form of a tape and it holds the assembly of fiber, filler and provides heat barrier to fiber during extrusion process of outer sheath. Materials used are cellulose paper etc.

- **Cable Sheath**

It protects cable from environmental damage. It makes moisture, chemical and fire resistant. Sheath material can be high-density polythene. PVC sheaths are common in fibers installed for indoor application.

- **Armour**

Whenever cables are to be buried directly in the earth to protect the cable against rodent attacks, armouring is considered essential. Armouring can be by stainless steel wire or steel tapes. Armouring gives extra strength and improves flexibility for easy handling. In case of RE area the problem of high voltage induced can be reduced by isolating the armour at periodical interval. The small or normal gap can be protected by applying epoxy resin etc.

- **Jacketing**

Normally outer most sheaths which are called jacketing provide protection from chemical acids, alkalis, solvents etc. Material used are high density polyethylene with anti termite compound, polyurethane, PVC, nylon etc.

4.3.2 Strength of Optical Fiber Cable

The common misconception about optical fiber is that it must be fragile because it is made of glass. The ultra pure glass of optical fibers exhibits both high tensile strength and extreme durability, even though traditional bulk glass is brittle. The Tensile strength is of the order of 44000 to 60000 kg per sq.cm. The tensile strength of copper is only 7500 kg per sq.cm.

4.3.3 Bending Parameters

The optical fiber and cable are easy to install because it is lightweight, small in size and flexible. But precautions are needed to avoid tight bends, which may cause loss of light or premature fiber failure. The bending radius should be greater than ’30d’, where’d’ is the diameter of the cable. The splice trays and other fiber handling equipments (racks) are designed in such way that the fiber installation losses can be prevented.

4.3.4 Cladding Diameter control on fibers

The cladding diameter tolerance controls the outer diameter of the fiber, with tighter tolerances ensuring that fibers are almost exactly the same size. During splicing, inconsistent cladding diameters can cause cores to misalign where the fibers join, leading to higher splice losses.

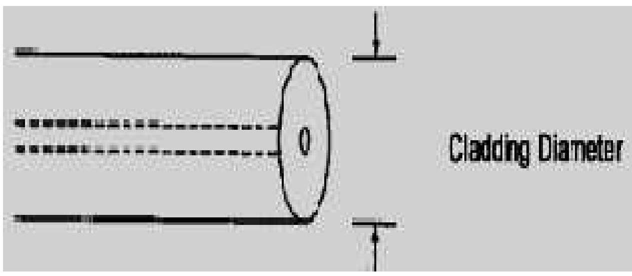


Figure 4.15 Cladding diameter

4.3.5 Core/clad concentricity control on fibers

The Tighter core/clad concentricity tolerances help to ensure that the fiber core is Centered in relation to the cladding. This increases the chance of cores that do match up precisely when two fibers are spliced together. Core/clad concentricity is determined during the first stages of the manufacturing process.

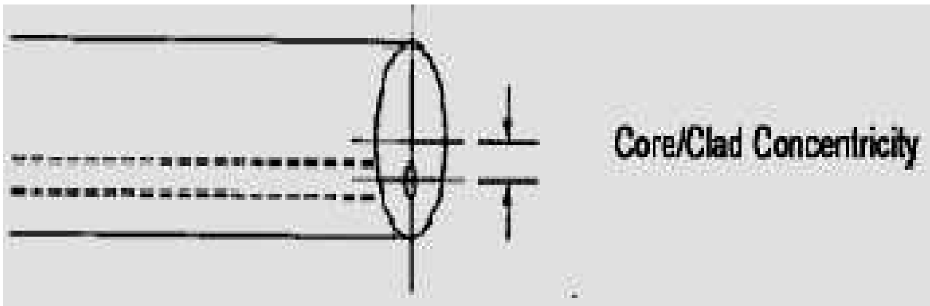


Figure 4.16 Core/Clad Concentricity

4.3.6 Fiber Curl

Fiber curl is the inherent curvature along a specific length of optical fiber that is exhibited to some degree by all fibers. It is a result of thermal stresses that occur during the manufacturing process. Tighter fiber-curl tolerances reduce the possibility of misalignment of fiber cores during splicing.

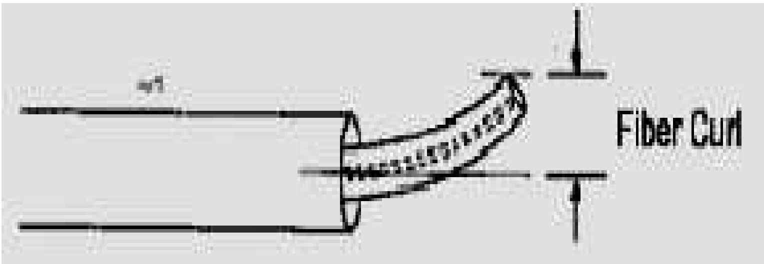


Figure: 4.17 Fiber curl

4.4 Specifications of Optical Fiber Cable used in Indian Railways

In Indian Railways, 24 Fiber armoured Optical Fiber Cable as per RDSO Spec. IRS: TC 55-2006 is used.

4.4.1 General requirement of cable

The cable shall consist of 24 monomode fibers and shall be suitable for direct underground burial as well as mechanized laying in the duct.

4.4.2 Service Condition

Optical Fiber cable shall be able to withstand the following environmental conditions.

Ambient temperature	0 to + 55^0 C
Storage temperature	-20^0 C to + 70^0 C

4.4.3 Technical requirements

Technical requirements are tabulated below:

Cut off wave length	Cut off wave length for 2m fiber section shall be 1320nm
Attenuation at 1310 nm between 1285 to 1330 nm at 1550 nm	 ≤ 0.36 dB/Km < 0.36+0.02dB/Km ≤ 0.23 dB/Km
Nominal diameter of core	8.8 µm - 9.8 µm for matched clad fiber
Nominal diameter of cladding	125 µm ± 1.0 µm
Non circularity of cladding	≤ 1%
Mode field concentricity error	≤ 0.8 µm
Primary coating	Material UV curable Acrylate, Diameter 245±10 µm. It should not have any reaction with cladding or cable material
Chromatic dispersion	
Polarization mode dispersion	For fiber : For cabled fiber :
Fiber curl	≥4m radius of curvature
Fiber micro bend at 1550 nm	≤0.5 dB

4.4.4 Marking on Cable

On the outer jacket of the cable there is indelible length marking at an interval not exceeding 1±.01 meter. The outer jacket is in black color and marking is in white color.

The sequential length marking shall not rub off during normal installation. The marking on the cable is as given below:

“Manufacturer/Company’s trade mark, IR marking, telephone mark, laser symbol, type of cable, number of fibers, month, year of manufacture and drum number.”

4.4.5 Overall Diameter

The overall diameter of the cable shall not be more than 20 mm and uniform throughout the length from top to end.

4.4.6 Fiber & Unit Identification

Fibers are colored with readily distinguishable durable colors. In case of four fibers in a tube the order of colored fibers are Blue, Orange, Green and Natural. The 6 loose tubes have the following colors:

Loose Tube numberColour of loose tube

1 Blue
2 Orange
3 Green
4 Brown
5 Slate
6 White

Cross-sectional view of 24 Fiber cable used in Indian Railways is shown in fig. 4.18

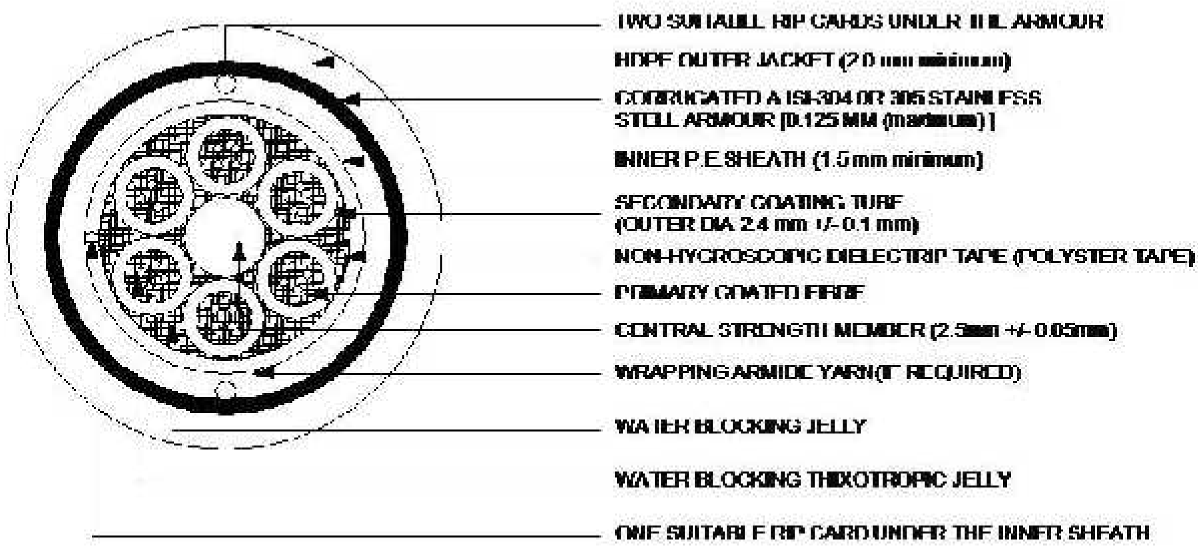


Fig 4.18 Cross-sectional view of 24 Fiber cable used in Indian Railways

Objective:

1. ITU-T recommendation G.652 describes the properties of ---------------------
   a) dispersion-shifted fiber b) Non dispersion-shifted fiber
   c) Non-zero dispersion-shifted fiber d) None

2. ITU-T recommendation G.653 describes the properties of ---------------------
   a) dispersion-shifted fiber b) Non dispersion-shifted fiber
   c) Non-zero dispersion-shifted fiber d) None

3. ITU-T recommendation G.655 describes the properties of ---------------------
   a) dispersion-shifted fiber b) Non dispersion-shifted fiber
   c) Non-zero dispersion-shifted fiber d) None

4. -------------------------------- has high dispersion at 1550 nm.
   a) G.652 b) G.653 c) G.655 d) None

5. ----------------- fiber the zero-dispersion point is shifted to the wavelength region 1550nm.
   a) G.652 b) G.653 c) G.655 d) None

6. The ------------------------ fiber is very much suitable for single wavelength 1550 nm but is unsuitable for DWDM systems.
   a) DSF b) NZDF c) None

7. The NZDSF fiber is very much suitable for operating the DWDM systems. (T/F)

8. Distribution fiber cables contain a number of fibers of individual 900-μm buffered fibers. (T/F)

9. Breakout cable contains buffered 900-μm fibers but every fiber is a sub-cable by itself. (T/F)

10. Ribbon fiber cables consists of 12 fibers side by side within a single jacket. (T/F)

11. Ribbon fiber cables are generally used for network applications. (T/F)

12. A loose tube buffer encloses multiple coated fibers surrounded by a gel compound to protect the cable from moisture and outside environment. (T/F)

13. Moisture resistance and temperature tolerance are the major factors while choosing materials for outdoor environment cables. (T/F)

Subjective:

List out the various type of Optical fiber cables and their applications.

Write the international standard sizes of SM and MM fibers.

Write different ITU-T recommended types of cables and their applications. (At least five different recommended types)

How do you identify the fibers and loose tubes? Name the color scheme.

Explain construction of optical fiber cable in brief.

What do you mean by ’ fiber curl ‘?

How an OFC acquires curl?

CHAPTER-5

OFC CABLE LAYING PRACTICES

5.1 Types of underground OFC cables

5.1.1 24F armoured cable

24 F armoured cables are used for underground laying. It consists of SIX loose tubes. They are colour coded as Blue, Orange, Natural 1, Natural 2, Natural 3 and Natural 4. Each loose tube contains FOUR fibers. The fibers are colour coded as Blue, Orange, Green and Natural.

5.1.2 12F armoured cable

12F armoured cable also used for underground and aerial laying purposes. It contains TWELVE single loose tubes. They are color coded as:

F1	Blue	F2	Orange
F3	Green	F4	Brown
F5	Slate	F6	White
F7	Red	F8	Black
F9	Yellow	F10	Violet
F11	Rose	F12	Aqua

The 48F, 96F aromured cables and 6F armoured and unarmoured cables are also available in the market**.**

5.2 Cable drum testing

Before laying every cable drum shall be tested. The normal length of drum is about 3 km. The drum number, length of the cable and running meters to be noted. All fibers shall be tested with OTDR and traces to be stored. The cable laying is avoided if any event or break is observed.

5.3 Site survey and estimation

The site survey is very important activity. It shall be done before preparing the estimate. The survey shall be done in THREE phases. The following observations are recorded during the survey by engineers.

Initial or First survey

- Initial/First survey by train with engineering drawing.
- Verify culverts, bridges and LC gates.
- Observe nature of land i.e. sand, black cotton soil, red soil, morrum and rocky.
- Prepare a chart with schedule items for rough estimation.

Second survey

- Second survey by trolley along with concerned PWI and S&T staff , at least one block
- Section per day.
- Take alignment along the Rly boundary.
- Note the off sets and existing cables en route.
- Note the places where cable requires protection with GI Pipe or RCC Pipe.

Third survey

- Third survey by foot with sufficient labors.
- Do the test pit for every 200 m and note down the nature of soil
- Compile the Estimation for one block section with 10-15% extra quantities.
- Prepare the proposed cable route drawing.
- Ensure the station yard, location boxes, signal posts, culverts and LC gates in the drawing.
- Submit drawings for engineering department for approval.

5.4 Laying of Optic fiber cable in trenches

5.4.1 Excavation

The excavation for trenching can be made either manually or by mechanical means.

Manual Excavation

The depth of the trench may be measured by a rule made of pipes as per drawing no. RDSO/TCDO/COP-11 given below:

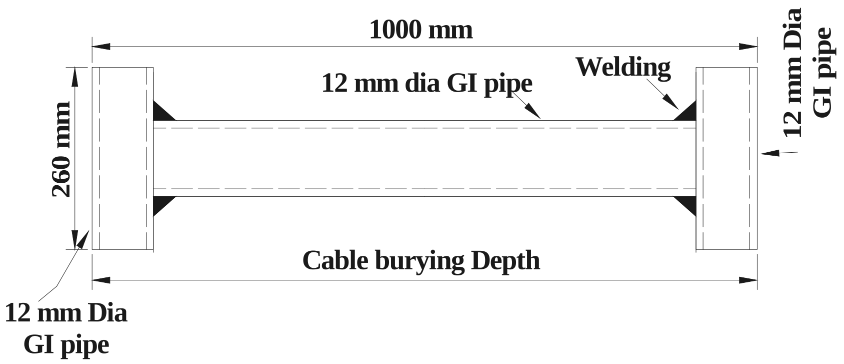


Fig 5.1 Depth of the trench in pipes as per drawing no. RDSO/TCDO/COP-11

When the surface of the ground where the trench is dug is slanting or uneven, the depth is measured with respect to lower edge.

Mechanical Excavation

Excavation of trench can also be done mechanically by loader backhoe (Escort 710X or similar) equipped with excavating bucket, cleaning bucket, back filling blade and lifting tackle.

After digging to specified depth, the bottom is leveled by removing the exposed stones or obstacles etc.

5.4.2 Laying of cable

In handling optic fiber cable, following cares shall be taken:

Cable shall normally be drawn out by hand. When using winch, tension should be monitored by a tension meter.

Cable shall be laid under a specified pulling tension, bending radius and pulling speed as shown below:

Item	Value
Pulling Tension	1.1 X W Kg.
Bending Radius	30 X D
Pulling Speed	Max. 15m/minute
W → Weight of cable per km. In kg. D → Outer diameter of cable.	

For effective and safe cable laying, communication may be provided between following points using portable VHF sets:

- Cable drum end
- Any intermediate manhole/diversion/track crossing through which the cable will be drawn.
- The winch/truck operator
- In charge of cable laying

Following necessary tools are to be checked before starting the optic fiber cable laying:

S.No.	Tool name	S.No.	Tool name	S.No.	Tool name
1	Cable jack	12	Flexible cable	23	Iron plate
2	Cable grip	13	Pulling rope	24	Loader backhoe for drilling
3	Reopening device	14	Brush	25	Warning tape
4	Free hood hook	15	Mandrel	26	Caterpillar tractor
5	Shackle free head hook	16	Chain	27	Fork lifter
6	Grouling hook	17	Measuring cord for strain gauge	28	Vehicle van type
7	Pulling bolt	18	Slip winch	29	Tachometer
8	Tension meter	19	Wire rope	30	Portable generator
9	Pulley	20	Portable VHF set	31	umbrella
10	Anti twist device	21	Measuring tape	32	Blank dark color cloth for splicing machine
11	Roller	22	Phawarah		

During cable laying care must be taken not to twist cable in any direction. For this purpose, the survival (Rotating hook) shall be attached between pulling line and pulling eye at the end of cable so as to avoid any possible twist during pulling and laying of the cable.

Whenever cable is to be laid in the duct (HDPE pipe or RCC pipe), suitable lubricant on cable may be used to reduce friction and consequently the tension on the cable.

In station yards where the cable is to be laid in zigzag route it is essential to use cable drums of smaller length.

Split RCC pipes may be use near over head sub-stations.

5.4.3 Preparation for Paying out cable

- Check the drum number and length of the cable.
- Entrust cable drum to the contractor after testing the fibers with OTDR for attenuation and ensure that no mechanical damage of the fiber exists.
- Place the cable jack to support the cable drum on a flat surface.
- Put spindle through cable drum and adjust cable jacks so that the drum may be clear 3-5 cm from the ground and the spindle may become horizontal. Remove logs of drum carefully with bar or other means to prevent damage to the cable.
- Pullout nails from legs or bend them for safe operation.
- Normally both end of the cable is provided with cable grip and pulling eye. In case, it is not already provided, fit the cable grip/pulling eye to the survival and pull the wires by means of shackle.

5.4.4 Laying of cable by winch

- Put rollers at an interval of 2-3 meter in the trench in fix position with longer rollers support portion facing the direction in which cable is to be pulled.
- At curve, put rollers in slanting position towards outside so that it may not tumble down during operation.
- Scratch pulling rope on rollers and fix its end on to winch.
- Use 2-3 ton winch and put it near the dugged trench. The winch shall be fastened at the back with wire to a pile driven into the ground to prevent it from moving out of place due to pulling tension that may arise during operation.
- Depute workman at winch, cable drum and in the trench and pull cable slowly into the trench by means of winch by using communication.

5.4.5 Laying of cable by hand

- Workmen, without use of winch and rollers, stretch the cable. Rope is pulled by 2 or 3 men and others hold the cable at the interval of 2 to 3 meters depending upon cable weight.
- When the cable is held on the shoulders, a suitable protection is needed to prevent its sharp bend.

5.4.6 Procedure for armoured OFC cable laying at site

- Cable should be laid by only experienced & skilled staff.
- Cable should be laid by placing the drum on a pay off stand at the site.
- Make a small cut with a knife on the outer sheath, armouring & inner sheath for tearing with the help of Rip Cord.
- To tear the sheath & Jacket, place the rip cord on the cut and pull it with a plier.
- Drum should be rotated as per the mark indicated on the drum.
- Minimum 3-4 persons should pull the cable with the maximum speed of 10 meter per minute.
- Pulling tension/force on the cable should not be exceeding 2670 Newton approximately 275 kg.
- Ensure that the cable should not get kinked while laying in trench or in ground
- Site should have wireless, flag etc for proper communication.
- While bending/rolling the cable, the bending radius should not be less than 200 mm.
- Attenuation and splice loss should be measured with OTDR.
- Parameters should be verified with supply details.

5.4.7 After laying OFC cable

Following items can be check after laying of cable:

- Confirm extra jointing length as required at both end.
- In case cable is damaged, take necessary preventive and remedial steps for removal of defects.
- If there is any snaking or rise in cable, put it right.
- Examine interior of the trench and remove any stones pebbles etc.
- Take protective step for such objects projecting into the trench such as sewer pipe etc.
- While laying one piece of cable, when the work is to be put off till the following day, keep the remaining portion of the cable wound on the drum. Reduce as much as possible the distance of the drum from already laid cable considering cable bending radius and general traffic safety. Ensure that drum is prevented from tumbling down or rolling away. Already laid cable shall be fully covered to avoid outside interference.

5.4.8 Cable markers

The cable markers are normally be provided at the distance of every 50 meters on the cable route and also at places or corner wherever the route of the cable changes. Joint indicators are provided at all types of cable joints.

5.4.9 Protection of Optic Fiber Cable at various places

Protection of cable crossing bridges/culverts

Drawing of protection for crossing culverts with high flood level as per RDSO/TCDO/COP-16 is shown below:

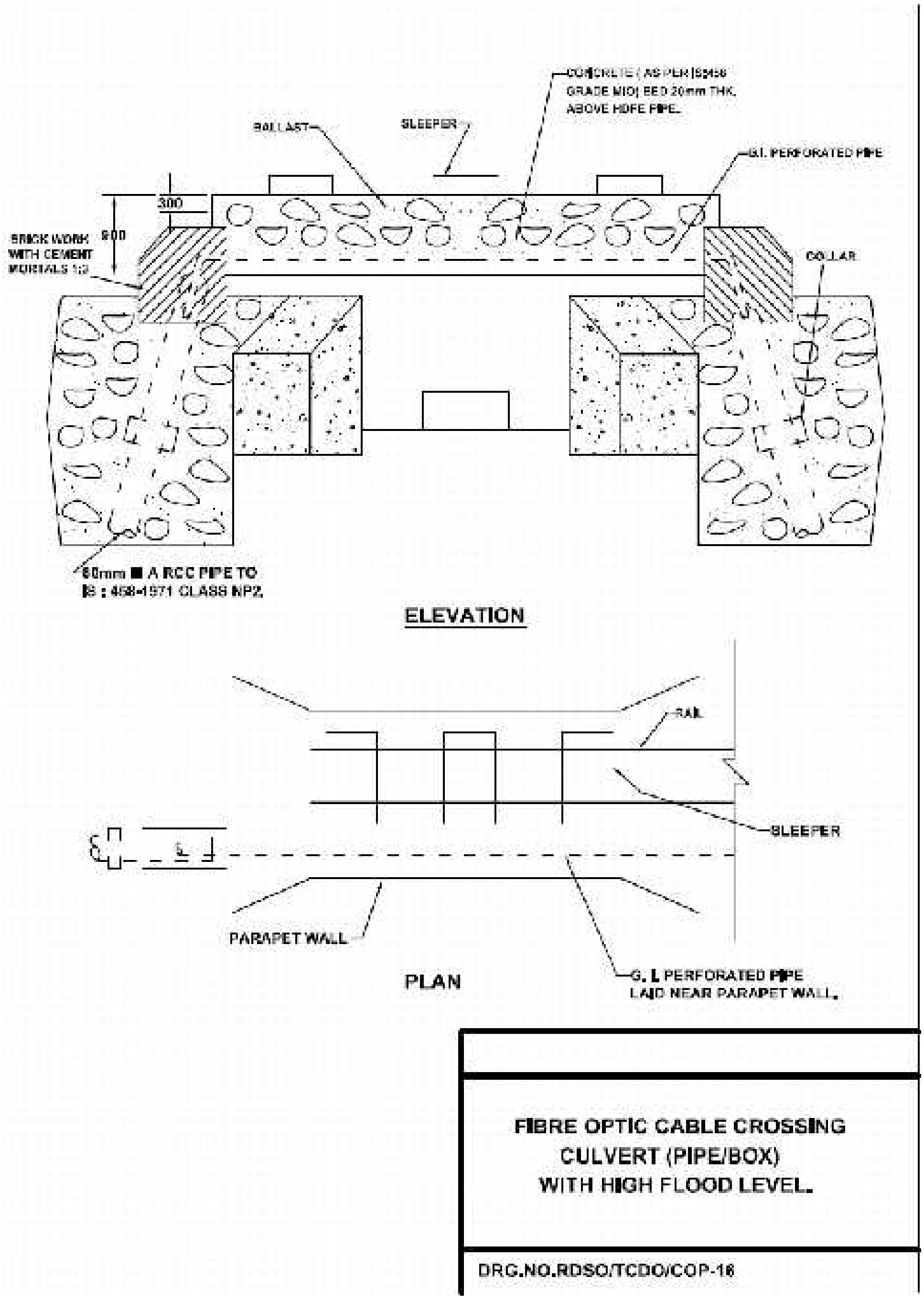
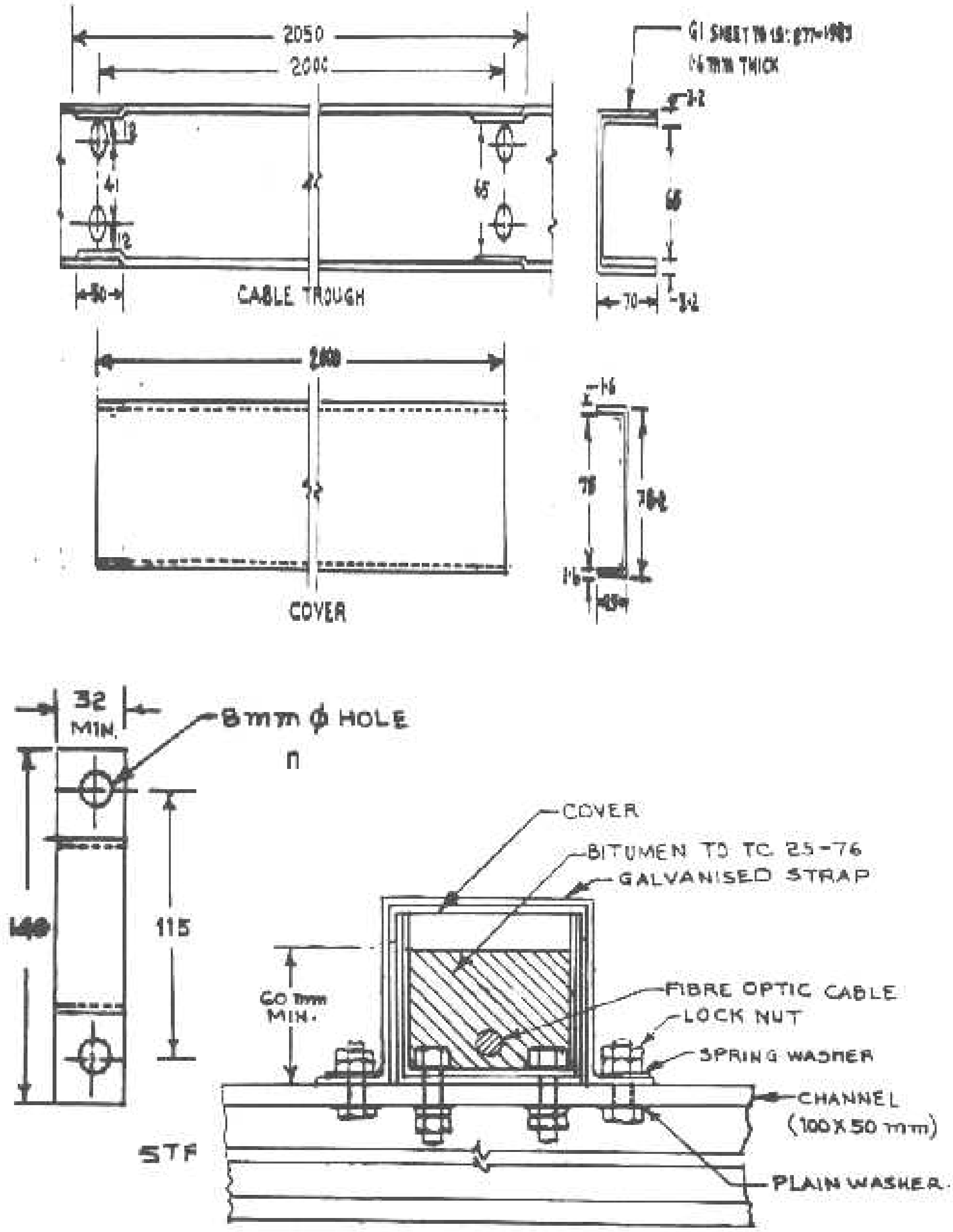


Fig 5.2 Drawing of protection for crossing culverts with high flood level as per RDSO/TCDO/COP-16

Drawing of arrangement of cable troughs and channel for girder bridges and major culverts as per RDSO/TCDO/COP-12 is shown below:



SCHEDULE OF MATERIALS		
S.NO.	DESCRIPTION	NO. REQD
1.	TROUGH 2.05 METRES LONG	1
2.	COVER 2.0 METRES LONG	1
3.	STRAP	2
4.	BOLT HEX. HEAD 6mm ϕ X 32 mm	4
5.	NUT FOR ABOVE	4
6.	LOCK NUT FOR SL4	4
7.	DISH WASHER FOR SL-5	4
8	PLAIN WASHER FOR SL-5	4

Fig 5.3 : Drawing of arrangement of cable troughs and channel for girder bridges and major culverts as per RDSO/TCDO/COP-12

Drawing of crossing major culverts (high flood level and normally blocked by water) and major bridges by steel troughs at rail level as per RDSO/TCDO/COP-14 is shown below:

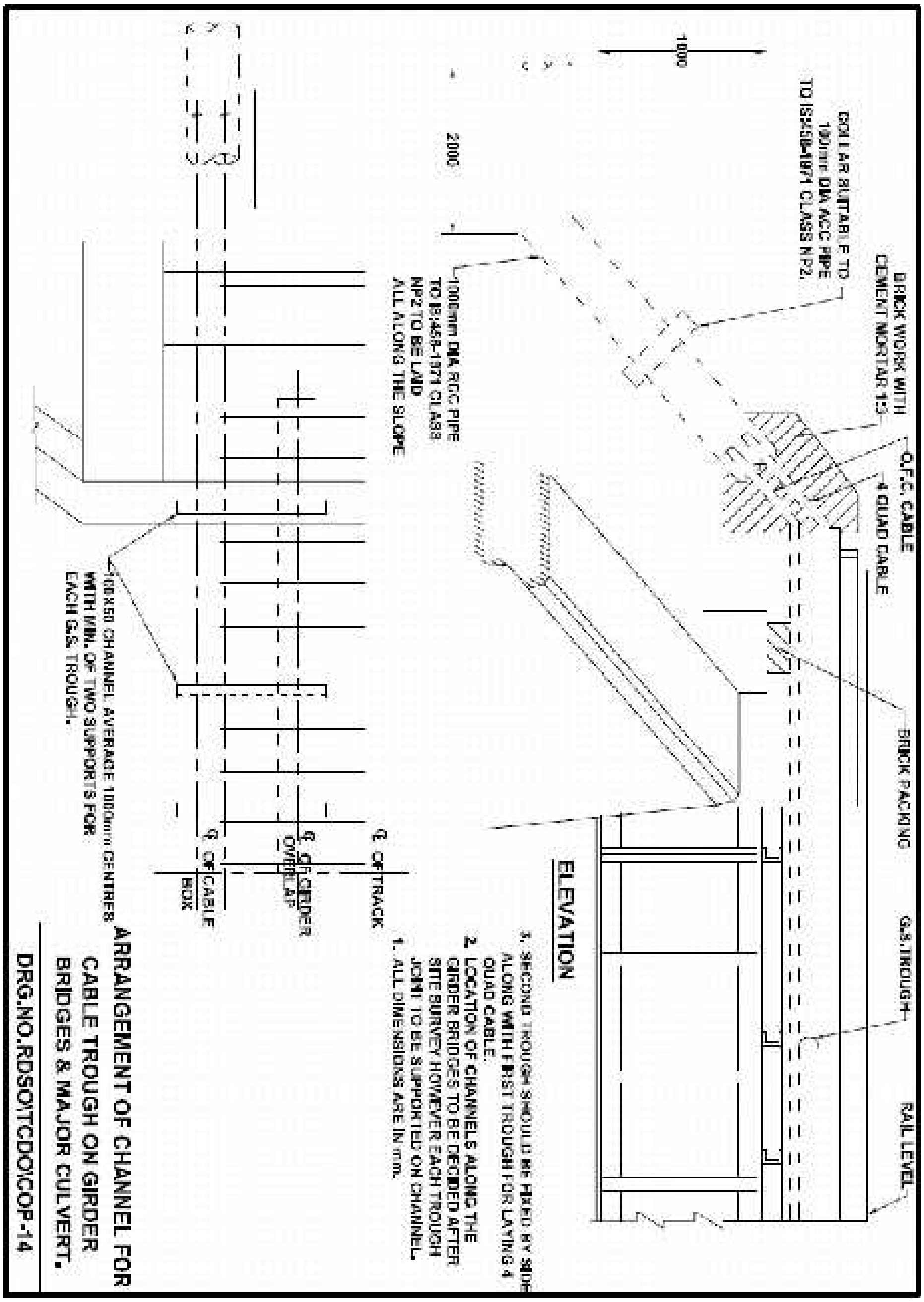


Fig No 5.4 : Drawing of crossing major culverts (high flood level and normally blocked by water) and major bridges by steel troughs at rail level as per RDSO/TCDO/COP-14

Measure against theft of steel troughs

- As per drawing RDSO/TCDO/COP-12, steel troughs are to be provided on the channels for major culverts and bridges.
- In order prevent theft of OFC steel troughs with optic fiber cable should be filled up by bitumen compound. The cover of the trough to be effectively secured.
- Bitumen filling job should be supervised by SSE.
- In order that the temperature of the cable does not increase beyond 55 C, bitumen compound should be poured in the early hours/late hours of day when the ambient temperature is around 18 C or less.
- While pouring the heated bitumen compound, steel trough covers should be removed throughout the bridge to permit fast cooling.
- Before pouring bitumen compound its temperature should be accurately measured to ensure that the poring temperature is not more than 140 C.
- The bitumen compound should be filled up to a height of approximate 60-mm.

Arrangement across culverts

- Most of the culverts are generally dry and as such the arrangement as shown in RDSO/TCDO/COP-16 can be adopted.
- For culverts which are normally filled with water or which are having high flood level, the protection arrangement as shown in RDSO/TCDO/COP-16 can be adopted.

Arrangement for laying of OFC across girder bridges

- Girder bridges up to span length of 12 meter
- The same arrangement can be followed for girder bridges of span length between 6 to 12 meter where an intermediate support to GI pipe can be provided.
- Girder bridges of span length more than 12 m.
- The crossing of girder bridges of more than 12 meters length can be done as shown in No. RDSO/ TCDO/COP-14.
- The procedure for filling bitumen compound is as described in para 4.1.2 above.
- Separate trough for laying 4 quad cables should be used.

Protection arrangement on the cable route

The typical drawing of cable trenches under various situations are described earlier. These drawings include the protection arrangement of brick provided along with the cable route. These protection arrangements are summarized below.

- The cable laid in station yard and on the embankment, after covering the armour OFC with riddled earth, B class bricks to be laid transversely throughout over the cable laid in the station yard / embankment.
- The cable marker shall normally be provided at the distance of every 50 meter of the cable route and cable joints.

Cable crossing tracks and level crossing gates

- In such cases the cable shall be laid in HDPE pipe keeping the depth same as in normal routes.

- In case of cable crossing the LC gates, HDPE pipe may be laid on the road and for a distance of at least 2 meters from the either side of the road.

- Minimum depth at any track crossing shall not be less than 1.0 meter with RCC/ Steel/HDPE pipe. In case of cable crossing the track, it may be ensure that cable should not be bent less than 600 mm radius. Suitable fixture with HDPE pipe should be provided to ensure the proper binding radius to be used at each end.

- The drawing for track crossing, road crossing, on platform is shown below as per drawing no. RDSO/TCDO/COP-19.

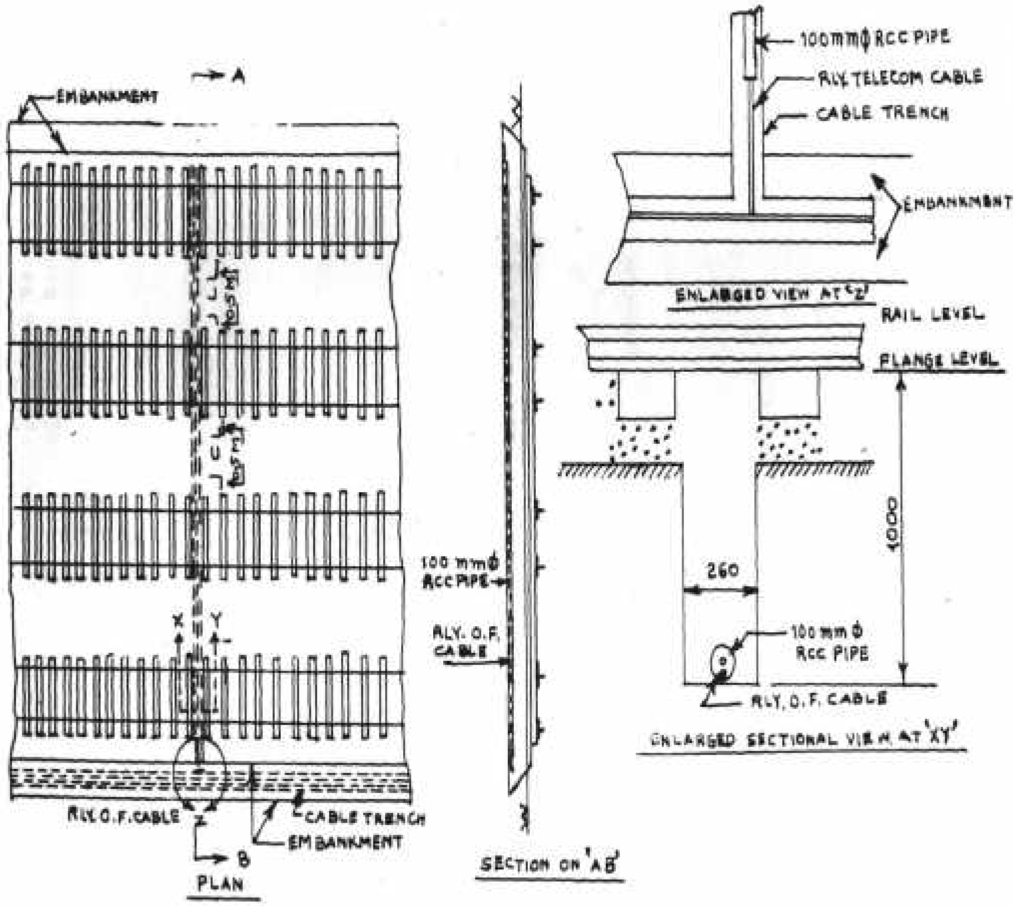


Fig 5.5 Drawing for track crossing, road crossing, on platform is shown below as per drawing no. RDSO/TCDO/COP-19

Arrangement of RCC pipe under metalled road is shown below as per drawing no. RDSO/TCDO/ COP-20.

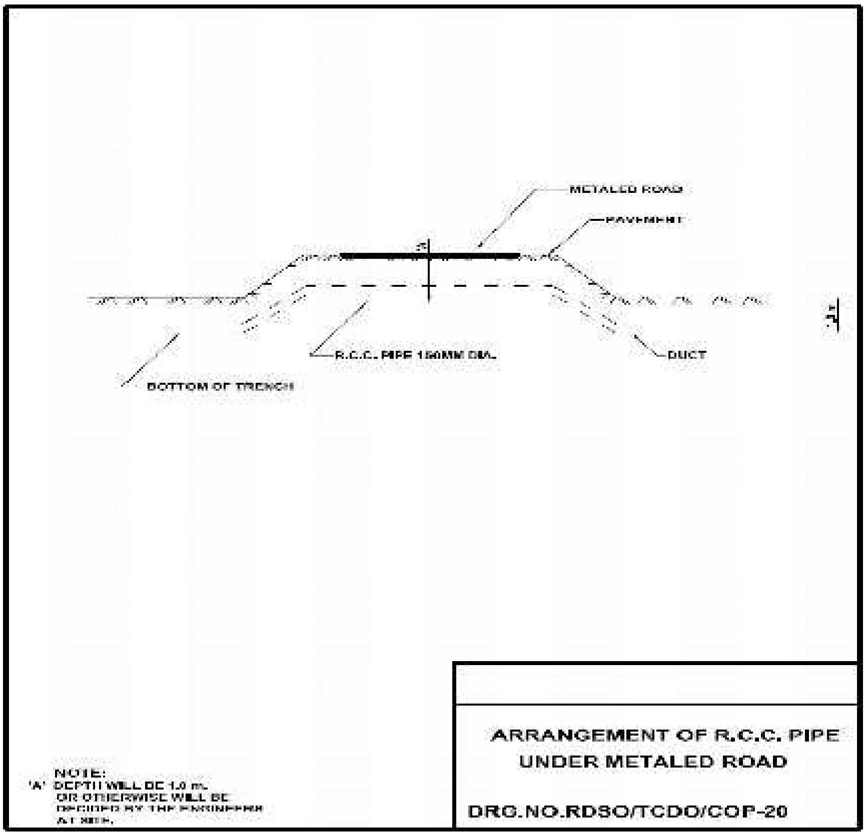


Fig No 5.6 Arrangement of RCC pipe under metalled road is shown below as per drawing no. RDSO/TCDO/ COP-20

5.4.10 Back filling of trenches

For back filling of cable trenches following precautions shall be taken.

- At least 120 mm from the surface of the last cable, cable should be covered with riddled earth. This portion of the of the earth should be rammed properly so that the earth is not loose. This will also prevent entry of rodents and other insects.
- For the remaining portion of the trenches, the released earth may be used. However, after filling up the trench, the earth shall be consolidated by ramming.
- Re-filling of trench and ramming shall be supervised by a responsible supervisor and also at officer level for the specified percentage of the section.
- It shall be ensured that before the start of monsoon session, all open trenches are properly back filled to avoid water logging of the trench.

Objective:

1. The normal optic fiber cable drum length is --------------------------.
   a) 2 Km b) 3 Km c) 1 Km d) 4 Km

2. 12-fiber armoured optic fiber cable can be used for -----------------------laying.
   a) Underground as well as for aerial b) Only Underground
   c) Only Underground d) only aerial

3. The 12-fiber armoured optic fiber cable contains -------------------------------.
   a) 2 loose tubes b) 3 loose tubes c) 12 single loose tubes d) 4 loose tubes

4. Cable markers are normally provided at every --------------------------- meters on the cable route.
   a) 5 b) 10 c) 150 d) 50

5. After laying the optic fiber cable at least ----------------------- mm from the surface of the cable should be covered with riddle earth.
   a) 1200 b) 12000 c) 120 d) 1120

6. The minimum depth of the trench at any crossing for optic fiber cable should not be less than one meter. (T/F)

7. In case of optic fiber cable crossing the LC gates, HDPE pipe should be laid on the road for a distance of at least 2 meters from either side of the road. (T/F)

8. In case of optic fiber cable crossing the track, it is to be ensured that the cable shall not be bent less than 600 mm radius. (T/F)

Subjective:

1. Write the short notes on 24 F and 12 F armoured cable.
2. Is Cable route survey required? Justify your answer.
3. What are the different phases of survey? Explain what you do in each phase
4. Write check points after laying Optical fiber cable.

CHAPTER-6

JOINTING AND TERMINATION OF OFC

6.1 Methods for jointing of fibre optic cable

There are two methods for jointing Optical fibre cable. They are splicing or by using connectors. The splicing is further divided into two methods. They are mechanical splicing and fusion splicing. Splicing is the process of connecting two bare fibers directly without any connectors. Both methods provide much lower insertion loss compared to fiber connectors.

- Fiber mechanical splicing – Insertion loss < 0.5dB
- Fiber optic cable fusion splicing – Insertion loss < 0.1dB

6.1.1 Mechanical Splicing

This aligns the axis of the two fibres to be jointed and physically hold them together (See figure 6.1). Mechanical splicing can be used for temporary splicing of fibres or where fusion splicing is not possible or undesirable.

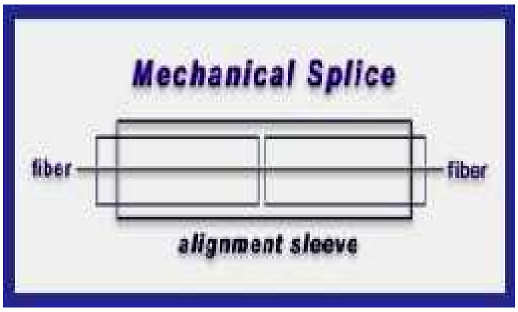


Figure 6.1 Mechanical Splice in OFC

6.1.2 Fusion Splicing

This is accomplished by applying localized heating (i.e. by electric arc or flame) at the interface between two butted, pre-aligned fibre ends, causing them to soften and fuse together (See figure 6.2).

During initial installation, fusion splicing should be adopted at all locations of fibre optic cable.

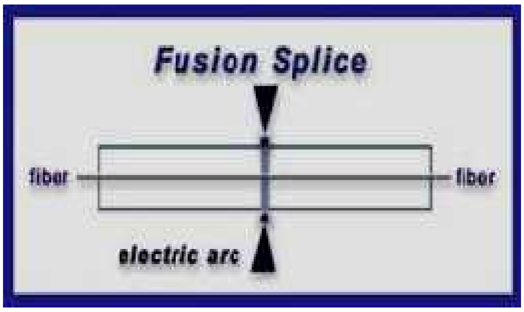


Figure 6.2 Fusion Splice in OFC

6.2 Straight joint for fibre optic cable

There are various types of joint enclosure available in the market. The procedure for assembly of joint closure is described in the installation manual supplied with straight joint closure. This includes the following:

- Material inside joint closure kit.
- Installation tools required.
- Detailed procedure for cable jointing.
- Procedure for reopening the closure.

However, generally, the following steps are involved for jointing of the cable:

- Preparation of cable for jointing
- Stripping / cutting of cable
- Preparation of cable and joint closure for splicing.
- Stripping and cleaving of fibres.
- Fibre splicing.
- Organising fibres and finishing joints.
- Sealing of joints closure
- Placing joint in pit.
- Reopening of the joint

Some of the general steps in most of the types of joint closure are as discussed Further.

6.2.1 Preparation of cable for jointing:

- During the installation a minimum of 10 meter of cable of each end is coiled in the jointing pit to provide for jointing to be carried out at convenient location as well as spare length to be available for future use in case of failures.

- The pit size must be choosen carefully to ensure the length of the wall on which joint is mounted is greater then closure length plus twice the minimum bending radius of the cable. A pit length of 1 meter is sufficient for most of the cable and joint closure. Bracket to support the cable coil are also fixed on the wall of the pit.

- The cable is then coiled on to the pit wall in the same position as required after the joint is complete. The marking is done on all the loops so that it will be easier to install it later.

- This distance firm the last centre to the end of the cable must be at least 1.8 meters. This is the minimum length to be stripped for preparation of joint.
- Sufficient cable from each end up to the jointing vehicle / enclosure is then uncoiled from the pit for jointing.

6.2.2 Stripping / cutting of the cable:

- The cables are stripped of their outer and inner sheath with each sheath staggered approximately 10 mm from the one above it.
- Proper care must be taken when removing the inner sheath to ensure the fibres are not scratched or cut with the stripping knife or tool. To prevent this, it is best to only score the inner sheath twice on opposite sides of the cable. Rather than cut completely through it. The two scores marking on either side of the cable are then stripped of the inner sheath be hand quite easily.
- The fibers are then removed from cable one by one and each fibre is cleaned individually using kerosene to remove the jelly.

6.2.3 Preparation of cable joint closure for splicing:

The type of preparation work performed by the cable prior to splicing differs on the type of joint closure and fibre organizer used. However, the following steps are usually common:

- The strength members of each cable are joined to each other and or the central frame of the joint closure.
- The joint closure is assembled around the cable.
- The sealing compound or heat shrink sleeve is applied to the cables and closure or prepared for application after splicing is complete.
- The fibres are protected (usually with plastic tubing) in their run from the cables core to the fibre organizer trays (particularly if cable construction is slotted core type).
- Tags, which identify the fibres nos., are attached at suitable location on the fibres.
- Splice protectors are slipped over each fibre in readiness for placing over the bare fibre after splicing.

6.2.4 Stripping and cleaving of fibre:

- Prior to splicing each fibre must have approximately 50 mm of its primary protective U.V. cured coating removed. Using fibre stripper, which is, manufactured to fine tolerances and only score the coating without contacting the glass fibre.
- The bare fibre is then wiped with lint free tissues doused with isopropyl alcohol.
- Cleaving of the fibre is then performed to obtain as close as possible to a perfect 90° face on the fibre.

6.3 Splicing of the fibre:

As discussed above there are two types of splicing methods, which can be used for fibre splicing. Some of the basic steps for both the types are discussed further.

6.3.1 Mechanical splicing of the fibre

In this there are two types of splicing system. One with precision alignment of fibre in "V" groove and fibre ends are sealed with some index matching fluid and adhesive (See figure 6.3). The other system uses ultrasonic light source for curing optical adhesive in addition to alignment etc.

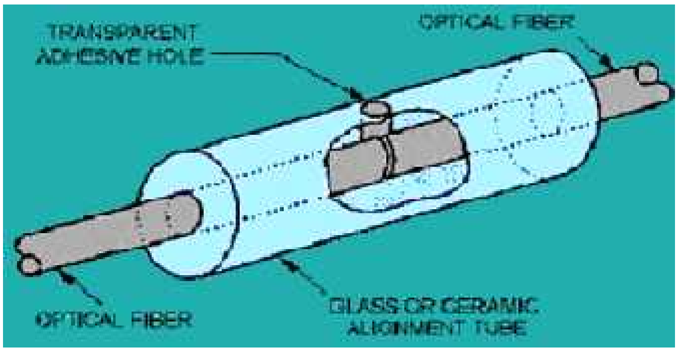


Figure 6.3 Mechanical splice Technique

The general steps involved for the above are as under:

- Stripping and cleaving of fibres is done as mentioned earlier.
- Remove protective end cap from mechanical splice and pull vent tube.
- Inject adhesive as specified by supplier in to splice.
- Insert fibre until it butts against fibre end already bounded in place.
- Cure adhesive with UV light following exposure times as indicated by supplier.
- Repeat the same procedure for all the fibres

6.3.2 Fusion splicing of fibre

Some of the general steps with full automatic microprocessor control splicing machine (See figure 6.4) are discussed further.

Figure 6.4 Fusion splicing technique

- Wash hands thoroughly prior to commencing this procedure.

- Dip the clean bare fibre in the beaker of ethyl alcohol of the ultrasonic cleaver. Switch on ultrasonic cleaver for 5-10 seconds (some of the manufacturers do not prescribe the above cleaning).

- Insert the bare fibre inside V grove of the splicing machine by opening clamp handle such that the end of fibre in app. 1 mm. over the end of the “V” groove towards the electrodes.

- Repeat the same procedure for the other fibre. However, first insert heat shrink splice protector.

- Press the start button on the splice controller.

- The machine will pre fuse. Set align both in X and Y direction and then finally fuse the fibre.

- Inspect the splice on monitor if provided on the fusion-splicing machine and assure no picking & bulging is there and cores appear to be adequately aligned. If the splice does not visually look good repeat the above procedure.

- Slide the heat shrink protector over the splice and place in tube heater. Heat is complete when soft inner layer is seen to be oozing out of the ends of the outer layer of the protector.

- Repeat the same procedure for all the fibres.

6.3.3 Organizing fiber and finishing joints:

- After each fibre is spliced and the heat shrink protection sleeve must be slipped over the bare fibre before any handling of fibre takes place as uncoated fibres are very brittle and cannot withstand small radius bends with out breaking.

- The fibre is then organized into its tray be coiling the fibre on each side of the protection sleeve using the full tray side to ensure the maximum radius possible for fibre coils.

- Then trays are placed in the position.

- OTDR reading are taken for all splice in this organized state and recorded on the test sheet to confirm that all fibres attenuation are with in spliced limit. This OTDR test confirms that fibres were not subjected to excessive stress during the organizing process.

- After this the joint can be closed with necessary sealing etc. and ready for placement in pit.

6.3.4 Placing of completed joint in pit:

Joint is taken out from the vehicle and placed on the tarpaulin provided near the pit.

The cable is laid on the ground, loop the cable such that pen mark previously place on the cable line up. Tape these loops together at the top of the coil.

The joint can now be permanently closed and sealed by heating the heat shrinkable sleeve etc.

Now the joint closure is fixed to the bracket on the pit wall and pit is closed.

6.3.5 Re-opening of the joint:

If required for attending faults manufacturers supply special kits for opening of the joint and the steps to be followed. However, the general steps are as under.

- Using suitable knife cut heat shrink sleeve longitudinally along its entire length.
- Do not damage the smaller heat shrunk sleeve on the ends of the joints.
- Apply heat to the cut sleeve until it begins to separate.
- Gently remove the cut sleeve from the joint. Now the joint can be opened.
- Protective sleeve cover can be removed for attending to faults etc.

6.4 General steps of Termination joint for fibre optic cable:

This joint is provided in the cable hut to terminating the outdoor fibre optic cable of both the sides. Splicing through fibres. Connecting fibres to pigtails for connection to optical line terminal equipment etc.

The procedure for installation of termination joint box depends upon the type of joint enclosure. The installation manual, give the step by step procedure for installation. However, the general steps are as under:

- Marking the cable
- Stripping/cutting the cable
- Gripping cable in sheath / clamp
- Treatment of tension member
- Fibre splicing
- Enclosing fibre
- Fixing strength member
- Closing the cover
- Fixing termination box
- Fixing the cable

6.4.1 Marking the cable:

Determine the cable length up to the proposed location of termination box. It is also to be ensured that at least 10 meters of cable is coiled in the cable pit. Determine the cutting point and mark the cable. Determine the length of sheath peeling point and mark the cable.

6.4.2 Cutting/stripping of the cable:

Cut the cable as per the marking. Remove the sheath from cable ends. During sheath stripping care should be taken not to damage the fibres. The length and the steps for various sheath cutting shall be as per instructions given in the manual.

6.4.3 Gripping the cable:

Wind PVC tape around the cable core just beside edge of the sheath. Insert the bushing inside sheath by cutting the cable sheath for about 25 mm. Place the sheath grip (lower half and upper half) and tighten it with the help of torque wrench.

6.4.4 Fixing of tension member:

Mark the tension member for the specified length and cut it. Clean the tension member thoroughly by Alcohol and cotton cloth. Fix tension member holder with the help of instant adhesive at the end of tension member.

6.4.5 Enclosing fibres:

Set the fibre cassette on the base. Arrange excess length of fibre to make double figure of eight. Enclose the spliced fibre and its excess length carefully. Repeat the procedure for other fibres.

6.4.6 Mounting of termination box:

Termination box can be fixed either on wall or on equipment rack. Mark the fixing holes on the walls/bracket/ frame. Place the termination box and tightened the nuts inside the base box. Put the covers and provide Silica gel.

6.4.7 Fixing the cable:

Secure the cable on wall / frame at two places within one meter from termination box keeping in view straight entry of cable in termination box.

6.4.8 Tools required and their functions

Tools required for sheath Removal are as shown in table below.

S.No.	Name of tool	Function
1	Cable cutter	To cut the cable in full
2	Jacket remover	To remove outer jacket
3	Utility knife	To cut narrow jacket circumferentially
4	Scissors	To cut rip cord, Aramid yarn, Binders, fibres etc.
5	Diagonal cutting pliers	To cut central members, fillers etc.
6	Sheath Ripper	To cut the polythene binders
7	Vinyle insulation tape	For proper marking of cable
8	Gel off paper	To clean the jelly
9	Towel cloth	To clean the cable
10	Number Book	For cable and buffer tubes identifications
11	Measuring Tape	For different length measurements

12	Buffer Stripper	To strip the buffer tubes
13	Paint Marker	To mark on cable

6.4.9 Tools required for fusion splicing are as shown in table below.

S.No	Name of tool	Function
1	Fibre Stripper	To strip the plastic cover coating of the fibre
2	Fibre Cleaver	To cut the fibre end perpendicular to the axis
3	Tissue Papers	To clean the fibre after stripping
4	Cleaning liquid	To clean the fibre and splicing machine's lens, V groove etc.
5	Jewellers Screw	To adjust some potentiometer in fusion splicing machine
6	Cotton swab	To clean the fibre and splicing machine's lens, V groove etc.
7	NO-NIK Tool	To remove white colour coating of tight buffer tube
8	Flash Light	To test the pig tails (tight buffer tube)

6.4.10 Tools required for preparation of splicing - closures are as shown table below.

S.No	Name of tool	Function
1	Tensioning Tool	To tight the clamping bends over the ends caps, clamping bars etc.
2	Opening Hook	To open the closure (used with tensioning tool)
3	Screw Drivers	To tight and loose the screw nuts etc.
4	Adjustable Wrench	To tight nuts and bolts in supporting bars.
5	Hammer	To open and close the clamping bars.
6	Tie-raps	To tie the buffer tubes into splice tray.
7	Tie-rap Fastner	To tie the buffer tubes into splice tray.
8	RTV Sealant	To tight the Tie-rap.
9	Tweezer	To lift and hold the fibre.
10	Spatula	To set the fibre splices into splice tray organiser.
11	Crocus Cloth	To clean the cable outer jacket.
12	Crimping Pliers	To fix the buffer tubes in splice tray.

6.5 Fiber Optic Connectors

More than a dozen types of fiber optic connectors have been developed by various manufacturers since 1980s. Although the mechanical design varies a lot among different connector types, the most common elements in a fiber connector, their parts and characterstics are summarized below.

6.5.1 Basic about connectors

Fiber optic connector facilitates re-mateable (disconnection or reconnection) connection. The connectors are used in following applications.

- Flexibility is required in routing an optical signal
- To couple the signal from sources to receivers
- Reconfiguration is wherever required
- Termination of cable is required

The connector consists of different parts (see figure 6.5)

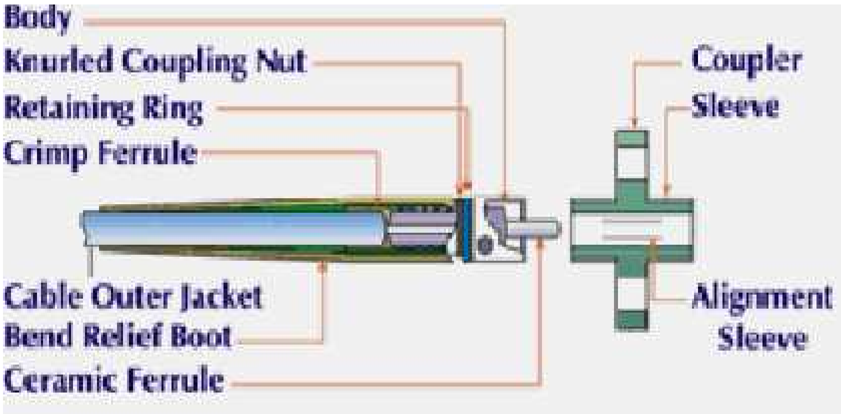


Figure 6.5 Parts of the connector and description

- **Ferrule**

  The fiber is mounted in a long and thin cylinder ferrule which acts as a fiber alignment mechanism. The ferrule is bored through the center at a diameter that is slightly larger than the diameter of the fiber cladding. The end of the fiber is located at the end of the ferrule. Ferrules are made of metal or ceramic or plastic.

- **Connector housing body**

  The connector body holds the ferrule. It is usually constructed of metal or plastic and includes one or more assembled pieces which hold the fiber in place. The details of these connector body assemblies vary among connectors. But bonding and crimping is commonly used to attach strength members and cable jackets to the connector body. The ferrule extends past the connector body to slip into the coupling device.

- **Cable**

  The cable is attached to the connector body. It acts as the point of entry for the fiber. A strain – relief boot is added over the junction between the cable and connector body to provide extra strength.

- **Coupling device**

  Most of the fiber optic connectors do not use the male – female configuration as electronic connectors. Instead, a coupling device such as an alignment sleeve is used to mate the connectors. Similar devices may be installed in transmitters and receivers to allow these devices to be mated via a connector. These devices are also known as feed through bulkhead adapters.

6.5.2 Characterstics of connectors

- **Insertion loss**

  This insertion loss is due to use of connectors which is unavoidable. The manufacturers specify typical value. The insertion loss can be minimised by using a strain relief boot over the junction between the cable and connector body and strength member to the connector minimize the insertion loss.

- **Repeatbility**

  Connector is re – useable upto 500 times. The increase in loss shall be less than the repeatability loss.

- **Suitability**

  This character decides whether connector is suitable for Single mode or Multimode Fiber.

- **Return loss**

  This is important factor for single mode fibers. It should be less than 60 dB.

6.6 Different types of connectors

6.6.1 FC connector (Ferrule Centered)

FC connector (see figure 6.6) also has a 2.5mm ferrule (made of ceramic (zirconia) or stainless alloy). It is specifically designed for telecommunication applications and provides non-optical disconnect performance. Designed with a threaded coupling for durable connections. It has been the most popular single mode connectors for many years. Simplex only, screw-on mechanism. Available in single mode and multimode.

Figure 6.6 FC connector

FC connector characteristics

Insertion loss	Repeatability	Fiber type	Application
0.5 to 1.0 db	0.20 db	SM / MM	Transmission NW

However it is now gradually being replaced by SC and LC connectors.

6.6.2 SC Connectors (Subscription Connector)

SC was developed by NTT of Japan. It is widely used in single mode applications for its excellent performance. SC connector is a non-optical disconnect connector with a 2.5mm pre-radiused zirconia or stainless alloy ferrule. It features a snap-in (push-pull) connection design for quick patching of cables into rack or wall mounts. Two simplex SC connectors can be clipped together by a reusable duplex holding clip to create a duplex SC connector. Simplex (see figure 6.7) and duplex (see figure 6.8), snap-in mechanism in single mode and multimode SC connectors available.

Figure 6.7 SC Connector and Adaptor - simplex

Simplex SC connector characteristics

Insertion loss	Repeatability	Fiber type	Application
0.2 to 0.45 db	0.10 db	SM / MM	Transmission NW

Figure 6.8 SC connector and adaptor - duplex

Duplex SC connector characteristics

Insertion loss	Repeatability	Fiber type	Application
0.2 to 0.45 db	0.10 db	SM / MM	Transmission NW

- **Elements in a SC connector**

Elements in a SC connector (see figure 6.9) are discussed in detailed.

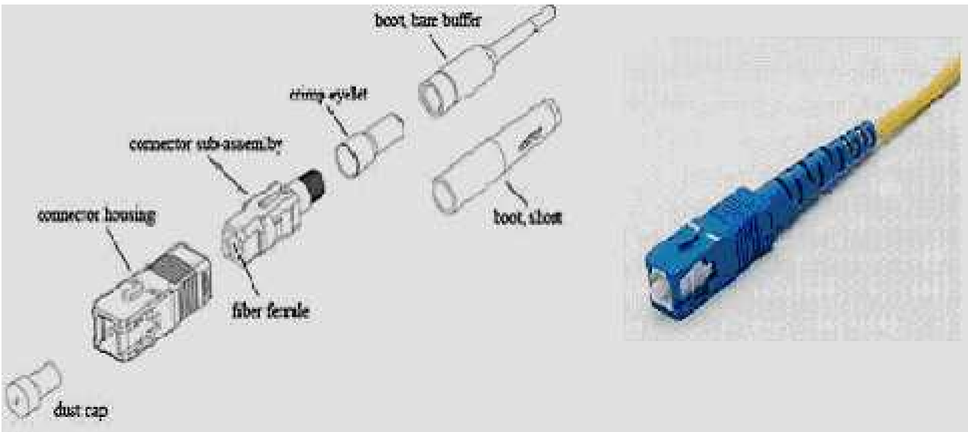


Figure 6.9 SC connector parts

- **SC connector fiber ferrule**

  SC connector is built around a long cylindrical 2.5mm diameter ferrule (see figure 6.10), made of ceramic (zirconia) or metal (stainless alloy). A 124~127um diameter high precision hole is drilled in the center of the ferrule, where stripped bare fiber is inserted through and usually bonded by epoxy or adhesive. The end of the fiber is at the end of the ferrule, where it typically is polished smooth.

Figure 6.10 Fiber ferrule

- **Connector sub-assembly body.**

  The ferrule is then assembled in the SC sub-assembly body which has mechanisms to hold the cable and fiber in place. The end of the ferrule protrudes out of the sub-assembly body to mate with another SC connector inside a mating sleeve (also called adapter or coupler).

- **Connector housing**

  Connector sub-assembly body is then assembled together with the connector housing. Connector housing provides the mechanism for snapping into a mating sleeve (adapter) and hold the connector in place.

- **Fiber cable**

  Fiber cable and strength member (aramid yarn or Kevlar) are crimped onto the connector sub-assembly body with a crimp eyelet. This provides the strength for mechanical handing of the connector without putting stress on the fiber itself.

- **Stress relief boot**

  Stress relief boot covers the joint between connector body and fiber cable and protects fiber cable from mechanical damage. Stress relief boot designs are different for 900um tight buffered fiber and 1.6mm~3mm fiber cable.

6.6.3 LC connector (Lucent Connector)

Externally LC connectors resemble a standard RJ45 telephone jack. Internally they resemble a miniature version of the SC connector. LC connectors use a 1.25mm ceramic (zirconia) ferrule instead of the 2.5mm ferrule. LC connectors are licensed by Lucent and incorporate a push-and-latch design providing pull-proof stability in system rack mounts. Simplex and duplex connectors available in market. Highly useful for single mode applications.

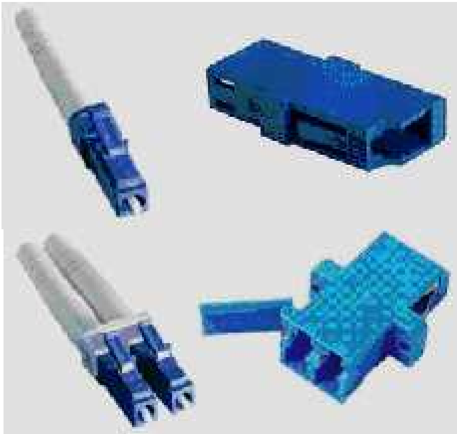


Figure 6.11 LC connector and adaptor -simplex and duplex

LC connecter characteristics

Insertion loss	Repeatability	Fiber type	Application
0.15 db (SM) 0.10 db (MM)	0.20 db	SM / MM	High density interconnection

6.6.4 FDDI Connector (Fiber Distributed Data Interface)

FDDI connector (see figure 6.12) utilizes two 2.5mm ferrules. The ferrules are sheltered from damage because of the fix shroud that has been constructed in the FDDI connector. FDDI connector is a duplex multimode connector designed by ANSI and is utilized in FDDI networks. FDDI connectors are generally used to connect to the equipment from a wall outlet, but the rest of the network will have ST or SC connectors.

Figure 6.12 FDDI connector

FDDI connector characteristics

Insertion loss	Repeatability	Fiber type	Application
0.2 to 0.7 db	0.20 db	SM / MM	FDDI LAN (Fiber distributed data interface)

6.6.5 ST connector (Straight Tip)

Simplex only, twist-on mechanism. Available in single mode and multimode. It is the most popular connector for multimode fiber optic LAN applications. It has a long 2.5mm diameter ferrule made of ceramic (zirconia), stainless alloy or plastic. It mates with an interconnection adapter and is latched into place by twisting to engage a spring-loaded bayonet socket.

Figure 6.13 ST Connector and Adaptor (mating sleeve)

ST connector characteristics

Insertion loss	Repeatability	Fiber type	Application
0.40 db (SM) 0.50 db (MM)	0.40 db (SM) 0.20 db (MM)	SM / MM	Inter/Intra Building

6.6.6 MT array connector (Mechanical Transfer)

MT-RJ connector (see figure 6.14), duplex only, multimode only. (not 1.25mm ferrule, but rather a two-fiber ferrule design derived from MT). Overall size is about the same as a RJ45 connector.

MT-RJ connector is derived from MT ferrule design. It has a miniature two-fiber ferrule with two guide pins parallel to the fibers on the outside. The guides pins align ferrules precisely when mating two MT-RJ connectors. MT-RJ connectors are designed with male-female polarity which means male MT-RJ connector has two guide pins and female MT-RJ connector has two holes instead.

MT-RJ connectors are used in intrabuilding communication systems. Since they are designed as plugs and jacks, like RJ-45 telephone connectors, adapters can be used with some designs, but are not required for all.

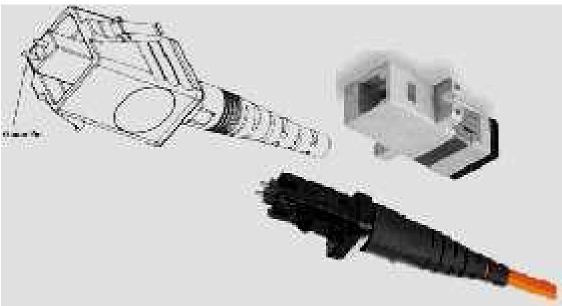


Figure 6.14 MT – RJ connector and adaptor

MT array connector characteristics

Insertion loss	Repeatability	Fiber type	Application
0.25 to 1.0 db	0.25 db	SM / MM	Ribbon fiber cables

6.6.7 ESCON connector

ESCON connectors (see figure 6.15) derive their name from their original application, IBM's enterprise system connection (ESCON) for mainframe computers. ESCON connectors are similar to FDDI connectors, but contain a retractable shroud instead of a fixed shroud. ESCON connectors have two 2.55 mm ceramic ferrules and a robust strain relief design.

Figure 6.15 ESCON Connector

6.6.8 E2000 connector

E2000 connector. 1.25mm ferrule, snap-in mechanism. Also called LX.5 connector. Available in single mode and multimode.

Externally an E2000 connector (see figure 6.16) looks like a miniature SC connector. The connector is easy to install, with a push-pull latching mechanism which clicks when fully inserted.

It features a spring-loaded shutter which fully protects the ferrule from dust and scratches. The shutter closes automatically when the connector is disengaged, locking out impurities which could later lead to network failure, and locking in potentially harmful laser beams. When it is plugged into the adapter the shutter opens automatically.

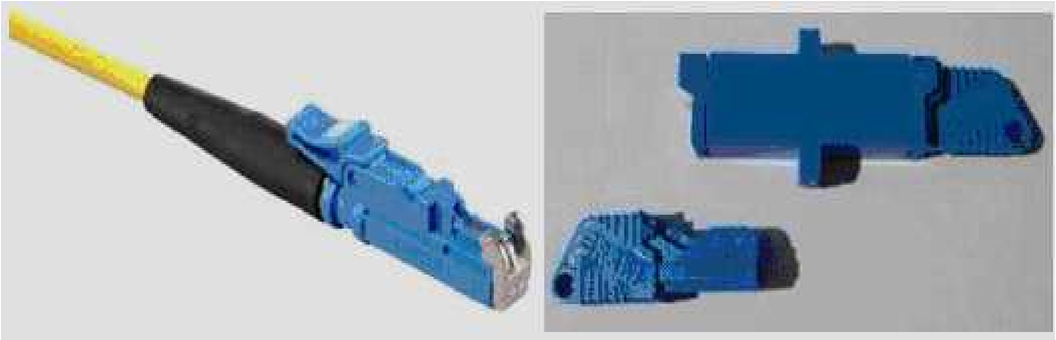


Figure 6.16 E2000 connector and adaptor

6.6.9 VF – 45 connector

VF-45 connector (3M Volition), duplex only. No ferrules at all. Plug and jack versions. VF-45 (3M Volition) is designed by 3M. VF-45 features plug and jack design without the need of adapters. VF-45 plug is inserted into the socket (jack) at a 45 degree angle, pressing a pair of fibers into V-grooves inside the socket. This design eliminates the need for expensive ferrules thus reduces connector costs.

Figure 6.17 VF – 45 connector

6.6.10 Opti – Jack connector

Opti-Jack connector (See figure 6.18), Duplex only. 2.5mm ferrule. Plug and jack version.

Opti-Jack connector is a version of Fiber Jack connector design from Panduit Corporation, which provides a snap-lock plug and socket for a pair of fiber cables. It enables fibers to be quickly plugged and removed in a manner similar to RJ-45 connectors. It is designed around two ST-type 2.5mm ferrules in a package the size of a RJ-45.

Fiber Jack is a duplex fiber-optic connector standardized by the TIA (FOCIS-6). TIA stands for Telecommunications Industry Association. Fiber Jack allows two fibers to mate in a snap-lock type of plug and socket similar in size and convenience to an RJ-45 connector.

Figure 6.18 Opti – Jack connector and adaptor

6.6.11 MTP and MPO connector

MTP and MPO are compatible ribbon fiber connectors based on MT ferrule which allow quick and reliable connections for up to 12 fibers, available in single mode and multimode. They are intended for installations that require many fiber connections. Up to 12 fibers in a ribbon are stripped to 125um cladding and inserted into 250um spaced parallel grooves. The ferrule also includes two 0.7mm diameter holes, running parallel to the fibers on the outer side of the ferrule. These two holes hold precision metal guide pins which align the fibers with tight tolerances.

MTP and MPO connectors (see figure 6.19) feature male and female connector design. Male connectors have two guide pins and female connectors do not. Both connector types need an adapter to mate a pair of male and female connectors.

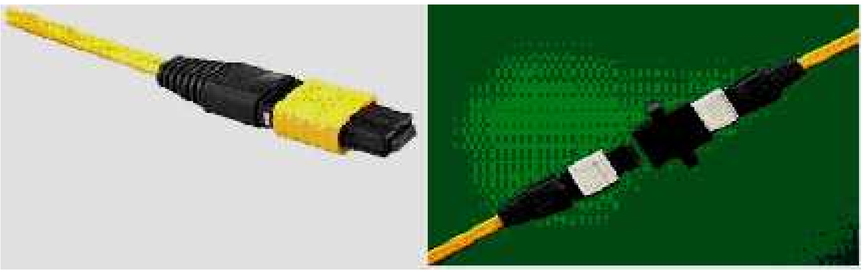


Figure 6.19 MTP – MPO connector and adaptor

Because MTP and MPO connectors are trying to align so many fibers at once, their coupling losses are typically bigger than single fiber connectors.

6.6.12 SMA 905 and SMA 906 connector (Sub Miniature Type ‘A’)

SMA 905 and 906 connectors make use of threaded connections and are ideal for military applications because of their low cost multimode coupling.

SMA 905 and SMA 906 multimode connectors are available with stainless alloy or stainless steel ferrules. The stainless alloy ferrule may be drilled from 125µm to 1550µm to accept various fiber sizes.

SMA 906 ferrule has a step, (see figure 6.20) which requires a half sleeve to be installed when mating a SMA 906 connector with SMA 905 mating sleeves.

Figure 6.20 SMA connector and adaptor

6.6.13 Biconic Connector

Simplex only. Available in single mode and multimode.

Biconic connectors (see figure 6.21) exhibit a cone-shaped ferrule that helps to align the optical fibers at the connection interface. Their robust design makes biconic connectors well-suited for military fiber optic applications. Fiber Connections terminates biconic connectors on either single mode or multimode fiber optic cable. The ferrule can be made with either polymer or metal.

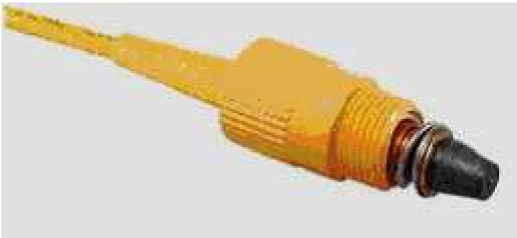


Figure 6.21 Biconic connector

Biconic connector's applications include LAN and premises networks, data processing systems, medical instrumentation, remote sensing, telemetry, and cable television.

6.6.14 D4 connector

D4 connector (see figure 6.22) has 2.5mm ferrule. Screw-on Simplex only.

D4 connectors are made from a 2.5mm diameter ceramic (zirconia) ferrule for durability. They have a high-performance threading mounting system and a keyed body for repeatability and intermateability.

Figure 6.22 D4 connector

6.7 Procedure to attach connectors to fiber

6.7.1Do's and Don'ts to attach connectors to fiber

Cut the cable one inch longer than the required finished length.

Carefully strip the outer jacket of the fiber with 'no nick' fiber strippers. Cut the exposed strength members and remove the fiber coating. There are two ways to remove fiber coating. They are, soaking the fiber for two minutes in paint thinner and wiping the fiber clean with soft lint – free cloth or by carefully stripping the fiber with a fiber stripper.

Do not use metal wire strippers for stripping, fiber may damage and losses increase. Ensure to use strippers made specifically for use with fiber.

Thoroughly clean the bared fiber with isopropyl alcohol poured onto a soft lint – free cloth. Never clean a fiber with a dry tissue. Industrial grade (99 %) isopropyl alcohol should be used exclusively.

Commercially available isopropyl alcohol is for medicinal use. This is diluted with water and a light mineral oil. The connector may be connected by applying epoxy or crimping. If using epoxy, fill the connector with enough epoxy to allow a small bead of epoxy to form at the tip of the connector.

Insert the clean, stripped fiber into the connector; follow the instructions provided by the epoxy manufacturer and fill. Anchor the cable strength members to the connector body. This prevents direct access on the fiber. Slide the back end of the connector into place where ever necessary.

Prepare the fiber face to achieve a good optical finish by cleaving and polishing the fiber end. Before the connection is made, the end of each fiber must have a smooth finish that is free of defects such as hackles, lips and fractures. These defects, as well as other impurities and dust change the geometrical propagation patterns of light inturn results in scattering.

6.7.2 Fiber optic connectors mate technique

Unlike electronic connectors, most fiber optic connectors don't have jack and plug design. Instead a fiber mating sleeve (adapter, or coupler) sits between two connectors. At the center of the adapter there is a cylindrical sleeve made of ceramic (zirconium) or phosphor bronze. Ferrules slide into the sleeve and mate to each other. The adapter body provides mechanism to hold the connector bodies such as snap-in, push-and-latch, and twist-on or screwed-on. The example shown (see figure 6.23) is FC connectors with a screwed-on mechanism.

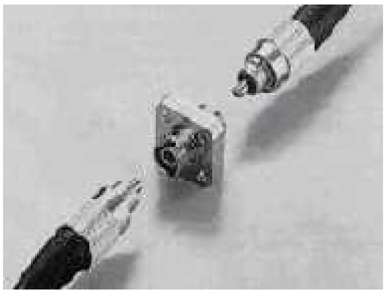


Figure 6.23 Fiber optic connector mate technique

Objective:

1. The loss offered by a mechanical splicing of optic fibers is less than ------------- dB.
   a) 0.005 b) 0.05 c) 0.5 d) 1.5

2. The loss offered by a fusion splice of optic fibers shall not exceed 0.2 dB under any circumstances.
   a) 0.002 b) 0.02 c) 0.2 d) 2.5

3. During installation a minimum of 10 meter of optic fiber cable on each end is coiled in the jointing pit.
   a) 10 b) 15 c) 5 d) 20

4. Ferules of optic fiber connectors are made of metal or ceramic or plastic materials.
   a) metal or ceramic or plastic b) only metal c) only ceramic d) only plastic

5. Biconic connectors are generally used in LAN applications in optic fiber communication. (T/F)

6. SMA connectors are ideally suited for military applications in optic fiber communications. (T/F)

7. E 2000 connector looks like a miniature SC connector of optic fiber. (T/F)

8. The E 2000 connector of optic fiber is easy to install with a push-pull latching mechanism. (T/F)

Subjective:

1. How many methods are available to joint OFC? What are they?
2. Fusion splicing is superior to the Mechanical splicing. Justify the statement.
3. Write different tools required for fusion splicing and their functions.
4. Could it be possible to connect two fibres with connectors?
5. What are the characteristics of Connectors an engineer should know? Explain.
6. List out different types of connectors available in market.
7. Write SC, FC, ST and FDDI characteristics and their applications.
8. Write Dos and Don’ts to attach a fibre to a connector.

CHAPTER-7

MEASUREMENTS AND SYSTEM TESTING

7.1 Light source

A light source (see figure 7.1) is a hand-held instrument able to provide a light output within one or more of the standard windows: visible, 850nm, 1300nm and 1550nm using an LED or laser light source. They often provide outputs at more than one of the wavelengths, as installation contracts generally require measurements to be taken at two different wavelengths and of course the popular choice being 850nm and 1300nm.

For reliable results, the power output of the light must be very stable over the period of the test, typically within 0.1 dB over 1 hour. The output can be switched between a test tone of 2 kHz or 270Hz or 10kHz and a continuous output called CW (continuous wave). The choice of test tones allows easy identification of fibers under test.

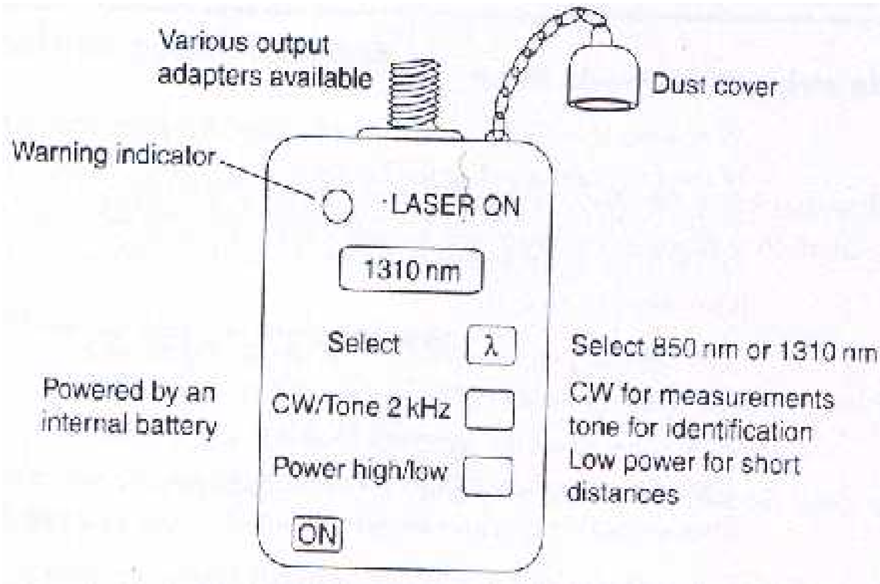


Figure 7.1 Light source

7.2 Power meter

Power meter look very similar to the light sources at the first instances. Compare Light source (figures 7.1) and power meter (figure 7.2). They are often sold as matching pairs, provided they are compatible.

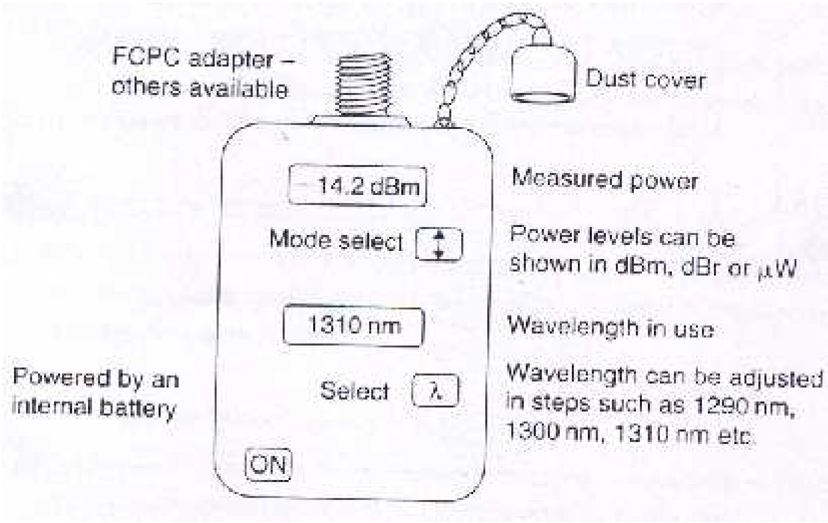


Figure 7.2 Power meter

The wavelength is adjustable over the three windows and some offer a facility to step up and down by small increments. This allows the fiber characteristics to be matched at any required wavelength.

The power levels can be indicated in µW or in decibels as dBm, relative to one milliwatt or as dBr, relative to a previously noted value.

Power meters are available with internal memories to store the day's work and a printer for hard copies.

7.3 A simple measurement

To measure the losses in a typical link as shown in Figure 7.3, we start by selecting a patchcord about 20m in length. If possible, it should be made from fiber of the same type; and fitted with identical connectors to those used in the link to be tested. In cases where this is not possible, the final result may not be accurate, this has to be tolerated. Keep a record of the patchcord and the instruments used so that the measurement could be repeated if a doubt arises at a later date.

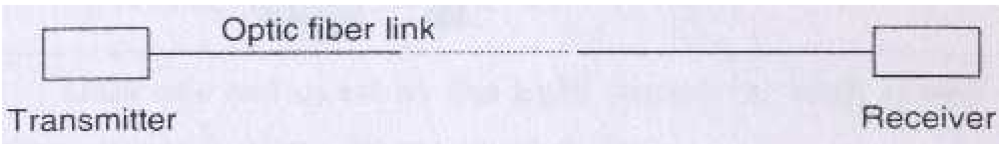


Figure 7.3 The optical fiber to be tested

The measurement procedure is explained in step by step for easy understand.

Step: 1 Setting up the light source and power meter

Connect the meters together using the patchcord as shown in Figure 7.4. Switch them on. Select the required wavelength and, on the power meter, switch to dBr mode.

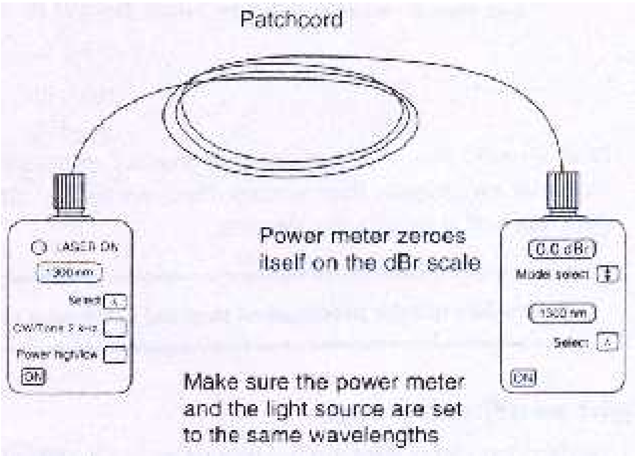


Figure 7.4 Measuring power from the light source

Wait until the readings are stabilized. At this stage, the power meter will indicate the incoming power level in dBm. Set the power meter to dBr and it will accept the incoming light level as the reference level. The reading will now change to 0 dBr.

Both the light source and the power meter must remain switched on now until all the measurements have been completed. This is to give the light source a good chance of maintaining a constant light level since the internal temperature and battery voltage will (hopefully) remain stable. The power meter needs to remain on in order to remember the level set as 0 dBr.

Disconnect the patch cord.

Step: 2 Connecting them to the system (see Figure 7.5)

Disconnect the fiber to be tested at the transmitter and plug in the light source. Connect the power meter to the far end. The power meter will immediately show a new figure such as –8.2 dBr. This is the loss over the system. We have actually assumed the patchcord loss (about 0.05dB) to be small enough to be ignored.

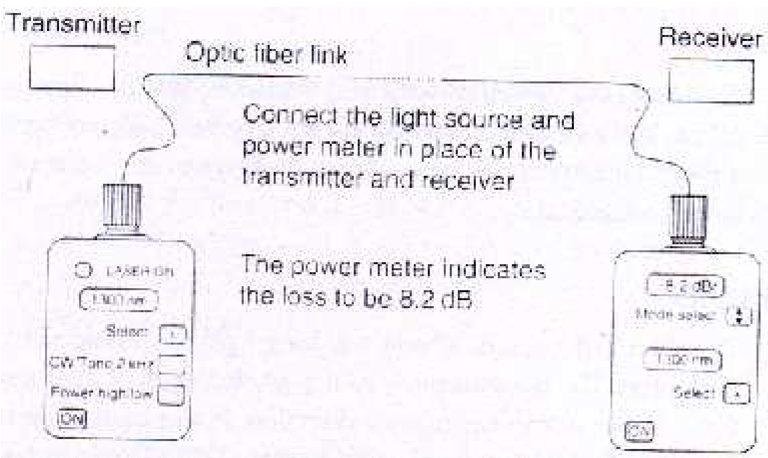


Figure 7.5 Measuring the Loss in the Optical fiber link

A few basic meters do not have dBr feature. Even if we use for measurement the result will be the same as explained below.

Step : 1 The power out from the light source

Using such a meter in the above system, we would have read the light source power out in dBm – let's assume this to be – 10 dBm.

Step : 2 The power out from the link

Leaving the meters switched on; connect them to the optic fiber link. The power meter would now indicate – 18.2 dBm.

Step : 3 The final result is difference between the above meter indications

The loss in the optic fiber link is the difference between the two measurements, (-10.0) – (-18.2) = 8.2 dB as in the previous case.
Limitations of the light source and power meter method

Assume an optic fiber link has become unreliable. Meters would give an accurate enough result for the overall loss of a system which would confirm that additional losses have occurred. They are, however, unable to indicate which part of the system is responsible for the additional loss.

Power meter/light source combinations are the quickest and cheapest method for acceptance testing of a short-haul datacommmunication link because they give a clear unambiguous reading of the light loss. The user can decide if that result is acceptable or not. If there is a fault the power meter/light source will indicate this, but it can't tell what or where that fault is. This is where an optical time domain reflectometer (OTDR) comes in use.

7.4 Introduction to optical time domain reflectometer (OTDR)

7.4.1 Loss measure technique of OTDR

This instrument is connected to one end of any fiber optic system up to 250km in length. Within a few seconds, we are able to measure the overall loss, or the loss of any part of a system, the overall length of the fiber and the distance between any two points in a link.

As light travels along the fiber, a small proportion of it is lost by Rayleigh scattering (see figure 7.6). As the light is scattered in all directions, some of it just happens to return back along the fiber towards the light source. This returned light is called backscatter.

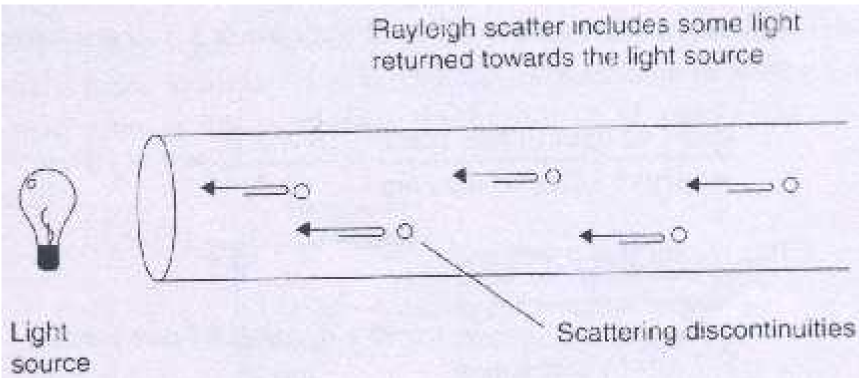


Figure 7.6 Rayleigh scattering

The backscatter power is a fixed proportion of the incoming power. As the light is scattered and absorbed, the power levels decrease as the light travels along the fiber. the returned power also diminishes as shown in Figure 7.7.

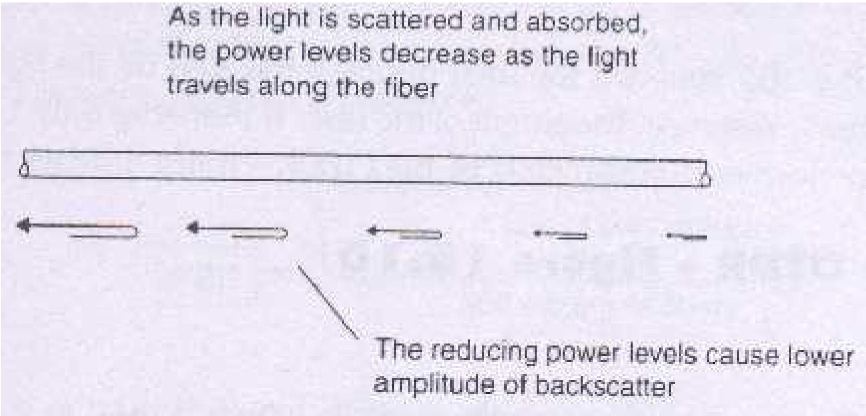


Figure 7.7 The Backscatter becomes weaker

The OTDR can continuously measure the returned power level and hence figure out the losses on the fiber link. Any additional losses such as connectors and fusion splices have the effect of suddenly reducing the transmitted power on the fiber and hence causing a corresponding change in backscatter power. The position and the degree of the losses can be seen on display.

7.4.2 An OTDR display of a typical system

The OTDR can 'see' Fresnel reflections and losses. With this information, we can deduce the appearance of various events on an OTDR trace as seen in Figure 7.8.

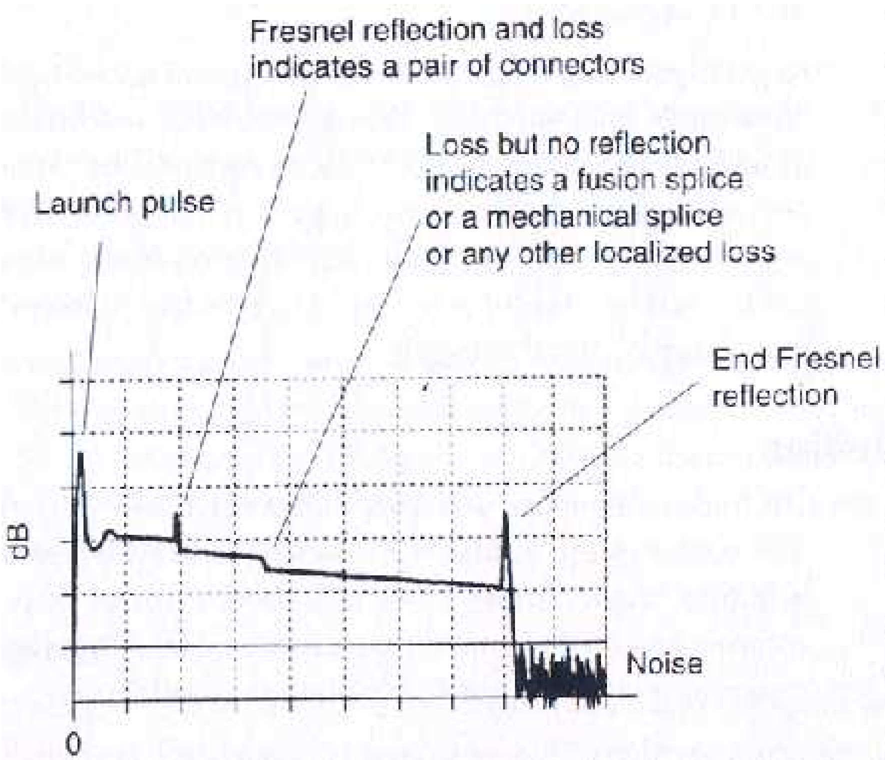


Figure 7.8 A typical OTDR trace

- Connectors

  A pair of connectors will give rise to a power loss and also a Fresnel reflection due to the polished end of the fiber.

- Fusion splice

  Fusion splices do not cause any Fresnel reflections as the cleaved ends of the fiber are now fused into a single piece of fiber. They do, however, show a loss of power. A good quality fusion splice will actually be difficult to spot owing to the low losses. Any sign of a Fresnel reflection is a sure sign of a very poor fusion splice.

- Mechanical splice

  Mechanical splices appear similar to a poor quality fusion splice. The fibers do have cleaved ends, of course, but the Fresnel reflection is avoided by the use of index matching gel within the splice. The losses to be expected are similar to the least acceptable fusion splices.

- Bend loss

  This is simply a loss of power in the area of the bend. If the loss is much localized, the result is indistinguishable from a fusion or mechanical splice.

7.4.3 A simple block diagram of OTDR

- Timer

  The timer produces a voltage pulse which is used to start the timing process in the display at the same moment as the laser is activated.

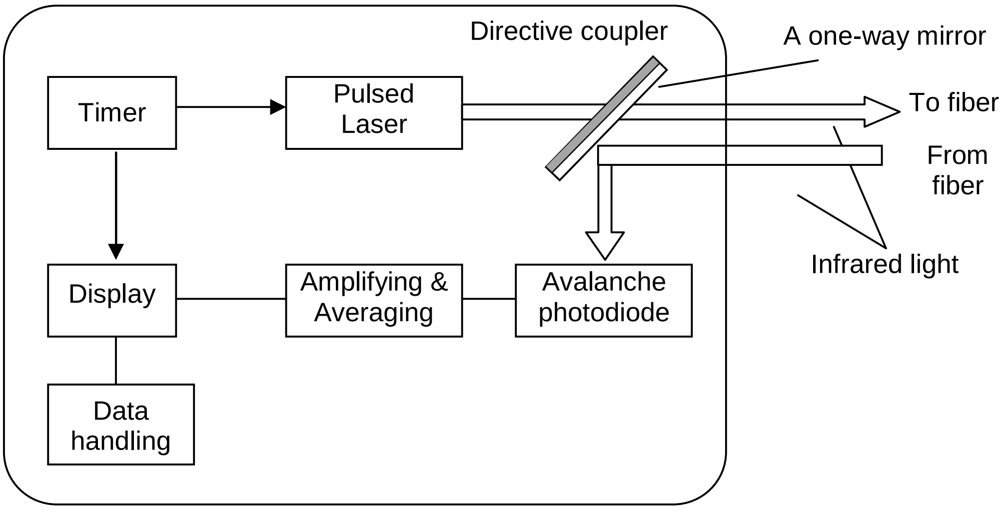


Figure 7.9 A block Diagram of an OTDR

- Pulsed laser

  The laser is switched on for a brief moment. The ‘on’ time being between 1 ns and 10µs. The choice of ‘on’ time or pulse width plays vital role in Optical communication system. The wavelength of the laser can be switched to suit the system to be tested.

- Directive Coupler

  The directive coupler allows the laser light to pass straight through into the fiber under test. The backscatter from the whole length of the fiber approaches the directive coupler from the opposite direction. In this case the mirror surface reflects the light into the avalanche photodiode (an APD). The light has now been converted into an electrical signal.

- Amplifying & averaging

  The electrical signal from the APD is very weak and requires amplification before it can be displayed.

The averaging feature is very useful and implemented before display the incoming signal.

The instantaneous value of the backscatter returning from the fiber is very weak and contains a high noise level which tends to mask the return signal.

As the noise is random, its amplitude should average out to zero over a period of time. This is the idea behind the averaging circuit. The incoming signals are stored and averaged before being displayed. The larger the number of signals averaged, the cleaner will be the final result but the slower will be the response to any changes that occur during the test. The mathematical process used to perform the effect is called least squares averaging or LSA.

Figure 7.10 demonstrates the enormous benefit of employing averaging to reduce the noise effect. Occasionally it is useful to switch the averaging off to see a real time signal from the fiber to see the effects of making adjustments to connectors, etc. This is an easy way to optimize connectors, mechanical splices; bends etc. simply play with it and observe the OTDR screen.

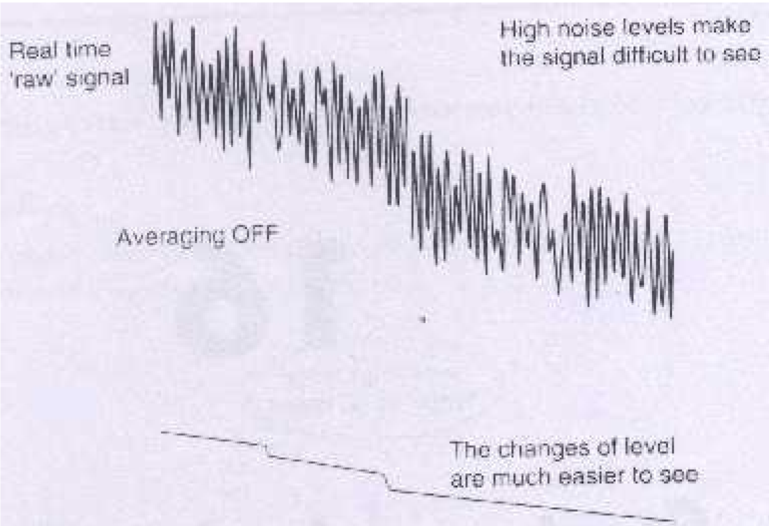


Figure 7.10 Benefits of averaging

- Display

  The amplified signals are passed on to the display. The display is either a cathode ray tube (CRT) like an oscilloscope or a computer monitor, or a liquid crystal as in calculators and laptop computers. They display the returned signals on a simply XY plot with the range across the X-axis and the power level in decibels on the Y-axis.

Figure 7.11 shows a typical display. The current settings are shown immediately over the grid. They can be modified to suit the measurements being undertaken. The range scale displayed shows a 50km length of fiber. In this case it is from 0 to 50 km but it could be any other 50 km slice, for example, from 20 km to 70km.

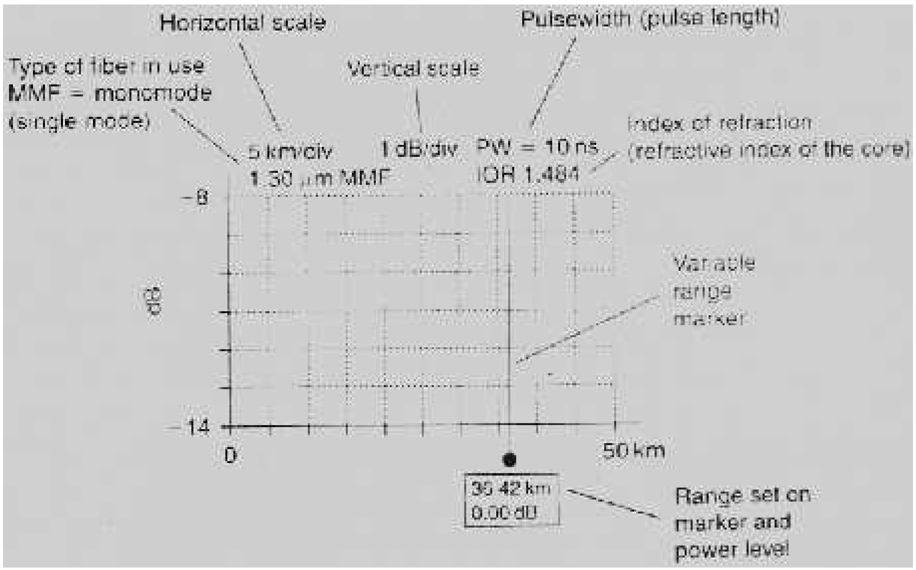


Figure 7.11 An OTDR display – no signal

It can also be expanded to give a detailed view of a shorter length of fiber such as 0-5m, or 25-30m.

The ranges can be read from the horizontal scale, but for more precision a variable range marker is used. This is a movable line which can be switched on and positioned anywhere on the trace. Its range is shown on the screen together with the power level of the received signal at that point. To find the length of the fiber, the marker is simply positioned at the end of the fiber and the distance is read off the screen. It is usual to provide up to five markers so that several points can be measured simultaneously.

- Data handling

  An internal memory or a floppy disk drive can store the data for later analysis. The output is also available via an RS232 link for downloading to a computer. In addition, many OTDRs have an onboard printer to provide hard copies of the information on the screen. This provides useful 'before and after' images for fault repair as well as a record of the initial installation.

The rest of the chapter explains the measurements and testing of the system with OTDR with an illustrative example.

7.5 Measurements and System Testing with OTDR

7.5.1 Measure the fiber length

The OTDR uses a system similar to radar set. It sends out a light pulse and act on the reflected light from the fiber.

It is easy to find the length of the fiber, if knows the speed of the light and can measure the time taken for the light to travel along the fiber.

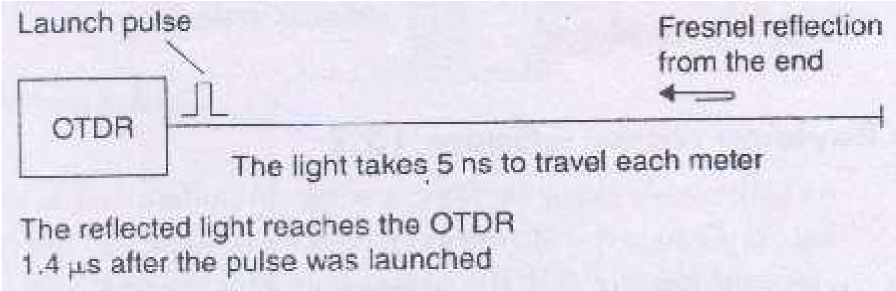


Figure 7.11a Find length of the fiber

Assume the refractive index of the core is 1.5, the infrared light travels in the glass at a speed of = (Speed of light in free space / Refractive index of the core)

$$= (3 \times 10^8) / 1.5 = 2 \times 10^8 \text{ m/s}$$

This means that it will take: $[1 / (2 \times 10^8)]$ s or 5ns to travel a distance of one meter.

If the OTDR measures a time delay of 1.4µs, then the distance traveled by the light is:

$$(1.4 \times 10^{-6}) / (5 \times 10^{-9}) = 280\text{m}$$

The 280 meters is the total distance traveled by the light and is the ‘there and back’ distance. The length of the fiber is therefore only 140m. This adjustment is performed automatically by the OTDR - it just displays the final result of 140m.

7.5.2 A simple measurement with OTDR

Connect a length of fiber, say 300m, to the OTDR as shown in Figure 7.12.

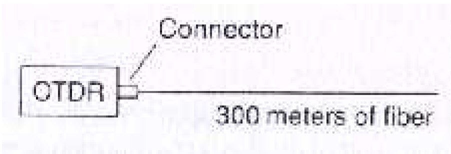


Figure 7.12 A simple fiber measurement

The result i.e OTDR screen display a trace as shown in figure 7.13.

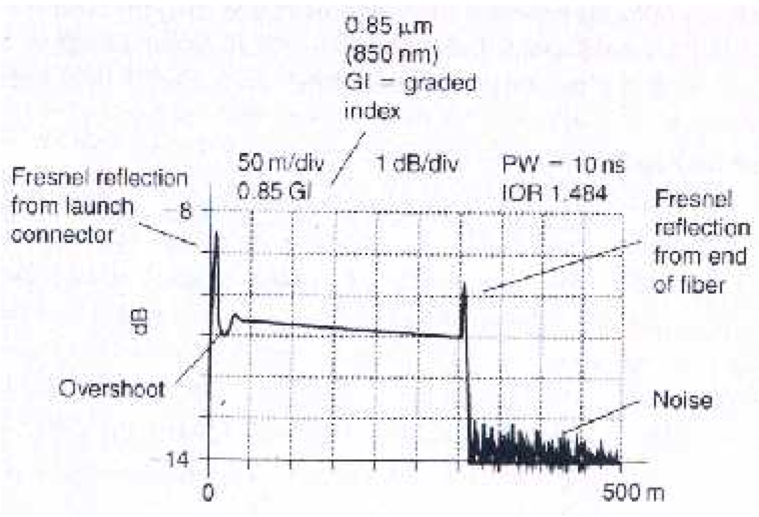


Figure 7.13 OTDR trace for 300 meters fiber

Whenever the light passes through a cleaved end of a piece of fiber, a Fresnel reflection occurs. This is seen at the far end of the fiber and also at the launch connector. Indeed, it is quite usual to obtain a Fresnel reflection from the end of the fiber without actually cleaving it. Just breaking the fiber is usually enough. The Fresnel at the launch connector occurs at the front panel of the OTDR and, since the laser power is high at this point, the reflection is also high. The result of this is a relatively high pulse of energy passing through the receiver amplifier. The amplifier output voltage swings above and below the real level, in an effect called ringing. This is a normal amplifier response to a sudden change of input level. The receiver takes a few nano seconds to recover from this sudden change of signal level.

- Dead zones

  The Fresnel reflection and the subsequent amplifier recovery time result in a short period during which the amplifier cannot respond to any further input signals. This period of time is called a dead zone. It occurs to some extent whenever a sudden change of signal amplitude occurs. The one at the start of the fiber where the signal is being launched is called the launch dead zone and others are called event dead zones or dead zones (see Figures 7.13a and 7.21)

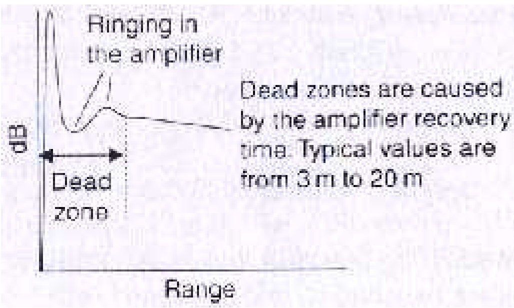


Figure 7.13a Dead zone (see also Figure 7.21)

- Solution to the launch dead zone

  As the launch dead zone occupies a distance of up to 20 meters or so, this means that given the job of checking a 300m fiber, we may only be able to check 280m of it. Our purpose of checking 300m fiber is not completed. The solution to this problem is use patchcord between OTDR and fiber under test.

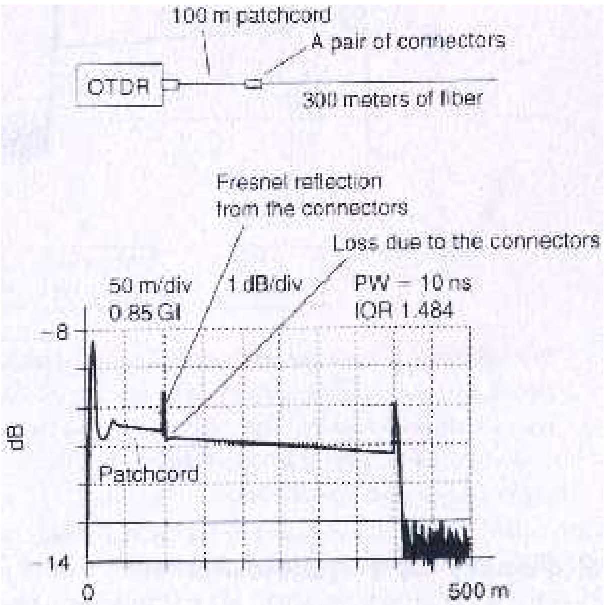


Figure 7.14 A patchcord overcomes dead zones problems

If we add a patchcord of 100m length, at the beginning of the system, we can ensure that all launch dead zone problems have been solved before the fiber under test is reached.

The patchcord is joined to the main system by a connector which will show up on the OTDR readout as a small Fresnel reflection and a power loss. The power loss is indicated by the sudden drop in the power level on the OTDR trace.

- Fiber length and attenuation

  The end of the fiber appears to be at 400 m on the horizontal scale but we must deduct 100m to account for patch cord. This gives an actual length of 300m for the fiber being tested.

Immediately after the patchcord Fresnel reflection, the power level shown on the vertical scale is about – 10.8 dB and at the end of the 300 m run, the power has fallen to about – 11.3 dB. A reduction in power level of 0.5dB in 300 meters indicates a fiber attenuation of:

(Attenuation) / (length in kilometer) = (0.5) / (0.3) = 1.66 dB / km

Most OTDRs provide a loss measuring system using two markers. The two markers are switched on and positioned on a length of fiber which does not include any other events, like connectors or whatever as shown in Figure 7.15.

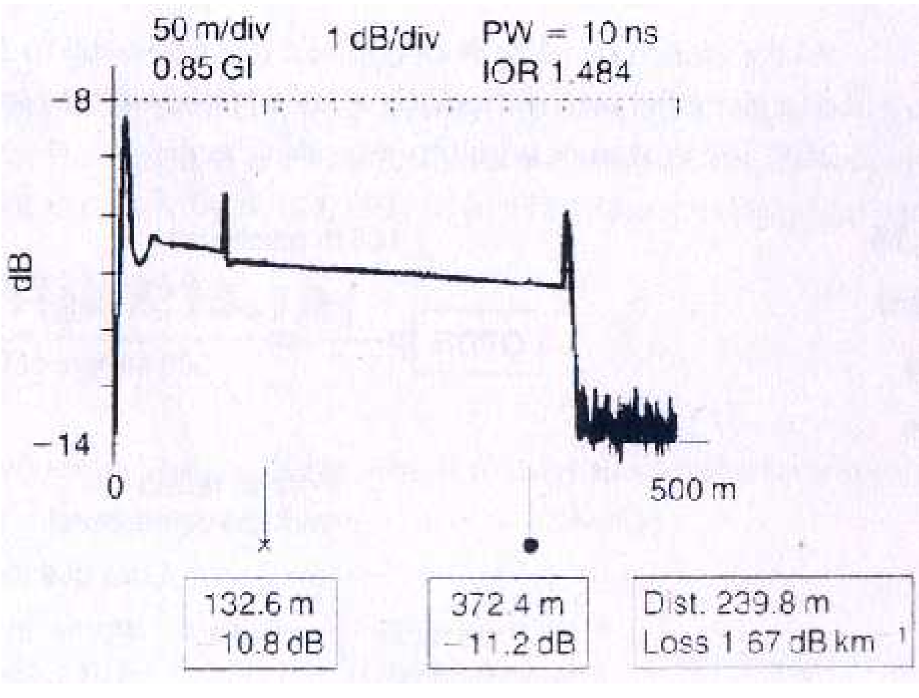


Figure 7.15 Using two Markers for loss measurement

The OTDR then reads the difference in power level at the two positions and the distance between them, performs the above calculation for us and displays the loss per kilometer for the fiber. This provides a more accurate result than trying to read off the decibel and range values from the scales on the display and having to do our own calculations.

- Ghost echoes (false reflections)

  In Figure 7.16, some of the launched energy is reflected back from the connectors at the end of the patchcord at a range of 100m. This light returns and strikes the polished face of the launch fiber on the OTDR front panel. Some of this energy is again reflected to be relaunched along the fiber and will cause another indication from the end of the patchcord, giving a false, or ghost, Fresnel reflection at a range of 200m and a false end to the fiber at 500m.

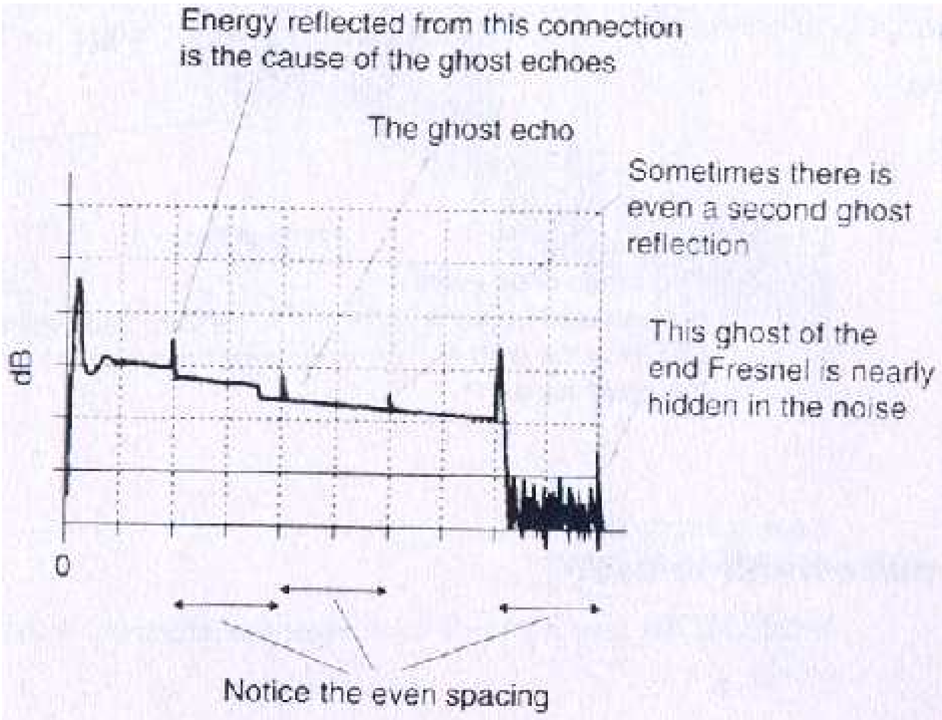


Figure 7.16 Ghosts

As there is a polished end at both ends of the patchcord, it is theoretically possible for the light to bounce to and fro along this length of fiber giving rise to a whole series of ghost reflections. In Figure 7.16 a second reflection is shown at a range of 300m.

It is very rare for any further reflections to be seen. We have seen earlier that the maximum amplitude of the Fresnel reflection is 4% of the incoming signal, and is usually much less. Looking at the calculations for a moment, even assuming the worst reflection, the returned energy is 4% or 0.04 of the launched energy. The relaunched energy, as a result of another reflection is 4% of the 4% or 0.042 = (0.0016 X input energy). This shows that we need a lot of input energy to cause a ghost reflection. A second ghost would require another two reflections giving rise to a signal of only 0.000 002 56 of the launched energy. Subsequent reflections die out very quickly.

Ghost reflections can be recognized by their even spacing. If we have a reflection at 387 m and another at 774 m then we have either a strange coincidence or a ghost. Ghost reflections have a Fresnel reflection but do not show any loss. The loss signal is actually of too small an energy level to be seen on the display. If a reflection shows up after the end of the fiber, it has got to be a ghost.

- Effects of changing the pulse width

  The maximum range that can be measured is determined by the energy contained within the pulse of laser light. The light has to be able to travel the full length of the fiber, be reflected, and return to the OTDR and still be of larger amplitude than the background noise. Now, the energy contained in the pulse is proportional to the length of the pulse and so to obtain the greatest range the longest possible pulse width should be used, as illustrated in Figure 7.17.

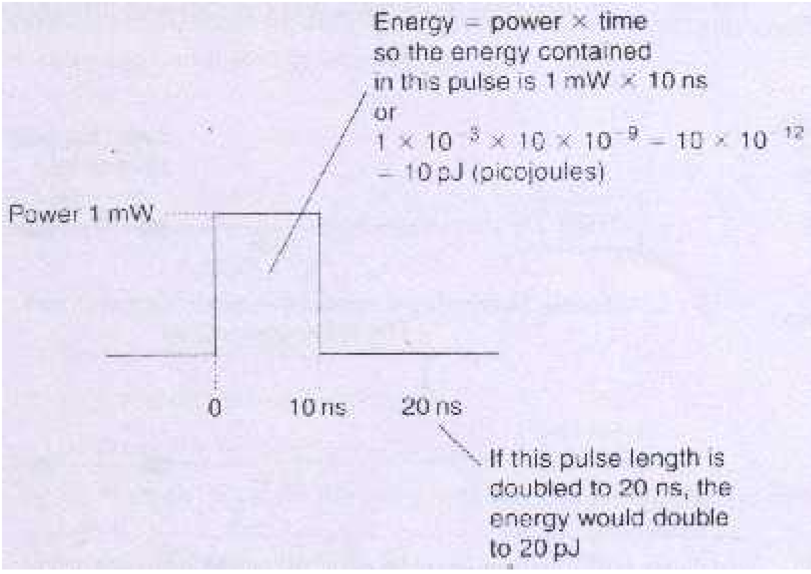


Figure 7.17 A longer pulse Contains more Energy

This cannot be the whole story, as OTDRs offer a wide range of pulse widths.

We have seen that light covers a distance of one meter every five nanoseconds so a pulse width of 100 ns would extend for a distance of 20 meters along the fiber (Figure 7.18). When the light reaches an event, such as a connector, there is a reflection and a sudden fall in power level. The reflection occurs over the whole of the 20m of the outgoing pulse. Returning to the OTDR is therefore a 20m reflection. Each event on the fiber system will also cause a 20m pulse to be reflected back towards the OTDR.

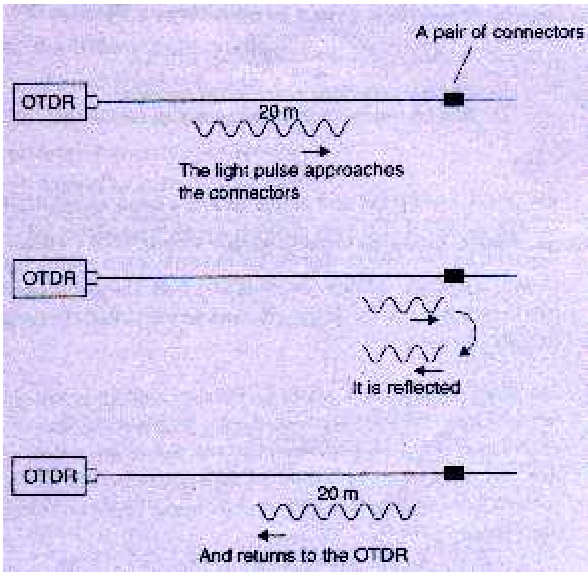


Figure 7.18 100 «s Pulse causes a 20 m reflection

Now imagine two such events separated by a distance of 10m or less as in Figure 7.19. The two reflections will overlap and join up on the return path to the OTDR.

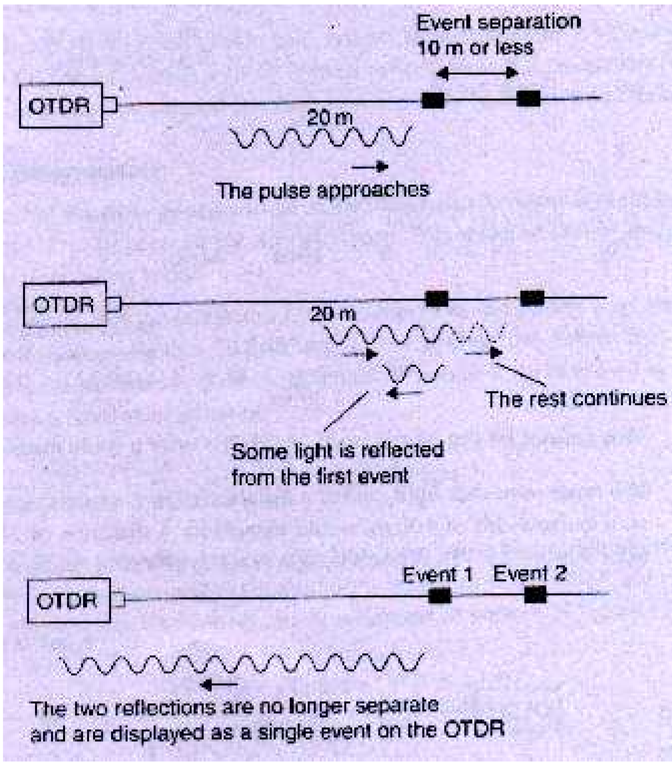


Figure 7.19 Pulse length determines the range discrimination

The OTDR will simply receive a single burst of light and will be quite unable to detect that two different events have occurred. The losses will add together, so two fusion splices, for example, each with a loss of 0.2 dB will be shown as a single splice with a loss of 0.4 dB. The minimum distance separating two events that can be displayed separately is called the range discrimination of the OTDR.

The shortest pulse width on an OTDR may well be in the order of 10 ns so at a rate of 5 ns/m this will provide a pulse length in the fiber of 2 m. The range discrimination is half this figure so that two events separated by a distance greater than one meter can be displayed as separate events. At the other end of the scale, a maximum pulse width of 10μs would result in a range discrimination of one kilometer.

Another effect of changing the pulse width is on dead zones. Increasing the energy in the pulse will cause a larger Fresnel reflection. This, in turn, means that the amplifier will take longer to recover and hence the event dead zones will become longer as shown in Fig. 7.20.

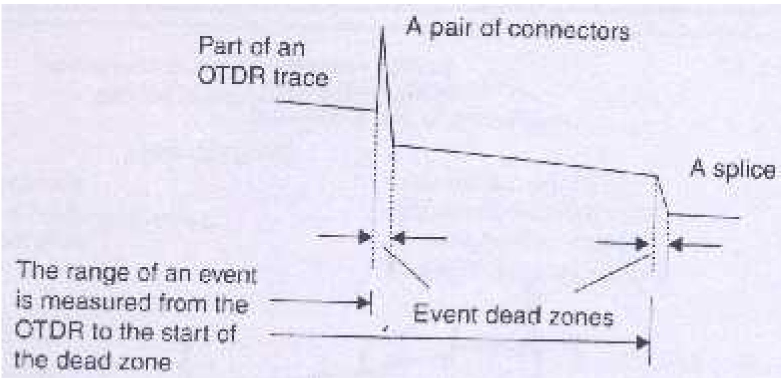


Figure 7.20 Event dead zones and distances

- Pulse width selection

  Most OTDRs give a choice of at least five different pulse lengths from which to select.

Low pulse widths mean good separation of events but the pulse has low energy content so the maximum range is very poor. A pulse width of 10 ns may well provide a maximum range of only a kilometer with a range discrimination of one meter.

The wider the pulse, the longer the range but the worse the range discrimination. A 1µs pulse width will have a range of 40km but cannot separate events closer together than 100m.

As a general guide, use the shortest pulse that will provide the required range.

- Dynamic range

  When a close range reflection, such as the launch Fresnel occurs, the reflected energy must not be too high otherwise it could damage the OTDR receiving circuit. The power levels decrease as the light travels along the fiber and eventually the reflections are similar in level to that of the noise and can no longer be used.

The difference between the highest safe value of input power and the minimum detectable power is called the dynamic range of the OTDR and, along with the pulse width and the fiber losses, determines the useful range of the equipment. If an OTDR was quoted as having a dynamic range of 36 dB, it could measure an 18 km run of fiber with a loss of 2 dB / km, or alternatively a 72km length of fiber having a loss of 0.5 dB / km, or any other combination that multiplies out to 36 dB.

7.6 Fault locator

These devices are used to locate faults quickly and easily rather than provide a detailed analysis of a system, and are therefore more likely to be met in a repair environment than at a new installation.

There are two types. The first is similar to the simple light source test.

This device extends the test range of a simple light source up to 5 km using a laser operating at 670 nm which is visible red light. It also provides a 2 kHz test tone which can be picked up by live fiber detectors and provides easy identification of the fiber under test.

If the continuity test fails, it can sometimes show us where the break has occurred. At the position of the break, the light is scattered. Using a powerful visible light source the fiber glows red from the scattered light. This assumes, of course, that the red light is able to penetrate the outer covering of the fiber.

The other device is very similar in principle to the OTDR. It is hand held and operated by internal batteries. It transmits an infrared light pulse along the fiber and 'listens out' for any sudden loss exceeding 0.25 dB, 0.5 dB or whatever value you have selected on the front panel control, all lesser events being ignored.

It doesn't actually provide us with a full OTDR type display but, instead, the result is shown on a liquid crystal display as a simple list of ranges at which losses exceed the selected magnitude occur, together with the total length of the fiber. By comparing this information with the expected values, any discrepancy can be seen and any serious fault is located in seconds.

Objective:

1. For reliable results, the power output of the light source must be very stable over the period of the test typically within --------------- over one hour.

   a) 0.01 dB b) 0.001 dB c) 0.1 dB d) 1.0 dB

2. The light output from a light source can be switched between a test tone of -- and a CW wave.

   a) 270KHz or 2 KHz or 10 KHz b) 270 Hz or 2 Hz or 10 Hz

   c) 270 KHz or 2 MHz or 10 MHz d) 270 Hz or 2 KHz or 10 KHz

3. Optical power meter has got the option for displaying optical power in ------------------------

   a) dBm or µW b) dBm only c) µW only d) dBm or pW

4. Using Light source and power meter can perform loss measurement on optic fiber. (T/F)

5. OTDR works on the principle of back scattering of light. (T/F)

6. A good quality fusion splice will actually be difficult to spot on the OTDR trace owing to the low loss. (T/F)

7. Fusion splices do not cause any Fresnel reflections as the fibers are fused into a single piece of fiber. (T/F)

8. Any sign of Fresnel reflection on the trace of the OTDR is a sure sign of very poor fusion splice. (T/F)

9. Fresnel reflection is avoided in case of mechanical splice by the use of index matching gel within the splice. (T/F)

Subjective:

1. Observe the Light source and Power meter figures. Write your Technical comments.
2. Write the importance of averaging technique in OTDR.
3. Define Dead Zone. Why it occurs? Write a solution.
4. Discuss in brief with figure about false reflections in OTDR trace.
5. Discuss the effects of change in pulse width of the laser light.
6. Define Dynamic range of OTDR.
7. Briefly write about fault locator.
8. Write a summary for this chapter (Measurements and System testing)

CHAPTER-8

OPTICAL SOURCES AND DETECTORS

8.1 Introduction to Optical sources

8.1.1 Introduction

An optical source is a major component of optical transmitters. Fiber optic communication systems often use semiconductor optical sources such as Light emitting diodes (LEDs) and semiconductor lasers. Some of the advantages are:

- Compact in size
- High efficiency
- Good reliability
- Right wavelength range
- Small emissive area compatible with fibre core dimensions
- Possibility of direct emulation at relatively high frequencies

8.1.2 Light emission technique

Under normal environment, all materials absorb light rather than emit it. The absorption process can be understood by see figure 8.1 (a), where energy levels E_1 and E_2 are the ground state and excited state respectively of atoms of the absorbing medium.

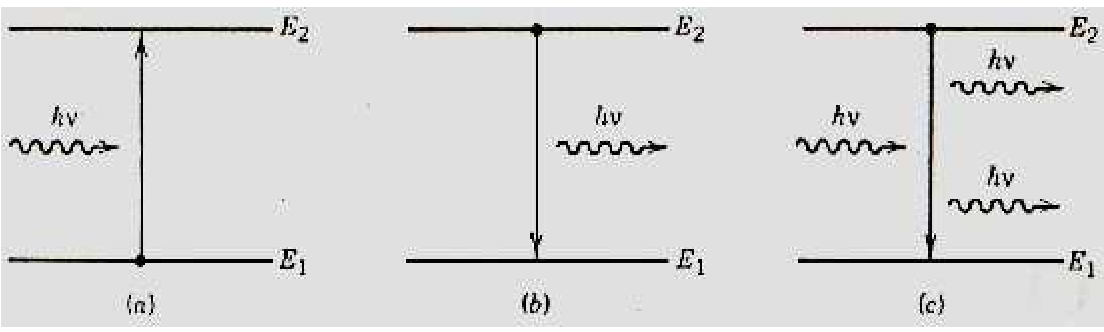


Figure 8.1 (a) absorption(b) spontaneous emission(c) stimulated emission

If the photon energy (hv) of the incident light of frequency (v) is same as energy difference ' E_g ' = (E_2 - E_1) , the photon is absorbed by the atom , which is in excited state. Incident light is attenuated as a result of many such absorption events occurring inside the medium. The excited atoms eventually return to their normal 'ground 'state and emits light in the process.

Light emission can occur through two fundamental processes. They are:

- Spontaneous emission

  In spontaneous emission (see figure 8.1 b) photons are emitted in random directions with no phase relationship among them. LEDs emit light through the process of spontaneous emission and emit incoherent light.

- Stimulated emission

  Stimulated emission (see figure 8.1 c) is initiated by an existing photon. The very noticeable feature of stimulated emission is that the emitted photon matches the original photon not only in energy (or in frequency), but also in its other characteristics, such as direction of propagation.

All lasers emit light through the process of stimulated emission and emit coherent light.

8.1.3 Semiconductor materials

The most common materials used for opto-electronic devices are:

- Gallium-Aluminium-Arsenide

  Gallium-Aluminium-Arsenide material can emit light in the range of wavelengths between 800 nm and 900 nm.

- Indium-Gallium-Arsenide-Phosphide

  Indium-Gallium-Arsenide-Phosphide material can emit light in the range of wavelengths between 1000 nm and 1600 nm. These materials are called compound semiconductors. Compound semiconductors are made from elements of different columns of Group III and Group V or Group IV and Group V of the periodic table.

The important characteristics of compound semiconductors are high electronic mobility and radiative efficiency.

8.1.4 Requirements of Optical sources

- Output wavelength

  The emission wavelength should be in the low loss region of the fiber. The light produced should be as nearly monochromatic as possible.

- Output power

  The optically emitted power should be as high as possible. It should be achievable with the highest conversion efficiency or minimum drive current to prevent junction heating and performance degradation.

- Output directivity

  Optical output shuould be highly directional to focus the light output into the fiber, to achieve a high source-fiber coupling efficiency.

- Spectral width

  The optical output should be as monochromatic as possible to reduce dispersion as a result of different wavelengths propagating in the fiber at different velocities.

- Linearity

  Easy and direct modulation should be possible to have linear input-output characteristics.

- Reliability

  It should have long life and good stability of operation.

- Physical size

  Small and compact should be compatible with commercially available fiber diameters.

- Cost

  The source cost should be economical to reduce total transmitter cost.

8.1.5 Efficiency of Optical sources

- Internal quantum efficiency (IQE)

  Internal quantum efficiency is the ratio of number of photons generated and number of carriers crossing the junction. It depends on structure of junction, type of impurity, level of impurity and type of semiconductor.

- External quantum efficiency (EQE)

  External quantum efficiency is the ratio of number of photons finally emitted and number of carriers crossing the junction. The external quantum efficiency is always less than the internal quantum efficiency. The reasons are:

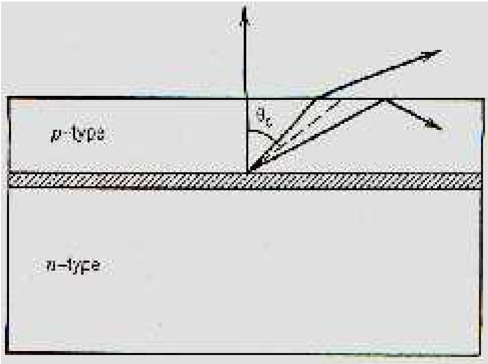
- Light emitted in the direction of semi-conductor air surface only is useful.
- Only light with incidence angle less than critical angle comes out to be coupled to the optical fiber.
- Light gets reflected at the semi-conductor air surface.
- There is absorption between the point of generation and emitting surface.
- Internal reflection at the surface (Interface) of semi-conductor crystal and the encapsulation material leading to re-absorption.

8.2 Optical Sources

8.2.1 Light emitting diodes

- Light emitting Technique in LEDs

  A forward biased p-n junction emits light through spontaneous emission, a phenomenon called as electroluminescence. A LED is a forward biased p-n junction. Radiative recombination of electron – hole pairs in the depletion region generates light, only light emitted (see figure 8.2) within a cone of angle (θ_c) is the critical angle for the semiconductor-air interface. A fraction of light escapes from the device and can be coupled into an optical fibre. The emitted light is incoherent with a relatively wide spectral width (30.0nm) and a relatively large angular spread.



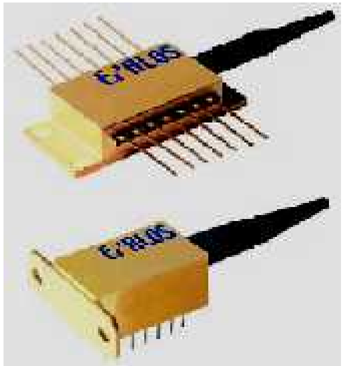


Figure 8.2 Total internal reflection at the output facet of an LED & LED in butterfly and DIL variety package

- Power current characteristic

  The output power of LEDs is 10 microwatt or less, even though the internal power can easily exceed 10 milliwatt. This is due to internal absorption and total internal reflection at the semiconductor-air interface. Internal absorption can be avoided by using heterostructure LEDs in which the cladding layers surrounding the active layer are transparent to the radiation generated.

A further loss occurs when emitted light is coupled into an optical fiber. Because of the incoherent nature of the emitted light, an LED acts as a Lambertian source. In view of the fact that numerical aperture (NA) for optical fibre is in the range 0.1 to 0.3, only a few percentage of emitted power is coupled into the fiber.

A measure of the LED performance is the total quantum efficiency defined as the ratio of the emitted optical power to the applied electrical power. The total quantum efficiency also called as the power-conversion efficiency or the wall-plug efficiency is a measure of the overall performance of the device.

- Responsivity characteristic

  The Responsivity characteristic also used to analyze the LED performance It is the ratio of emitted power and current. The typical values are approximately 0.01 watt/ampere. The responsivity remains constant as long as the linear relation between emitted power and current maintained. The linear relation maintained only over a limited current range, decreases at high currents above 80 mA because of non-linearity of P-I curve (see figure 8.3).

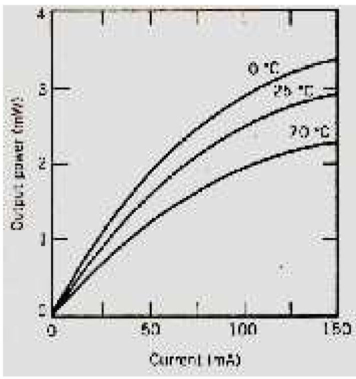


Figure 8.3 Power – current curves at several temperatures

- LED spectrum

  The spectrum (see figure 8.4) of a light source affects the performance of optical communication system through fibre dispersion. Because of large spectral width approximately 50 to 60 nm, the bit rate – distance product is limited considerably by fibre dispersion when LEDs are used in optical communication systems. LEDs are suitable for local area network applications with bit rates of 10-100 Mbits/second and transmission distances of a few kilometres.

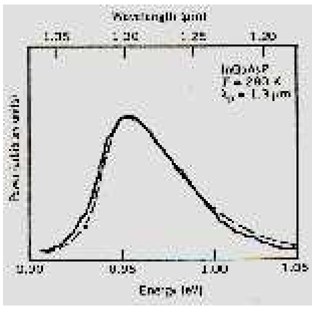


Figure 8.4 Spectrum of emitted light for 1.3μm LED – Dotted line theoretical spectrum

- Modulation response of LEDs

  The modulation response of LEDs depends on carrier dynamics and is limited by the carrier life time. The charge carrier is in the range of 2 to 5 ns for InGaAsP LEDs. The corresponding LED modulation bandwidth is in the range 50 to 140 Mhz.

- LED structures

  The LED structures can be classified as surface-emitting or edge emitting, depending on whether the LED emits light from a surface that is parallel to the junction plane or from the edge of the junction region. Both types can be made using either a p-n homo-junction or heterostructure design in which the active region is surrounded by p and n type cladding layers. The heterostructure design leads to superior performance, as it provides a control over the emissive area and eliminates internal absorption because of the transparent cladding layers.

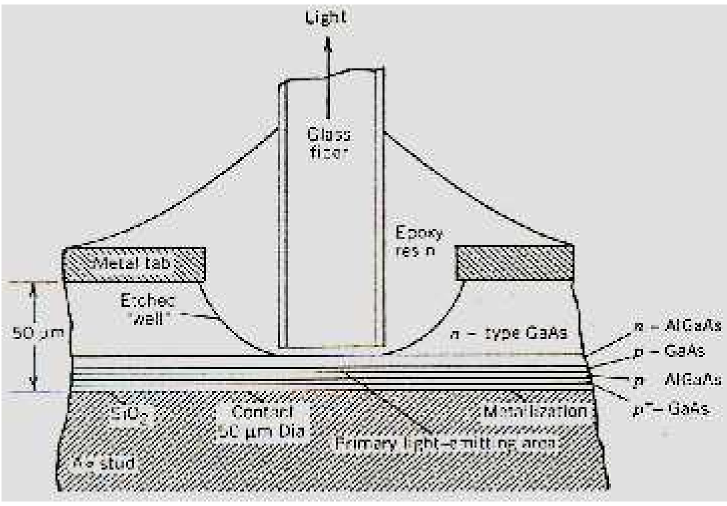


Figure 8.5 Surface emitting LED

The emissive area of the device is limited to a small region whose lateral dimension is comparable to the fibre-core diameter. The use of gold stud avoids power loss from the back surface. The coupling efficiency is improved by etching a well and bringing the fibre close to the emissive area.

The power coupled into the fibre depends on many parameters, such as the numerical aperture of the fibre and the distance between fibre and LED. The addition of epoxy in the etched well tends increase the external quantum efficiency as it reduces the refractive index mismatch.

Several basic design exist, one of the method is a truncated spherical microlens fabricated inside the etched well is used to couple light into the fibre. In another design the fibre end itself formed in the form of a spherical lens. With a proper design, surface-emitting LEDs can couple up to 1% of the internally generated power into an optical fibre.

The edge-emitting LEDs employ a design commonly used for stripe-geometry semiconductor lasers. In fact, a semiconductor laser is converted into an LED by depositing antireflection coating on its output facet to suppress lassing action. Considerable light can be coupled into a fibre of even low numerical aperture (less than 0.3) because of reduced divergence and high radiance at the emitting facet. The modulation bandwidth of edge-emitting LEDs is larger (approx. 200 MHz) than that of surface-emitting LEDs because of reduced carrier lifetime at the same applied current.

8.2.2 Semiconductor Lasers

Semiconductors lasers emit light through stimulated emission. As a result of the basic differences between spontaneous and stimulated emission, they are capable of emitting high power (~ 100 mW) and coherent light. A relatively narrow angular spread of the output beam compared with LEDs permits high coupling efficiency (~50%) into single mode fibers. A narrow spectral width of emitted light allows operation at high bit rates (~10Gb/s).

Further Semiconductor lasers can be modulated directly at high frequencies (up to 25 Ghz) because of short recombination time associated with stimulated emission. Most fiber-optic communication systems use semiconductor lasers as an optical source because their superior performance compared with LEDs.

8.2.2.1 Threshold current and its importance

Threshold current is the minimum value of the current at which laser emits light. The threshold current is approximately in the range of 50-100 mA. The threshold should be minimum to maintain junction temperatures low, inturn laser reliability increases and low noise.

8.2.2.2 Classification of Lasers based on physical structures

- Broad area semiconductor lasers

  The simplest structure of a semiconductor laser consists of a thin active layer (thickness : ~0.1micrometer) sandwiched between p – type and n – type cladding layers of another semiconductor with a higher band gap. The resulting p-n heterojunction is forward biased through metallic contacts. Such lasers are called ‘broad area semiconductor lasers’ (see figure 8.6) because the current is injected over a relatively broad area covering the entire width of the laser chip (~100 micrometer). Similar to optical fibres, it supports a certain number of modes, known as transverse modes. In practice, the active layer is thin enough (~0.1 micrometer) that the planar waveguide supports a single transverse mode. However there is no such light confinement in the lateral direction parallel to the junction plane.

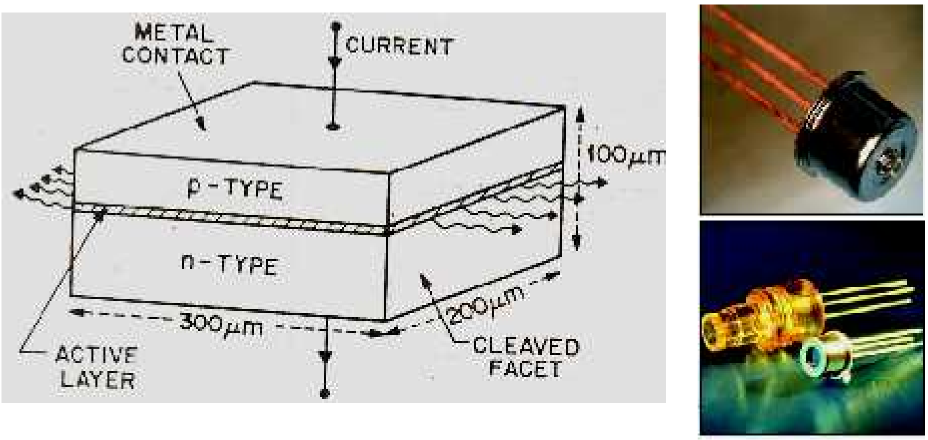


Figure 8.6 Broad area semiconductor laser

The light generated spreads over the entire width of the laser. The major draw backs are high threshold current and a highly elliptical spatial pattern which affects the optical communication systems. The spatial pattern changes in uncontrollable manner with the current. These problems can be solved by introducing a mechanism for light confinement in lateral direction.

- Gain guided semiconductor lasers

  The light confinement problem is solved by limiting current junction over a narrow stripe. Such lasers are called ‘Stripe geometry semiconductor lasers’. There are two stripe geometry laser structures used to design gain guided semiconductor lasers. They are ‘ oxide stripe ‘ and ‘junction stripe ‘.

The threshold current range is approximately 50 to 100 mA and light is emitted in the form of an elliptic spot of ~ 1 X 5 μm^2 . The major disadvantage is the spot size is not stable as the laser power is increased. This type of lasers affects optical communication systems because of mode stability problems.

- Index guided semiconductor lasers

  The elliptic pattern light spot size problem is solved by introducing an index strip the lateral direction so that a waveguide is formed in a way similar to the waveguide formed in the transverse direction by the heterostructure design.

These lasers are sub classified as ‘weak index guided ‘with ridge waveguide structure and ‘ strong index guided ‘ with etched-mesa buried heterostructure.

The spot is in elliptical shape with a dimension of 2 X 1 μm^2. The elliptic spot size and large divergence angle limits coupling efficiency in the range of 30 -50 % for most optical transmitters. A spot size converter is used to improve coupling efficiency.

8.2.2.3 Control of Longitudinal modes

The lasers oscillate in several longitudinal modes simultaneously because of a less gain (~ 0.1 cm^{-1}) difference between adjacent modes of the FP (Fabry-Perrot) cavity. The resulting spectral width (2-4 nm) is acceptable for light wave systems operating near 1.3µm at bit rates of 1Gbps. However such multimode lasers cannot be used for systems designed to operate near 1.55µm at high bit rates. The solution is to design semiconductor lasers such that they emit light in a single longitudinal mode (SLM).

The performance of the SLM lasers are characterised by the Mode suppression ratio (MSR) which is the ratio of main mode power and power of the most dominant side mode. The MSR should exceed 1000 (or 30 dB) for a good SLM laser.

This requirement leads to manufacture lasers with different designs. They are Distributed feedback lasers, Coupled cavity semiconductor lasers, Tunable semiconductor lasers and Vertical – Cavity surface emitting lasers. These are used in present Wavelength Division Multiplexing (WDM) systems.

8.2.2.4 Noise generated by Lasers

- Affect of Relative intensity Noise

  The output of a semiconductor laser exhibits fluctuations in its intensity, phase and frequency even when the laser is biased at a constant current with negligible current fluctuations. The two fundamental noise mechanisms are spontaneous emission and electron-hole recombination (shot noise). Noise in semiconductor material is dominated by spontaneous emission. Each spontaneously emitted photon adds to the coherent field (established by stimulated emission) a small field component whose phase is random. As a result both amplitude and phase fluctuate in a random manner. Intensity fluctuations lead to limited signal to noise ratio (SNR), whereas phase fluctuations lead to a finite spectral width when semiconductor lasers are operated at a constant current. Such fluctuations affect the performance of optical communication systems.

- Affect of Mode partition noise

  The laser has been assumed to oscillate in a single longitudinal mode but one or more side modes also presents. Even though the side modes suppressed by more than 20dB on the basis of the average power their presence can affect the relative intensity noise (RIN) significantly. Specifically the main and side modes can fluctuate in such a way that individual modes exhibit large intensity fluctuations, but the total intensity remains relatively constant. This phenomenon is called Mode partition noise (MPN). This occurs due to anti correlation between the main and side modes.

In the absence of fibre dispersion, mode partition noise would not affect the optical communication systems, as all modes would remain synchronized during transmission and detection.

However, in practice all modes do not arrive simultaneously at the receiver because they travel at slightly different speeds. Such a non synchronization not only degrades the signal to noise ratio (SNR) of the received signal but also leads to inter symbol interference (ISI).

8.2.2.5 Laser safety

Both visible and infrared light can cause immediate and permanent damage to the eyes. The shorter wavelengths cause damage to the retina and the longer wavelengths affect the cornea. In both the cases, the medical science cannot offer remedy once the damage is done. Permanent loss of eyesight can take less than a second by exposure to light. We can not even see.

It is very important that we should take precautions and careful while handing laser sources. We should never look into:

- A live laser source
- An unknown light source
- Any fibers until you have ascertained that it is safe. Check it yourself even it trusted colleagues say that ‘it is OK we have just checked it out’. They may be talking about a different fiber or they may have made a mistake.
- Beware of concentrating the light by instruments such as all happen when checking a cleave or the end condition of a connector with a microscope.

8.2.2.6 International standards on Laser classifications

Laser classifications are based on international standard titled Radiation Safety of Laser Products, Equipment Classification, Requirements and User’s Guide, referred to as IEC standard 60825. Additional national standards apply in each country. In the European Union they are published as EN 60825 or more specifically as:

EN 60825	Safety of laser products
EN 60825-1	Safety of laser products Part -1: Equipment classification requirements and user guides
EN 60825-2	Safety of laser products Part-2: Safety of optical fibre communication systems (OFCS)

The IEC 60825 classification has used four classes of laser based on the accessible emission limit (AEL). Every laser must carry a warning label stating the class of laser as shown in figure 8.7

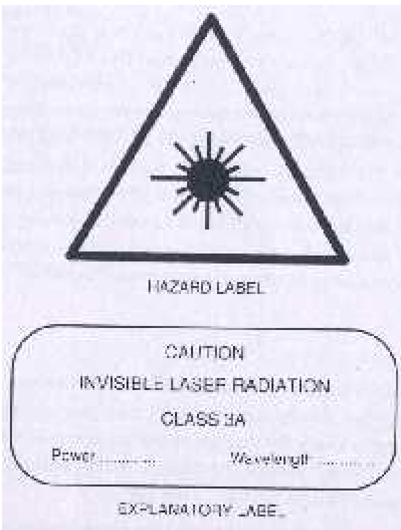


Figure 8.7 laser warning label

It is the responsibility of manufacturer to determine the classification of the laser. They classify by measuring the wavelength, output power and the pulsing characteristics.

IEC classifications are:

Class 1	Safe under reasonably foreseeable conditions of operations. Note that it does not say 'safe under any conditions'.
Class 2	Visible lasers with light output within the visible spectrum of 400-700nm. There is an assumption here that the blink reflex will close the eyes within a fraction of a second and hence provide protection. Prolonged exposure will cause damage.
Class 3a	Safe for viewing by the unaided eye either, visible or infrared light but possibly unsafe when viewed with instruments.
Class 3b	Direct viewing is hazardous but reflected light is normally OK. Not to be viewed with instruments.
Class 4	Very **DANGEROUS**. Even reflections are hazardous and the direct beam can cause fires and skin injury. Not normally used for communications.

- Control measures

  For classes 2, 3and 4, control measures are employed such as interlocks, keys, laser 'on' warning lights, remote switching, prevention of reflections across walkways. The precautions depend on the situation, use and power of the laser. The appropriate national standards as well as IEC 60825 should be consulted for guidance.

8.2.2.7 Laser specifications

- Wavelength

  The wavelength quoted is only a typical value. So if we want to buy a laser for the 1300nm window, the one offered may well be quoted as 1285-1320nm and the actual wavelength will fall somewhere between these limits. Sometimes it would be available in market as 1300nm (nominal).

- Rise and fall time

  This is a measure of how quickly the laser can be switched on or off measured between the output levels of 10-90% of maximum (see figure 8.8). A typical value is 0.3ns.

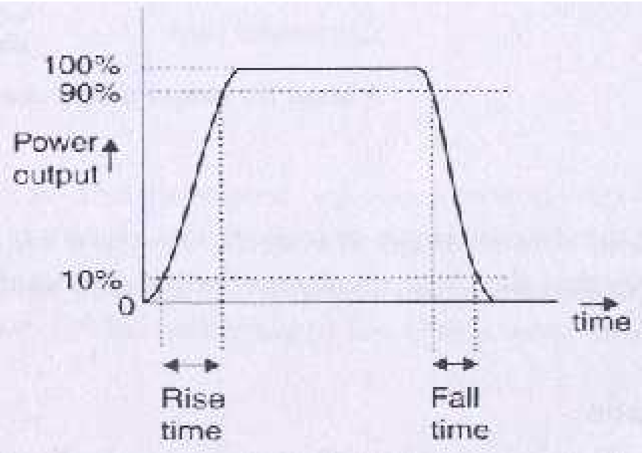


Figure 8.8 Rise and Fall time

- Threshold current

  This is the current (see figure 8.9) at which the laser operates. A typical value is 50mA and the normal operating current would be around 70 mA.

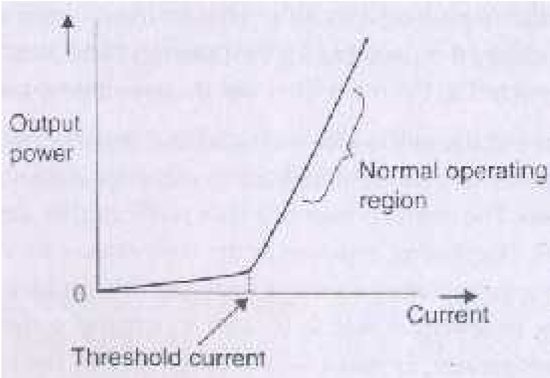


Figure 8.9

- Spectral width

  This is the bandwidth of the emitted light. Typical spectral widths (see figure 8.10) lie between 1nm and 5nm. A laser with an output of 1310nm with a spectral width of 4nm, would emit infrared light between 1308nm and 1312nm.

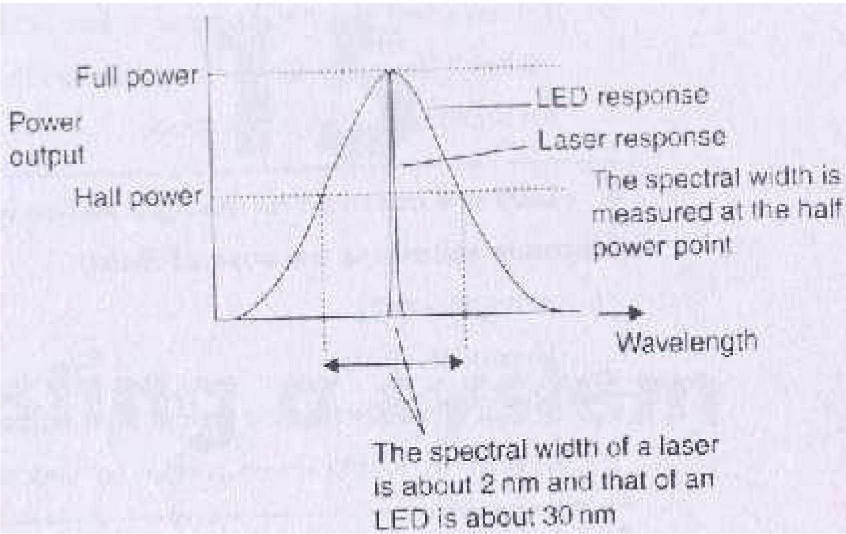


Figure 8.10 spectral width of LEDs and lasers

- Operating temperature

  Typical values are -10^{0}C to +65^{0}C and therefore match the temperature ranges of fibres quite well.

- Voltages and currents

  The specifications also list the operating voltages and currents of the monitor detector, the cooler current and the thermistor resistance. These values are very much required for the equipment designer and engineers.

- Output power

  The output power may be quoted in watts or in dBm.

8.3 Optical Detectors

8.3.1 Introduction to Optical detectors

The role of an optical receiver is to convert the optical signal back into electrical signal and recover the data transmitted through the optical fibre communication system. Its vital component is a photo detector that converts light into electricity through the photoelectric effect. Some the advantages are:

- high sensitivity
- fast response
- low noise
- low cost
- high reliability

8.3.2 Light absorption technique

The fundamental mechanism behind the photo-detection process is optical absorption. If the energy (hv) of incident photons exceeds the band gap energy, an electron-hole pair is generated each time a photon is absorbed by the semiconductor. Under the influence of an electric field setup by an applied voltage, electrons and holes are swept across the semiconductor, resulting in a flow of electric current.

The photocurrent (I_p) is directly proportional to the incident optical power (P_{in}).

$$I_p = RP_{in}$$

Where ' R ' is the responsivity of the photodetector

8.3.3Important characteristics of Optical detectors

- Wavelength (λ)

  The wavelength of the photodector is depends upon the semiconductor material by which it is made.

- Responsivity (R)

  It is ratio of the photocurrent and Optical power incident on a photo-detector. The unit is Photo current per unit optical power incident (A/W).

It can be calculated as : $R = \eta\,(e/hv)$

where η - Quantum efficiency
e - Elementary charge
hv - photon energy

- Quantum efficiency (η)

  It can be defined as fraction of photons which contribute to the external photocurrent. It is the ratio of electron generation rate and photon incidence rate. The quantum efficiency of a photodiode can be very high – in some cases more than 95% – but significantly varies with wavelength. Apart from a good internal efficiency, a good quantum efficiency requires good suppression of reflections e.g. with an anti-reflection coating.

- Dark current (I_d)

  Dark current is the current generated in a photodetector in the absence of any optical signal. It develops from stray light or from thermally generated electron-hole pairs. For a good photodector, the dark current should be negligible (I_d <10nA) .

- Rise time (T_r)

  It is defined as the time over which the current rise from 10 to 90% of its final value when the incident optical power is changed abruptly. The rise time depends on the time taken by electrons and holes to travel to the electrical contacts. It also depends on the response time of the electrical circuit to process the photocurrent. There is always trade off between the bandwidth and the responsivity (speed vs sensitivity) of a photodetector.

- Bandwidth (Δf)

  The speed, i.e. the bandwidth, related to the rise and fall time, often influenced by the capacitance. The speed (bandwidth) of a photodiode is limited either by electrical parameters (capacitance and external resistor - RC) or by internal effects such as the limited speed of the generated carriers.

Highest bandwidths of tens of gigahertz are usually achieved with small active areas (diameters well below 1 mm) and small absorption volumes. Such small active areas are still practical particularly for fiber-coupled devices, but they limit the achievable photocurrents to the order of 1 mA or less, corresponding to optical powers of ≈2 mW or less. Higher photocurrents are actually desirable for suppression of shot noise and thermal noise. Larger active areas (with diameters up to the order of 1 cm) allow for handling larger beams and for much higher photocurrents, but at the expense of much lower speed.

The combination of high bandwidth (tens of GHz) and high photocurrents (tens of mA) is achieved in velocity-matched photodetectors, containing several small-area photodetectors, which are weakly coupled to an optical waveguide and deliver their photocurrents into a common RF waveguide structure.

8.3.4 Semiconductor Materials

Typical photodiode materials are:

Name of the material	Operational characteristics
silicon (Si)	low dark current, high speed, good sensitivity roughly between 400 nm and 1000 nm (best around 800-900 nm)
germanium (Ge)	high dark current, slow speed due to large parasitic capacity, good sensitivity roughly between 600 nm and 1800 nm (best around 1400-1500 nm)
indium gallium arsenide (InGaAs)	expensive, low dark current, high speed, good sensitivity roughly between 800 nm and 1700 nm (best around 1300-1600 nm)

8.3.1 Types of Photo detectors

- p-i-n photodiode
- avalanche photodiode
- metal-semiconductor-metal (MSM)
- p-i-n photodiode

A p-i-n photodiode, also called as PIN photodiode, is a photodiode with an intrinsic (i) (i.e., undoped) region in between the n- and p-doped regions. Most of the photons are absorbed in the intrinsic region, and carriers generated therein can efficiently contribute to the photocurrent. In Figure 1, the electrodes are shown in black: the cathode is a flat electrode, whereas the anode has the form of a ring (of which two opposite parts are seen in the shown cross section). The positive pole of the (reverse) bias voltage is connected to the cathode. On top of the p region, there is an anti-reflection coating.

Compared with an ordinary p-n photodiode, a p-i-n photodiode (see fig 8.11) has a thicker depletion region, which allows a more efficient collection of the carriers and thus a larger quantum efficiency, and also leads to a lower capacitance and thus to higher detection bandwidth.

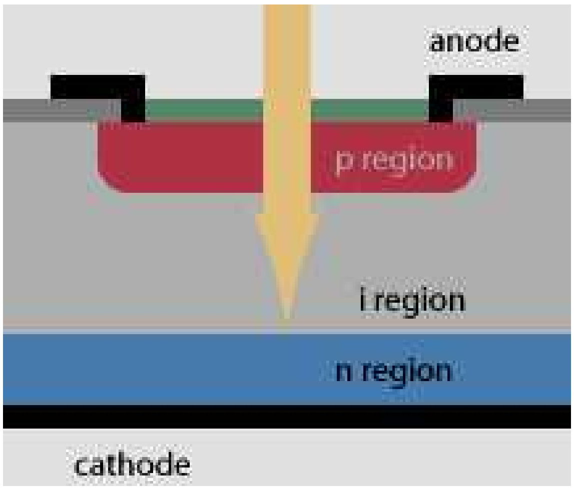


Figure 8.11 PIN diode with regions

The most common p-i-n diodes are based on silicon. They are sensitive throughout the visible spectral region and in the near-infrared up to roughly 1 μm. At longer wavelengths, the absorption efficiency and thus the responsivity drops sharply, but the parameters of this cut-off depend on the thickness of the i region.

For longer wavelengths up to ≈1.7 μm (or with extended spectral response up to 2.6 μm), InGaAs p-i-n diodes are available, although at significantly higher prices (particularly for large active areas). Germanium p-i-n diodes can be an alternative.

The fastest p-i-n photodiodes have bandwidths of the order of tens of GHz. Their active areas typically have a diameter of only a few hundred microns. Some of them are available in fiber-coupled form and can be applied e.g. for receivers in optical fiber communications.

The operating characteristics of p-i-n photodiodes made with Si, Ge, and InGaAs listed in below table for better understanding parameters.

Parameter	Symbol	Unit	Si	Ge	InGaAs
Wavelength	λ	μm	0.4-1.1	0.8-1.8	1.0-1.7
Responsivity	R	A/W	0.4-0.6	0.5-0.7	0.6-0.9
Quantum efficiency	η	%	75-90	50-55	60-70
Dark current	I_d	nA	1-10	50-500	1-20
Rise time	T_r	ns	0.5-1	0.1-0.5	0.02-0.5
Bandwidth	Δf	GHz	0.3-0.6	0.5-3	1-10
Bias voltage	V_b	volts	50-100	6-10	5-6

- Avalanche photodiode

  An avalanche photodiode is a semiconductor-based photo-detector (photodiode) which is operated with a relatively high reverse voltage (typically tens or even hundreds of volts), sometimes just below breakdown. In this system, carriers (electrons and holes) excited by absorbed photons are strongly accelerated in the strong internal electric field, so that they can generate secondary carriers, as it also occurs in photomultipliers. The avalanche process effectively amplifies the photocurrent by a significant factor. In this way, avalanche photodiodes can be used for very sensitive detectors, which need less electronic signal amplification and are thus less sensitive to electronic noise. However, the avalanche process itself is subject to quantum noise and amplification noise, which can offset the mentioned advantage. Tentatively, their noise performance is better compared with ordinary p-i-n photodiodes in the high-speed systems, but not for low detection bandwidths.

Silicon-based avalanche photodiodes are sensitive in the wavelength region from 450 to 1000 nm, with the maximum responsivity occurring around 600-800 nm, i.e., at somewhat shorter wavelengths than for silicon p-i-n diodes. For longer wavelengths, APDs based on germanium or indium gallium arsenide (InGaAs) are used.

The operating characteristics of avalanche photodiode made with Si, Ge, InGaAs listed in below table for better understanding parameters.

Parameter	Symbol	Unit	Si	Ge	InGaAs
Wavelength	λ	μm	0.4-1.1	0.8-1.8	1.0-1.7
Responsivity	R_{APD}	A/W	80-130	3-30	5-20
APD gain	M	-	100-500	50-200	10-40
k-factor	k_A	-	0.02-0.05	0.7-1.0	0.5-0.7
Dark current	I_d	nA	0.1-1	50-500	1-5
Rise time	T_r	ns	0.1-2	0.5-0.8	0.1-0.5
Bandwidth	Δf	GHz	0.2-1	0.4-0.7	1-10
Bias voltage	V_b	volts	200-250	20-40	20-30

- Metal-Semiconductor-Metal (MSM)

  These are fast photodetector devices based on metal-semiconductor (Schottky) contacts.

A metal-semiconductor-metal photodetector (MSM detector) is a photodetector device containing two Schottky contacts, i.e., two metallic electrodes on a semiconductor material, in contrast to a p-n junction as in a photodiode. During operation, some electric voltage is applied to the electrodes. When light impinges the semiconductor between the electrodes, it generates electric carriers (electrons and holes), which are collected by the electric field and thus can form a photocurrent.

MSM detectors can be made faster than photodiodes. Their detection bandwidths can reach hundreds of GHz, making them suitable for very high speed optical fiber communication systems.

8.3.2 Optical detectors specifications

- Wavelength

  This is quoted as a range, example 1000nm to 1600nm, or by stating the frequency that provides the highest output, example peak wavelength is 850nm.

- Dynamic range or optical input power

  Dynamic range is the ratio of the maximum input power to the lowest. It is quoted in decibels, example : 21dB.

The typical input power is the same information expressed in watts, example 1µW to 125µW.

- Responsivity

  A measure of how much output current is obtained for each watt of input light, example : 0,8A/W . This means that the current will increase by 0.8 amps for every watt of increased light power.

- Responsive time

  This is the rise and fall time, determines that fastest switching speed of the detector and hence limits the maximum transmission rate, example t_r or t_f is 3.5ns.

- Bit rate or data rate or bandwidth

  These are all measures of the maximum speed of response to incoming signals and are therefore determined by the response time.

Objective:

1.Gallum-Aluminium-Arsenide material emits light in the range of wavelengths between ---------------------------------------.
a) 800 – 900 nm b) 800 – 900 µm c) 800 – 900 m d) 800 – 900 cm

2.Indium-Gallium-Arsenide-Phosphide material can emit light in the range of wavelengths between ---
a) 1000 – 1600 µm b) 1000 – 1600 nm c) 1000 – 1800 nm d) 1200 – 1600 nm

3.Compound semiconductors are made from elements of different columns of --- of the periodic table.
a) Group III and Group V or Group IV and Group V b) Group III and Group V only
c) Group IV and Group V only d) Group III and Group V and Group IV and Group V

4.The external quantum efficiency is always ------------------------ the internal quantum efficiency.
a) more thanb) equal to c) less than

5.The internal quantum efficiency is always ----------------------------- the external quantum efficiency.
a) more thanb) equal to c) less than

6.LED sources are suitable for local area network applications with bit rate ---
a) 10 – 100 bps b) 10 – 100 Kbps c) 10 – 100 Mbps d) 10 – 100 Gbps

7.Normally an LED can couple up to --------------------- of the internally generated power into an optical fiber.
a) 1 % b) 10 % c) 100 % d) 0.1 %

8.The normal operating current of laser source is about -----------------------
a) 70 µA b) 70 nAc) 70 mAd) 70A

9.The spectral width of laser is about -------------------------------
a) 1 – 5 µm b) 1 – 5 nm c) 1 – 5 mm d) 1 – 5 m

Objective:

1. Explain Two fundamental processes of light emitting with diagrams. Write short notes on LEDs.
2. Write your observations on figure 8.3 i.e. power-current curves at several temperatures.
3. 'Semiconductor lasers are better than LEDs as an optical sources'. justify the statement.
4. Is it required to be follow safety methods while working with optical sources? why ?
5. Mention the important precautions.
6. Write the importance of Rise time, fall time and threshold current.
7. What are the different types of photo detectors? write a short notes on each detector.
8. What do you mean by 'Dark current' ? How it is generated in photo detectors?

CHAPTER 9

BASIC OPTICAL NETWORK COMPONENTS AND INTERFACES

9.1 Optical Transmitters

The Optical transmitter consists of two main sub parts. They are light sources (LEDs and Laser) and modulators. We recollect few seconds about sources.

There are different types of LED sources. They are Surface emitting LEDs and Edge emitting LEDs. Similarly we have two types of laser sources. They are Febry – Perot and DFB.

There are two different types of transmitter. They are transmitter with Internal modulators or Intensity modulators. The intensity of radiated power is varied between maximum and minimum values. The block diagram of transmitter with internal modulators consists of different sub components are shown in figure 9.1.

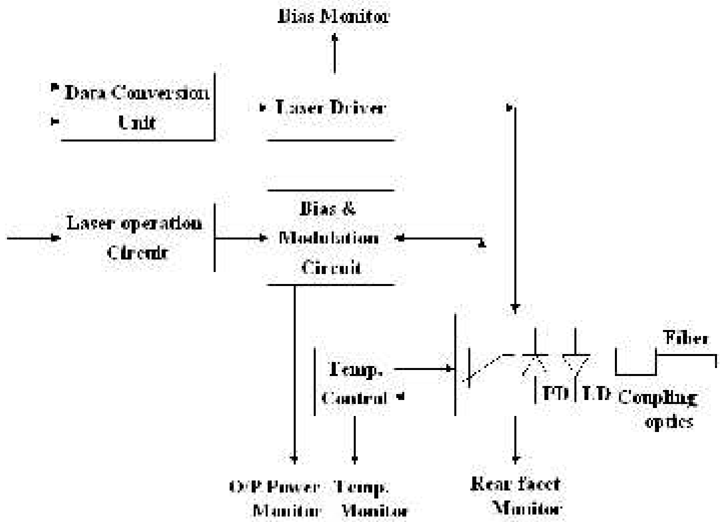


Figure 9.1 Block diagram of transmitter with internal modulator

The transmitter with internal modulator is rarely used due to following disadvantages.

9.1.1Disadvantages

The bandwidth is restricted by LDs relaxation frequency. The fast variation of LDs radiating frequency as per pulse or modulating current results in broadening of pulse known as ‘chirp’.

This severely affects the limits the high speed. Finally high driving current required to launch high power into fiber for long-haul optical links.

Another type of transmitter is with External modulator. In this type, the Laser diode radiates continuous light while change in power occurs outside laser diode (see figure 9.2)

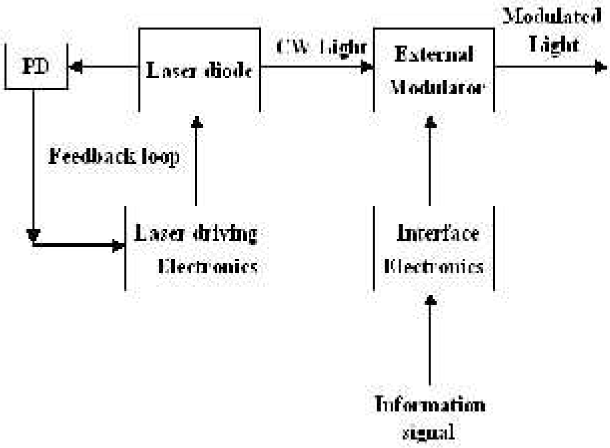


Figure 9.2 Functional blocks of transmitter with external modulator

9.1.2 Advantages of external modulators

The LD circuit is not loaded with extra task of modulation. The feedback loop using photo diode provides a very stable level of power radiated by the LD. This avoids chirp.

There are two types of external modulators. They are Mach-Zender External Modulator (MDM) and Electro absorption modulator (EA).

9.1.3 Operation of Mach-Zender External Modulator

The Optical waveguide is made of lithiumniobate (see figure 9.3), which is interposed between LD and fiber. The light from LD is split equally when it enters waveguide. When no modulating voltage is applied, both halves of beam are equal and add constructively. The refractive index of lithiumniobate changes when an electrical voltage is applied to it. When modulating voltage is one beam phase shifted by $+90^0$ (due to change of RI of that portion of waveguide) and other beam phase shifted by $–90^0$. In practice, any desired phase shift can be achieved.

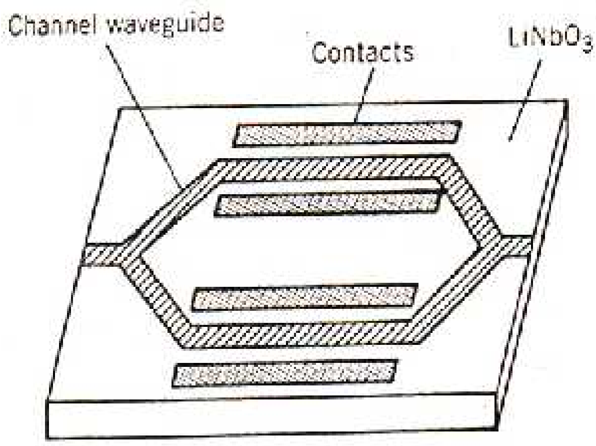


Figure 9.3 MDM modulator

9.1.4 Disadvantages of MDM

The insertion loss is about 5 dB. It couples high power LD output to modulator. It requires Y-fed Balanced Bridge Modulator for proper functioning.

9.1.5 Electro absorption modulator

A DFB laser radiates continuous wave light, which is fed through waveguide made of semiconductor material. When no modulation voltage applied, the waveguide is transparent to light fed. Because it's cut off wavelength is less than wavelength of incident light. When modulation voltage is applied, the band gap energy of waveguide decreases (Franz-Keldysh effect). In turn the band-gap energy decreases, cut off wavelength increases and waveguide absorbs incident light.

9.1.6 Advantages of Eletro absorption modulator

This modulator can be fabricated onto one substrate as DFB laser. It is easy to handle because the Optical power output is 0dBm. The modulator drive voltage is low (i.e 2V). It can handle 10Gbps (STM – 64) data rates very easily. It is most suitable for WDM applications.

9.2 Optical Receivers

The Digital Optical receiver has three major sections (see figure 9.4). The three major sections are the front end, the liner channel and the decision circuit.

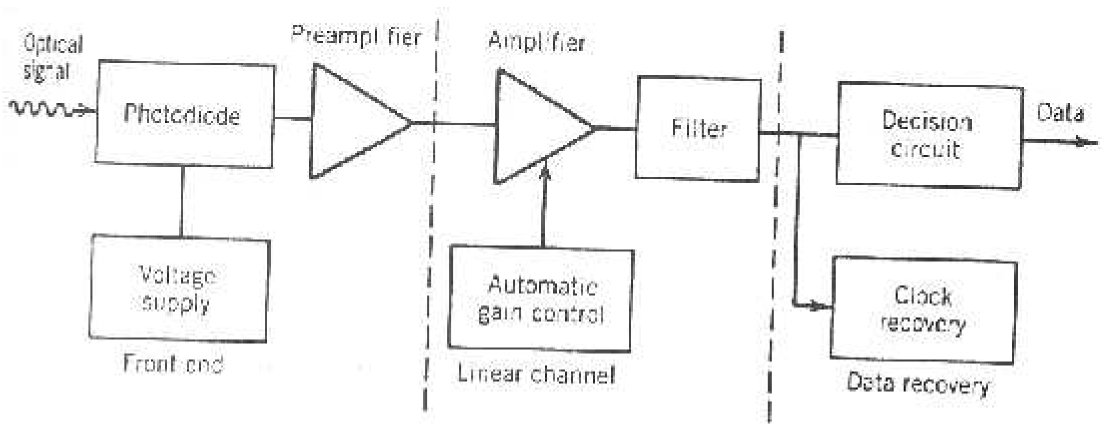


Figure: 9.4 Digital Optical receivers with components and sections

Let us discuss in brief the functions of the each major sections of receiver.

9.2.1 The Front end

The front end of a receiver consists of a photodiode followed by a preamplifier. The optical signal is coupled onto the photodiode. The photodiode converts optical bit stream into an electrical time-varying signal. The function of the preamplifier is to amplify the electrical signal for further processing. The design of front end requires a trade-off between speed and sensitivity.

9.2.2 The Linear channel

The linear channel in optical receivers consists of a high gain amplifier and low pass filter. An equalizer is added before the amplifier to correct for the limited bandwidth of the front end. The amplifier gain is controlled automatically to limit the average output voltage to a fixed level irrespective of the incident average optical power at the receiver.

The low pass filter shapes the voltage pulse. Its purpose is to reduce the noise without introducing much Inter symbol interference (ISI).

9.2.3 The Decision circuit

The data-recovery section of optical receivers consists of a decision circuit and a clock recovery circuit. The function of the clock recovery circuit is to isolate a spectral component when frequency (f) is equal to Bit rate (B) from the received signal. This component provides information about the bit slot (T_B = 1/B) to decision circuit and helps to synchronize the decision process.

The decision circuit compares the output from the linear channel to a threshold level, at sampling times determined by the clock-recovery circuit, and decides whether the signal corresponds to bit 1 or bit 0. The best sampling time corresponds to the situation in which the signal level difference between 1 and 0 bits is maximum. It can be determined from the ‘eye diagram’ (see figure 9.5) formed by superposing 2-3 bit long electrical sequences in the bit stream on top of each other. The resulting pattern is called an eye diagram because of its appearance.

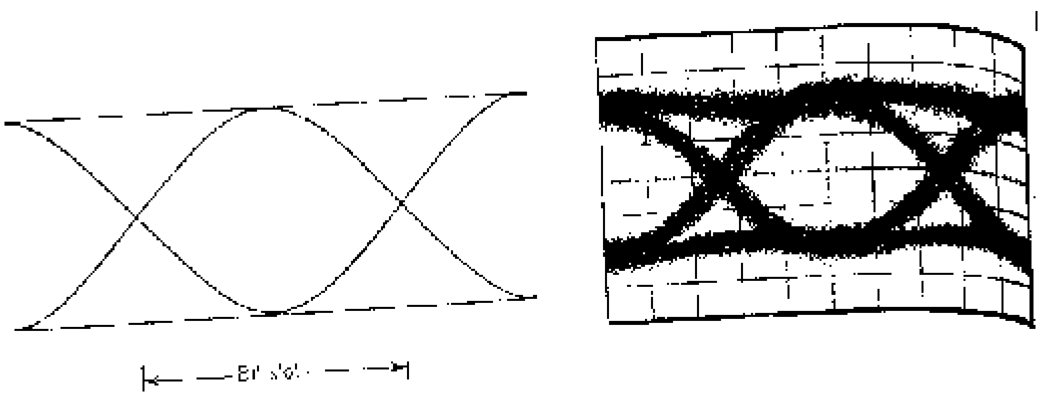


Figure 9.5 Ideal and degraded eye patterns for the NRZ format

The eye diagram provides a visual way of monitoring the receiver performance. The above figure: 9.5 shows an ideal eye diagram together with a degraded one in which the noise and the timing jitter lead to a partial closing of the eye. The best sampling time corresponds to maximum opening of the eye. The closing of the eye means, it is an indication that the receiver is not performing properly.

Because of noise inherent in any receiver, there is always a finite probability that a bit would be identified incorrectly by the decision circuit. Digital receivers are designed to operate in such a way that the error probability is quite small (less than 10^{-9}).

9.3 Optical Amplifiers (OA)

The Optical signal is attenuated due to fiber, passive components and different ports. The signal strength can be improved using either regenerators or Optical Amplifiers. Due to attenuation, there are limits to how long a fiber segment can propagate a signal with integrity before it has to be regenerated. Before the introduction of optical amplifiers (OAs), there had to be a repeater for every signal transmitted. The Optical Amplifier has made it possible to amplify all the wavelengths at once and without optical-electrical-optical (OEO) conversion. Besides being used on optical links, optical amplifiers also can be used to boost signal power after multiplexing or before de multiplexing, both of which can introduce loss into the system

The regenerators are specific to bit rate and modulation format. The system up gradation requires replacement of regenerators. Each wavelength of WDM requires separate regenerator. It also source for jitter. The advantage is, it eliminates noise at every stage of regeneration.

But the Optical amplifiers are independent of bit rate and modulation format. The system up gradation does not require change in amplifiers. These have large gain and bandwidth, hence can simultaneously amplify the different wavelengths. It avoids jitter. But it introduces noise in signal.

The amplifiers can be categorized into three different types based on their working principle. They are Erbium Doped Fiber Amplifier (EDFA), Raman Amplifier and Semiconductor Optical Amplifier. The Erbium Doped Fiber Amplifier is discussed in brief due to its advantages over other two types.

9.3.1 Erbium-Doped Fiber Amplifier

Erbium is a rare-earth element that, when excited, emits light around 1.54 micrometers—the low-loss wavelength for optical fibers used in DWDM. Figure: 9.6 shows a simplified diagram of an EDFA. A weak signal enters the erbium-doped fiber, into which light at 980 nm or 1480 nm is injected using a pump laser. This injected light stimulates the erbium atoms to release their stored energy as additional 1550-nm light. As this process continues down the fiber, the signal grows stronger. The spontaneous emissions in the EDFA also add noise to the signal; this determines the noise figure of an EDFA.

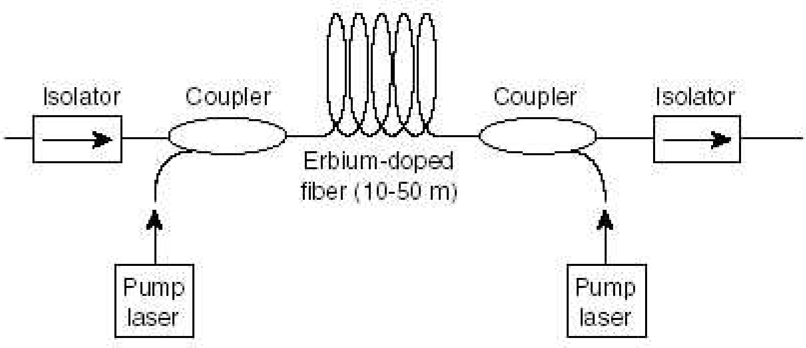


Figure 9.6 Erbium-Doped Fiber Amplifier Design

The key performance parameters of optical amplifiers are gain, gain flatness, noise level, and output power. EDFAs are typically capable of gains of 30 dB or more and output power of +17 dB or more. The target parameters when selecting an EDFA, however, are low noise and flat gain. Gain should be flat because all signals must be amplified uniformly. While the signal gain provided with EDFA technology is inherently wavelength-dependent, it can be corrected with gain flattening filters. Such filters are often built into modern EDFAs. Low noise is a requirement because noise, along with signal, is amplified. Because this effect is cumulative, and cannot be filtered out, the signal-to-noise ratio is an ultimate limiting factor in the number of amplifiers that can be concatenated and, therefore, the length of a single fiber link. In practice, signals can travel for up to 120 km between amplifiers. At longer distances of 600 to 1000 km the signal must be regenerated. That is because the optical amplifier merely amplifies the signals and does not perform the 3R functions (reshape, retime, retransmit). EDFAs are available for the C-band and the L-band.

A typical Optical amplifier (see figure: 9.6a) based on EDFA Technology features, applications and specifications are listed below for the clear understanding about OA.

Figure : 9.6a Optical amplifier module

EDFA DWDM model is designed and manufactured especially for applications in dense WDM optical networks. It provides high power, high gain and low noise amplification for 16, 32 and even 64 channels at wavelengths of C band.

Following three sub-types are provided under this class to meet the optical amplification requirement on different segment of DWDM networks.

Type 1: Inline amplifier - features medium input power, high output power, high optical gain and low noise figure. This type is designed for optical amplification between two network nodes on the main optical link and handles all optical channels.

Type 2: Booster amplifier - features high input power, high output power, medium optical gain. This type is design for amplification of high overall input optical power.

Type 3: Two stage amplifier - features with medium input power, high output power, high optical gain and middle stage design. Up to 11dB loss can be tolerated in the middle stage, which enables the use of DCM (dispersion compensation module), optical filters, add/drop modules, etc. in the middle stage.

- Features

Excellent gain flatness, Low noise figure, Wide operating wavelength range and Good network control interface.

- Applications

Digital optical communication networks, DWDM networks and High power optical amplification.

9.3.2Specifications

- General Specifications

Parameter	Conditions	Min	Max	Units	Notes
Operating Temperature		-5	55	*C	
Maximum Case Temperature			70	*C	
Operating Humidity	Non-condensing	5	90	%RH	
Signal Wavelength Range	Vacuum	1529.55	1561.42	nm	
Transient Response Time	6 dB Add/Drop		100	µs	@<2µs rising time step function @Modulated frequency=270HZ
Transient Overshoot	6 dB Add/Drop		±1	dB	@<2µs rising time step function @Modulated frequency=270HZ
Input/output Return Loss			-25	dB	Measured with pumps turned on and worst case reflection at other ports
Input/output pump leakage			-25	dBm	
PDG			0.5	dB	Measured with a small signal probe over all states of polarization across the bandwidth of the amplifier under saturated condition
PMD			0.6	ps	Wavelength sweep method

- Inline Amplifier

Parameter	Min	Typical	max	units	Notes
Rated Gain	22	25	28	dB	
Input Signal Power (Pin)	-19		0	dBm	@gain=22dB
	-22		-3	dBm	@gain=25dB
	-25		-6	dBm	@gain=28dB
Total Output Power (Pout)		22	22.3	dBm	@Gain range from 22dB to 28dB @At the APC mode, the output power can be set and work well in. the actual gain range 22~28dB.
Noise Figure		5.5	6.0	dB	@Pin=(-25~0dBm)
Amplifier Gain ripple	-	1.0	2.0	dB	@Gain range from 22dB to 28dB @-5~55ºC
Output Power Stability	-0.15		0.15	dB	-25 dBm <Pin <0dBm
Output Power Stability over Temperature	-0.35		0.35	dB	-25 dbm <Pin<0dbm

- Power Booster Amplifier

Parameter	Min	Typ	Max	Unit	Notes
Rated Gain	14	17	20	dB	
Input Singnal Power (Pin)	-11		8	dBm	@Gain=14dB
	-14		5	dBm	@Gain=17dB
	-17		2	dBm	@Gain=20dB
Total Output Power (Pout)		22	22.3	dBm	@Gain range from 14dB to 20dB @At the APC mode, the output power can be set and work well in the actual gain range 14~20dB
Noise Figure		6.5	9	dB	@Pin=-17~8dBm
Amplifier Gain ripple		1.0	2.0	dB	@Gain range from 14dB to 20dB @-5~55ºC
Output Power Stability	-0.15		0.15	dB	-17dBm <Pin<2dBm
Output Power Stability Over Temperature	-0.35		0.35	dB	-17 dBm <Pin<2dBm

- Two-Stage Amplifier

Parameter	Min	Typical	Max	Units	Notes
Rated Gain	22	25	28	dB	
Rated mid-stage loss			11	dB	Gain range from 22 dB to 28 dB
Input Signal Power	-19		0	dBm	@gain=22dB
	-22		-3	dBm	@gain=25dB
	-25		-6	dbm	@gain=28dB
Total Output Power (Pout)		22	22.3	dBm	@Gain range from 22dB to 28 dB At the APC mode, the output power can be set and work well in the actual gain range 22~28dB
Pre-amp Output Power (/channel)			3.0	dBm	Including connector @Gain range from 22 dB to 28 dB
Noise Figure			7.5	dB	@Mid-stage loss=10dB @Pin+(-25~0dBm)
Amplifier Gain ripple		1.0	2.0	dB	Gain range from 22dB to 28dB @-5~55ºC
Output Power Stability	-0.15		0.15	dB	-25 dBm <Pin<0dBm
Output Power Stability over Temperature	-0.35		0.35	dB	-25dBm < Pin<0dBm

9.4 Wave length Division Multplexing (WDM) principles

WDM systems send signals from several sources over a single fiber on different wavelengths closely spaced. A multiplexer, which takes optical wavelengths from multiple fibers and converges them into one beam. At the receiving end the system must be able to separate out the components of the light so that they can be discreetly detected. Demultiplexers perform this function by separating the received beam into its wavelength components and coupling them to individual fibers. Demultiplexing must be done before the light is detected, because photo detectors are inherently broadband devices that cannot selectively detect a single wavelength.

In a unidirectional system (see Figure 9.7), there is a multiplexer at the sending end and a demultiplexer at the receiving end. Two systems would be required at each end for bidirectional communication, and two separate fibers would be needed.

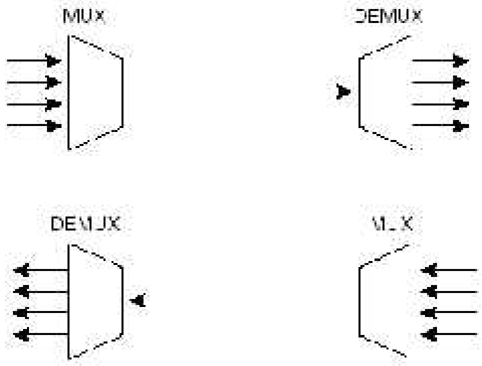


Figure 9.7 Unidirectional multiplexer system

In a bidirectional system, there is a multiplexer/demultiplexer at each end (see Figure 9.8) and communication is over a single fiber pair.

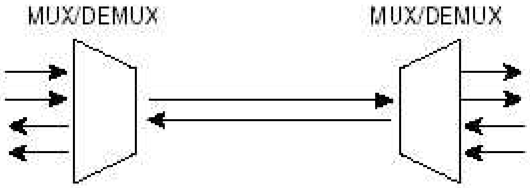


Figure : 9.8 Bidirectional mux/demux system

Multiplexers and demultiplexers can be either passive or active in design. Passive designs are based on prisms, diffraction gratings, or filters, while active designs combine passive devices with tunable filters. The primary challenges in these devices are to minimize cross-talk and maximize channel separation. Cross-talk is a measure of how well the channels are separated, while channel separation refers to the ability to distinguish each wavelength.

9.4.1 Techniques for Multiplexing and Demultiplexing

A simple form of multiplexing or demultiplexing of light can be done using a prism. Figure : 9.9 demonstrates the demultiplexing case. A parallel beam of polychromatic light impinges on a prism surface; each component wavelength is refracted differently. This is the “rainbow” effect. In the output light, each wavelength is separated from the next by an angle. A lens then focuses each wavelength to the point where it needs to enter a fiber. The same components can be used in reverse to multiplex different wavelengths onto one fiber.

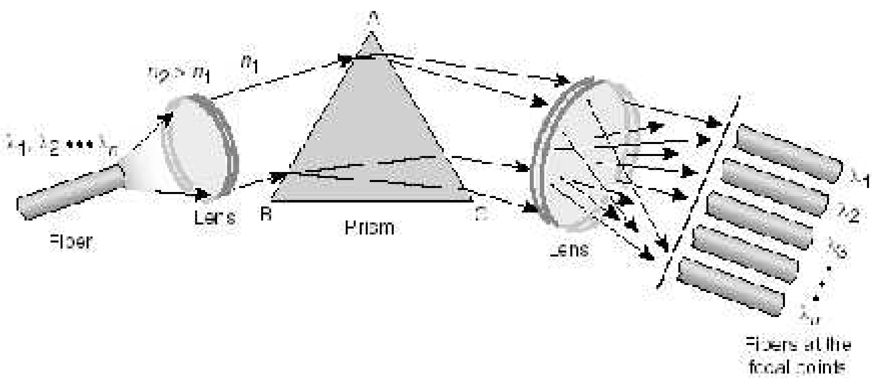


Figure: 9.9 Demultiplexing technique with prism

Another technology is based on the principles of diffraction and of optical interference. When a polychromatic light source impinges on a diffraction grating (see Figure 9.10), each wavelength is diffracted at a different angle and therefore to a different point in space. Using a lens, these wavelengths can be focused onto individual fibers.

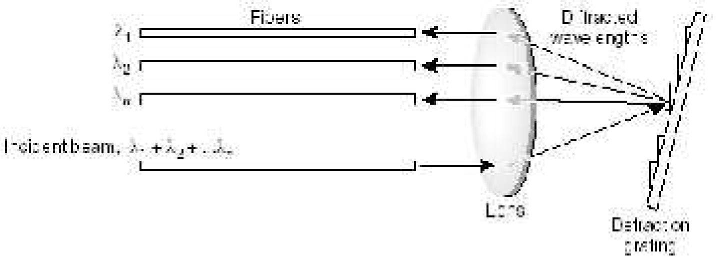


Figure 9.10 Principle of diffraction and optical interference

Arrayed waveguide gratings (AWGs) 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 waveguides with a fixed difference in the path length between adjacent channels (see Figure 9.11). The waveguides are connected to cavities at the input and output. When the light enters the input cavity, it is diffracted and enters the waveguide array. There the optical length difference of each waveguide introduces phase delays in the output cavity, where an array of fibers is coupled. The process results in different wavelengths having maximal interference at different locations, which correspond to the output ports.

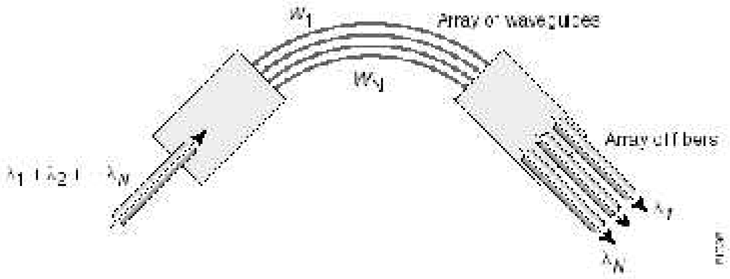


Figure 9.11 AWG principle

A different technology uses interference filters in devices called thin film filters or multilayer interference filters. By positioning filters, consisting of thin films, in the optical path, wavelengths can be sorted out (demultiplexed). The property of each filter is such that it transmits one wavelength while reflecting others. By cascading these devices, many wavelengths can be demultiplexed (see Figure 9.12).

Of these designs, the AWG and thin film interference filters are gaining prominence. Filters offer good stability and isolation between channels at moderate cost, but with a high insertion loss. AWGs are polarization-dependent (which can be compensated), and they exhibit a flat spectral response and low insertion loss. A potential drawback is that they are temperature sensitive such that they may not be practical in all environments. Their big advantage is that they can be designed to perform multiplexing and demultiplexing operations simultaneously. AWGs are also better for large channel counts, where the use of cascaded thin film filters is impractical.

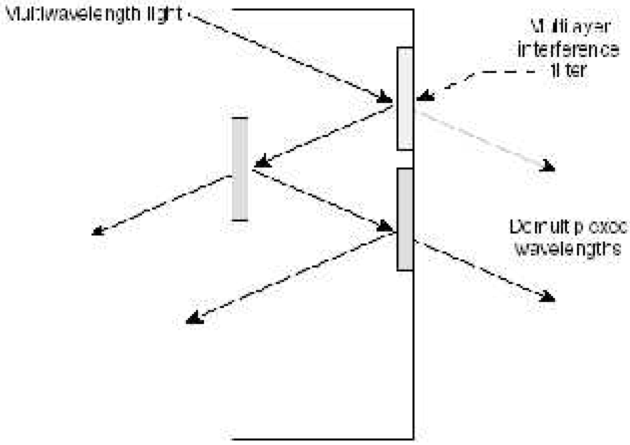


Figure: 9.12 Mux/Demux with filter

9.4.2 Add-Drop multiplexers

Between multiplexing and demultiplexing points in a optical communication system, there is area in which multiple wavelengths exist. It is often desirable to be able to remove or insert one or more wavelengths at some point along Optical link. An optical add/drop multiplexer performs this function. Rather than combining or separating all wavelengths, the OADM can remove some while passing others on. OADMs are key part of moving toward the goal of all optical networks.

OADMs are similar in many respects to SONET ADM, except that only optical wavelengths are added and dropped. And no conversion of the signal from optical to electrical takes place. Figure 9.13 is a schematic representation of the add-drop process. This example includes both pre and post amplification; these components that may or may not be present in an OADM, depending upon its design.

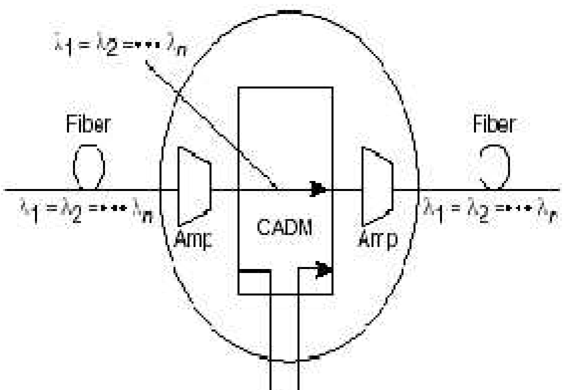


Figure 9.13 Add-drop multiplexing process

There are two general types of OADMs. The first generation is fixed device that is physically configured to drop specific predetermined wavelengths while adding others. The second generation is reconfigurable and capable of dynamically selecting which wavelengths are added and dropped.

Thin-film filters have emerged as the technology of choice for OADMs in current metropolitan systems because of their low cost and stability. For emerging second generation of OADMs, other technologies, such as tunable fiber gratings and circulators, will come into prominence.

9.5 Optical Switches

The optical switches are used in Optical cross connects (OXC). The switch use a mechanical or thermo-optic or electro-optic or all optical technique to switch a input signal to spatially separated output ports.

Mechanical switch is simplest. A simple mirror can act as a switch if the output direction can be changed by tilting the mirror. The use of bulk mirrors is impractical because large number of switches are needed to make a Optical cross connect (OXC). For this reason, a micro-electro-mechanical system (MEMS) is used for switching. This MEMS switch uses a two dimensional array of free-rotating micro mirrors.

Many other technologies like liquid crystals, bubbles and electroholography can be used for switching optical signals. Liquid crystals in combination with polarizers either absorb or reflect the incident light depending on the electric voltage and thus act as an optical switch. It is relatively slow, is difficult to integrate with other optical components and requires fixed input polarization.

The bubble technology makes use of phenomenon of total internal reflection for optical switching. A two dimensional array of optical waveguides is formed in such a way that they intersect inside liquid filled channels. When an air bubble is introduced at the intersection by vaporizing the liquid, light is reflected (i.e switched) into another waveguide because of total internal reflection. This technical approach looks very simple but lot of care requires for design to reduce crosstalk and insertion loss.

Electrographic switches are similar to 2-D MEMS but employ a $LiNbO_3$ crystals for switching in place of rotating mirror. Incident light can be switched at any point within the 2-D array of such crystals by applying an electric field and creating a Bragg grating at the location. Because of the wavelength selectivity of the Bragg grating, only a single wavelength can be switched.

The features, applications and specifications for 1X2 fiber optical switch is tabulated below.

- Features

  Small size/footprint, Low insertion loss, Fast switching speed, High reliability, Single mode/multimode modules and Low PDL.

- Applications

  Optical network protection and restoration, Reconfigurable add/drop multiplexers, Optical network monitoring, Wavelength router, Transmission equipment protection and R&D lab applications.

The Optical switches available in market are shown in fig: 9.14.

Figure 9.14 Optical switches modules

- Specifications:

Parameter	Single Mode	Multimode
Wavelength Range	1280~1340 1520~1625	850 or 1300
Insertion Loss (dB, typical)	≤ 0.6	≤ 0.5
Insertion Loss (dB, max)	≤ 1.0	≤ 0.8
Return Loss (dB)	≤ -45	--
PDL (dB)	≤ 0.1	--
WDL (dB)	≤ 0.3	--
Cross Talk (dB)	≤-80	
Switching Time (ms)	≤ 5	≤ 10
Repeatability (dB)	≤ 0.1	
Coil Resistance (Ω)	125 (±10%)	
Operating Current (mA, typ.)	4. (±10%)	
Operating Voltage (V, typ.)	5.0	
Operating Voltage Range (V)	4.5~5.5	
Power Consumption (mW, typ.)	200(±10%)	
Operating Temperature (ºC)	-5~70	-20~75
Storage Temperature (ºC)	-40~70	
Humidity	5~85%RH	
Durability (cycles)	$>10^7$	
Dimension (mm, HxWxL)	8.8X11X30	
Weight (g)	<20	

9.6 Optical Routers

9.6.1 Static Router

An important WDM component is an N X N wavelength router, a device that combines the functionality of a star coupler with multiplexing and demultiplexing operations. The figure: 9.15 shows the operation of such a wavelength router schematically for N=5. The WDM signals entering from N ports are demultiplexed into individual channels and directed toward the N output ports of the router in such a way that the WDM signal at each port is composed of channels entering at different input ports. This results in a cyclic form of demultiplexing. Such a device is an example of a passive router since its use does not involve any active element requiring electrical power. It is also called as static router since routing topology is not dynamically reconfigurable.

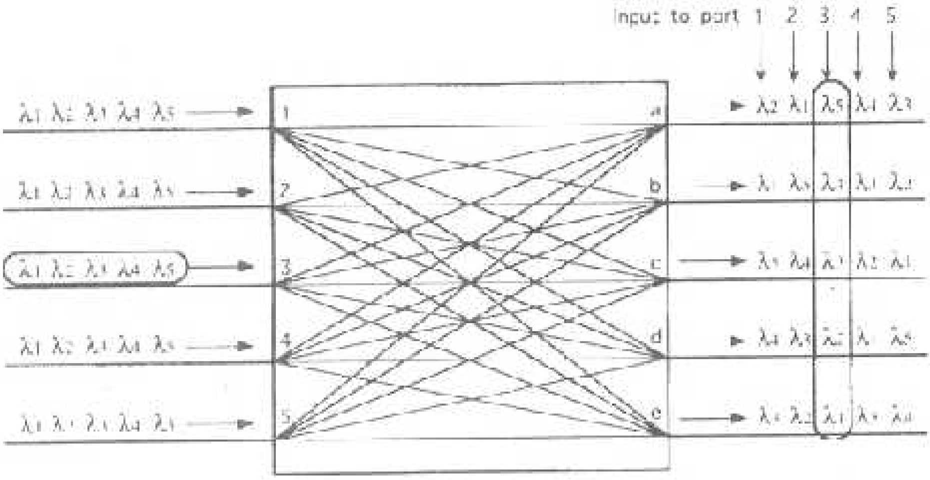


Figure 9.15 Static router principles

9.6.2 Wave guide-grating router (WGR)

It consists of two N X M star couplers such that M output ports of one star coupler are connected with N input ports of another star coupler (see figure 9.16) through an array of M waveguides that acts as an arrayed waveguide grating (AWG). The working principle of WGR is change in phase of different wavelength signals diffract through the free propagation region inside star couplers and propagate through the waveguide array.

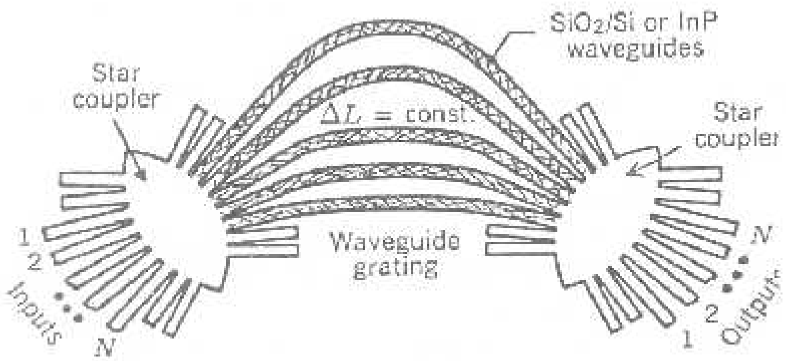


Figure : 9.16 Wave guide grating router implementation

The optimization of a WGR requires precise control of many design parameters for reducing the crosstalk and maximizing the coupling efficiency.

9.7 Passive Fiber Optic Components

9.7.1 Couplers

In a communication system, it may be required to split input signal in to two (splitter) and combine two signals into one (combiner). This is achieved by a coupler. Couplers can carry signals in both the directions (bidirectional).

9.7.1.1 Coupler sizes

A coupler with a single at one end and two at the other end would be called as 1X2 coupler (read as one by two). The 1X2 and 2X2 are the most common sizes (see figure 9.17), they are available in wide range.

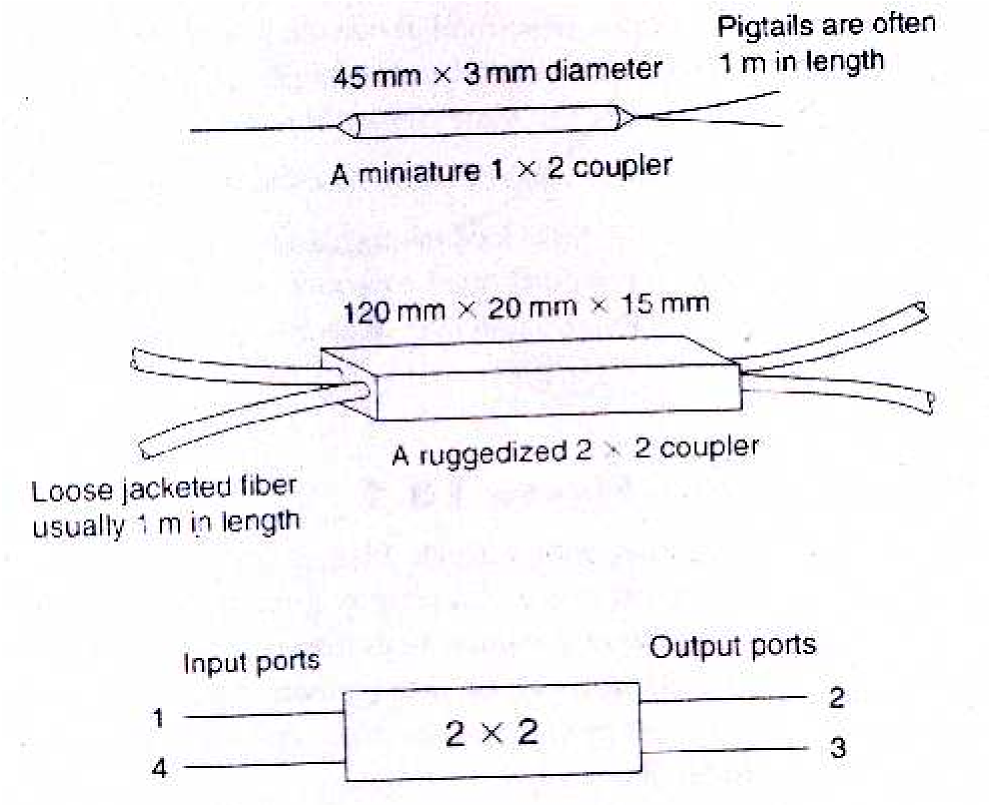


Figure 9.17 couplers and its ports

9.7.1.2 Splitting ratio or coupling ratio

The proportion of the input power at each output is called the splitting ratio or coupling ratio. In a 1x2 coupler, the input signal can be split between the two outputs in any desired ratio. In practice however, the common ones are 90:10 and 50:50. These are also referred as 9:1 and 1:1.

In the cases where the splitting ratio is not 1:1, the port which carries the high power is called as ‘throughput port’ and other is called the ‘tap port’.

9.7.1.3 Losses

- Excess loss

  Light energy has been scattered or absorbed within the coupler and is not available at the output. The output power is the sum of ports of 2 and 3 (see figure 9.18).

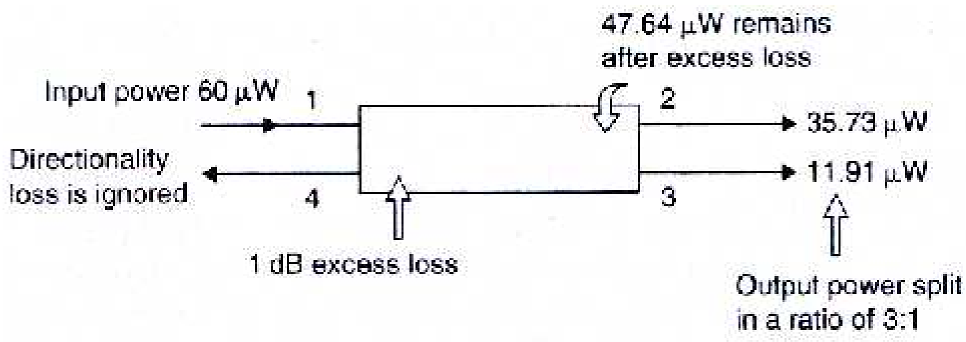


Figure: 9.18 power levels at different ports

Excess loss = 10log{(P_2+P_3)/P_1} dB

Where P_1, P_2 and P_3 are the power levels at the respective ports.

- Directionality loss or crosstalk or directivity

  Due to backscatter within the coupler, some of the energy is reflected back and appears at port 4. This is called as directionality loss or crosstalk.

  Directionality loss = 10log{P_4/P_1} dB

Insertion loss or port-to-port loss or throughput loss or tap loss

This the ratio of optical power output at individual ports and optical input power.

Insertion loss = 10log{$P_{output\ port}$/$P_{input\ port}$} dB

- Coupling loss

  Whenever a coupler is used, it has to be joined to the rest of the circuit. This involves two pairs of connectors and a splice at each end. The losses caused by these connectors or splices must be added to the losses introduced by coupler.

9.7.1.4 The Tee-coupler

This is simple a 1X2 coupler used to convey a single signal to a number of different workstations. It would use a high splitting ratio of 9:1 or similar to avoid draining the power from the incoming signal.

The main advantage is it simplicity. The couplers are readily available and, if required can be supplied with connectors already fitted. The network can easily extended with Tee couplers.

The disadvantage is the rapid reduction in the power available to each of the workstations as we connect more and more terminals to the network. As the power is reduced, the number of data errors increases and the output becomes increasingly unreliable. The solution is only to increase input power.

The Power levels in a Tee network are:

Incoming power = 1mW

Splitting ratio of each coupler = 9:1

Excess loss of each coupler = 0.3dB. The couplers are joined by connectors with an insertion loss of 0.2dB each.

9.7.1.5 The star coupler

This alternative solution to the Tee coupler, when a more number of terminals are to be connected in a network. The star coupler takes the input signal at a central location, and then splits it into many outputs. The 4X4 or 1X32 or 32x32 is available.

The main advantage of using star couplers is that the losses are lower than a Tee coupler for networks of more than three or four terminals.

The disadvantage is that the star coupler demands lengthy cables to connect the terminals, because the coupler is located at the central place and separate cable is connected to each terminal.

9.7.1.6 Classification of couplers based on their construction

- Fused couplers

  The fibers are brought together and then fused as seen in figure 9.19. The incoming light effectively meets a thicker section of fiber and spreads out. At the far end of the fused area, the light enters into each of the outgoing fibers.

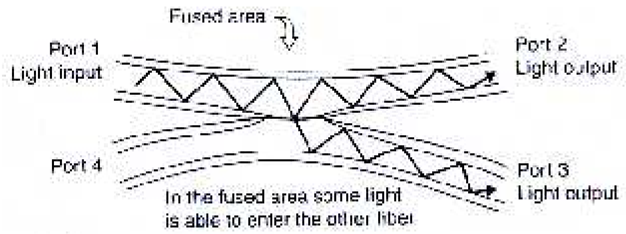


Figure 9.19 light sharing in fused coupler

- Mixing rod couplers

  If several fibers are connected to a short length diameter fiber, called a mixing rod (see figure 9.20), the incoming light spreads out until it occupies the whole diameter of the fiber. If more fibers are connected to the far end they each receive some of the light.

  A receive coupler can be produced by putting a mirror at the end of the mixing rod. The light traveling along the missing rod is reflected from the end mirror and all the attached fibers receive an equal share of the incoming light.

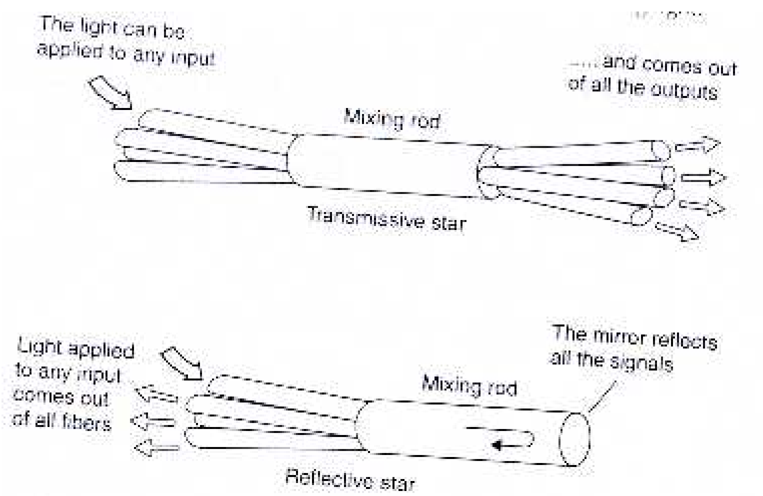


Figure: 9.20 star couplers by mixing rods

- Variable coupler

  A vernier adjustment allows precise positioning of the incoming fiber so that the light can be split accurately between the two output fibers to provide any required splitting ratio. This form of variable coupler (see figure 9.21) is available for all plastic as well as glass fibers single mode and multimode.

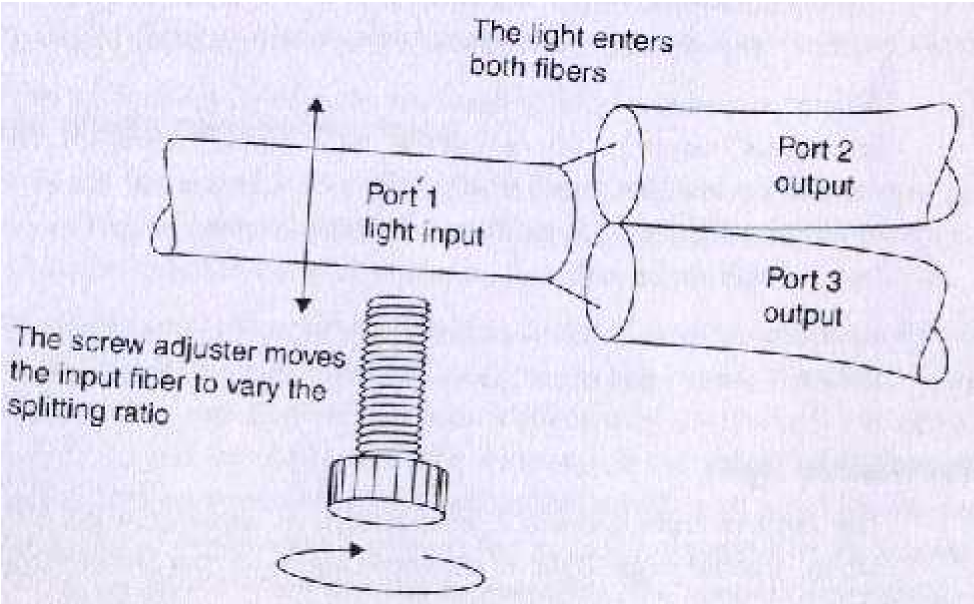


Figure: 9.21 variable coupler

9.7.1.7 A 1 X 2 WDM Coupler

1x2 Triplexer WDM Coupler (see figure 9.22) is designed for the "triple-play" fiber to the home (FTTH) systems. It can be used to mux/demux three wavelengths at 1310nm, 1490nm and 1550nm that carry the voice, video and data services.

This device has 1 to 2 port configuration. All three wavelengths are fed into the device through the common input port. One wavelength is reflected from one output port and the other two wavelengths pass through the device at the other output port.

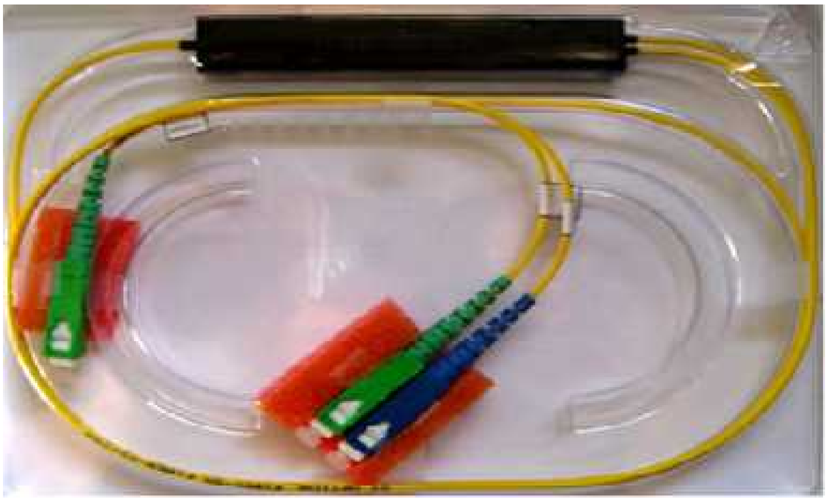


Figure : 9.22 1X2 Triplexer WDM couplers for FTTH

- Specifications

Parameter	Unit	Values
Central wavelength	nm	1310, 1490, 1550
Passing band	nm	1310±50; 1490±10; 1550±10
Passing/Reflection wavelength	nm	On customer request
Pass band insertion loss	dB	≤0.8 (0.6 typical)
Reflection band insertion loss	dB	≤0.6 (0.4 typical)
Pass band isolation	dB	≥30
Reflection band isolation	dB	≥15
Directivity	dB	≥55
Return loss	dB	≥50
PDL	dB	≤0.1
Wavelength thermal stability	nm/ ºC	≤0.003
Insertion loss thermal stability	dB/ºC	≤0.005
Power handling	mW	≤500
Operating temperature	ºC	-40 ~ +85
Storage temperature	ºC	-40 ~ +85
Dimensions	mm	Φ5.5 X L34

- Features:

  Wide passing bands, High isolation between channels, Low insertion loss , High stability and reliability.

- Applications

  FTTH (FTTx) triple play systems and Testing instruments.

The high isolation WDM coupler 1310nm/1550nm and 3-port CWDM add/drop module are shown in figures 9.23 and 9.24 respectively to have close look at variety couplers.

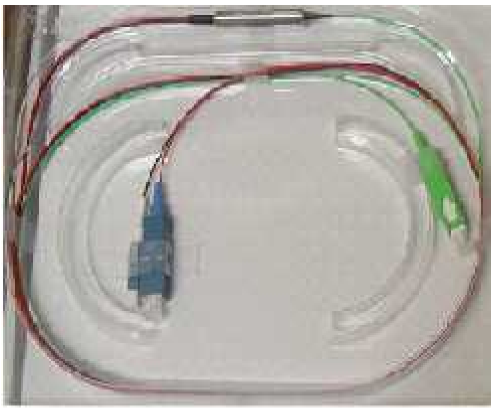


Figure : 9.23 High isolation WDM coupler 1310nm/1550nm

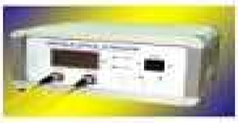
Figure : 9.24 3-port CWDM add/drop module

9.7.2 Attenuators

It is a passive device (see figure 9.25) for reducing the amplitude of optical signal without appreciably distorting the waveform.

Figure: 9.25 Fiber optic attenuator

Variety of attenuators are available in the market. The following table shows the figures of fixed and variable attenuators.

 Fixed Optical Attenuator	 Fixed Optical Attenuator - Adapter Type
 Hanheld Variable Optical Attenuator	 Inline Fixed Optical Attenuator
 Variable Optical Attenuator	 Variable Optical Attenuator - Benchtop
 Variable Optical Attenuator - Collimator Type	 Variable Optical Attenuators - Adapter Type

A plug-type single mode attenuator (see figure 9.26) can be used directly on the fiber optic connectors and provides a fixed level of optical attenuation. It has low return loss and works at both 1310nm and 1550nm wavelength range. FC and SC connector types with PC or APC polish are available, as well as ST and LC types of attenuators.

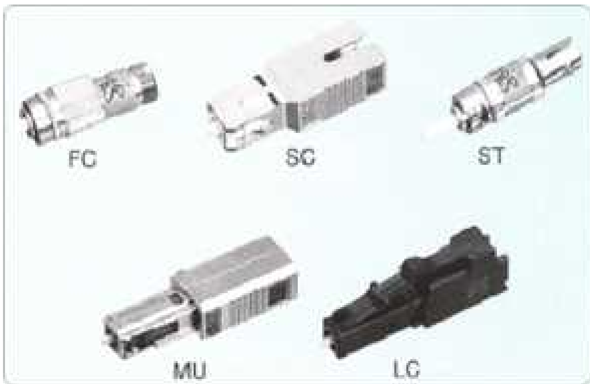


Figure : 9.26 attenuator with variety connectors

- Features

  Good repeatability, High precision, High return loss, Small size, Good directivity, FC and SC types available.

- Application

  Fiber communication, Fiber CATV , LAN and Test equipment.

- Specifications

Grade Parameter	P	A
Type	FC/UPC˛ FC/APC˛ SC/UPC˛SC/APC etc.	
Wavelength (nm)	1310/1550 ± 50nm	
Attenuation range (dB)	5dB ' 40dB	
Attenuation precision (dB)	± 0.5dB (Attenuate <10dB) ± 10% (Attenuate >< (0dB)	±1.0dB (Attenuate <10dB) ± 10% (Attenuate >10dB)
Return loss (dB)	≥ 45	≥ 40
PDL (dB)	≤ 0.1	
Repeatability (dB)	≤ 0.1	
Operating temperature (ºC)	-40 ‘ 85	
Storage temperature (ºC)	-40 ‘ 85	

9.7.3 Isolators

The principal functionality of an optical fiber isolator is to block the reflection from the next segment of the optical link from entering the previous stages. It ensures the one-way transmission of light in the optical fiber. Single stage or dual-stage isolators provide different degrees of optical isolation. Two identical isolators or one WDM coupler and one isolator can also be fabricated inside a "single" package, which provides small component size and more reliable performance. Multimode isolators are useful with multimode fiber networks. Wide band isolator, covering S, C and L bands, can be used in DWDM optical amplifier design. We can also provide isolators at special wavelengths or polarization maintaining isolators. Variety of Isolators listed with figures in below table.

 Fiber Optic Faraday Mirror	 Optical Fiber Isolators - Dual Stages
 Optical Fiber Isolators - Dual Stages 2 in 1	 Optical Fiber Isolators - Single Stage
 Optical Fiber Isolators - Single Stage 2 in 1	 Optical Isolator - Multimode 1310nm or 1550nm
 Optical Isolator - Wide Band (S+C+L Bands)	 Optical Isolator at 1480nm or 1064nm
 Optical Isolator Hybrid with WDM Coupler	 Optical Isolators (PMD Compensated)
 Optical Isolators - Dual Window 1310 & 1550nm	 Polarization Maintaining Isolator - 1064nm
 Polarization Maintaining Isolator 1310 1480 1550nm C+L bands	

- Features

  Low insertion loss, Input SOP independent, compact size and environmentally stability.

- Applications

  Fiber laser, Optical instrument , WDM and CATV systems

- Specifications

Parameter		Unit	Grade "A"
Wavelength Range		nm	+/-15
Center wavelength		Nm	1310, 1550
Insertion Loss (λ c, 23ºC)	Max	dB	0.7 (0.5 Typ.)
Farady Rotation Angle (λ c, 23ºC)		Degree	90
Farady Rotation Angle Tolerance[1]		Degree	+/-1
PDL	Max.	dB	0.05
Fiber type			SMF-28e (Can be customized)
Fiber Length		M	1.0±0.1
Optical Power	Max	MW	300
Operation Temperature		ºC	-5 to 70
Storage Temperature		ºC	-40 to 80

9.7.4 Circulators

Passive three-port devices (see figure 9.27) that couple light from Port 1 to 2 and Port 2 to 3 and have high isolation in other directions.

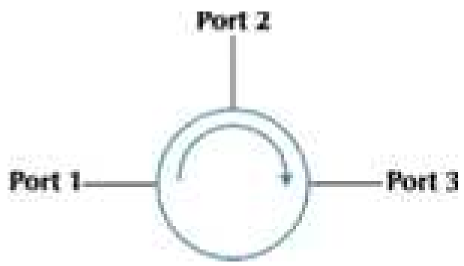
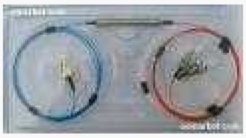


Figure 9.27 circulator with 3 ports

Optical circulators typically have three ports: an input, a common port and an output. The light from input port is guided out at the common port, while the light fed in from the common port can only emit from the output port. Optical circulators can be used to separate the light transmitted in opposite directions inside a single optical fiber. They are used together with fiber gratings components in multiplexing or sensoring systems, in bi-directional communications and in optical filter systems. 3-port circulators with low insertion loss, high isolation and polarization insensitive performance. Advanced models include 4-port, wide band (C and L bands) and polarization maintaining circulators.

Four-port optical circulators are a special type of circulator that has one input (port 1), one output (port 4) and two common ports (port 2&3). The light goes through port 1 to port 2. At port 2, any incoming light is guided to port 3 as output, while all input from port 3 is guided to port 4 as output.

Varieties of couplers are with figures tabulated in the following table.

 Optical Fiber Circulator - Polarization Insensitive	 Optical Fiber Circulators - Wideband (C+L Bands)
 Optical Fiber Circulators 4-Port	 Optical Fiber Circulators 4-Port Wideband (C+L Bands)
 Polarization Maintaining Optical Circulator	

Wideband four-port circulator that covers the whole C and L bands from 1520nm to 1625nm is also available. It has ultra low insertion loss and high isolation. It is an ideal component for applications in optical fiber sensoring systems, high performance optical communication networks (including mux/demux, add/drop modules, dispersion compensation modules, optical filters, etc.)

- Specifications

Parameter	values
Port	Port 1 to Port 2 to Port 3 to Port 4
Operating Wavelength (nm)	1520~1625
Insertion Loss (Typ., dB)	0.8 (grade P), 1.0 (grade A)
Insertion Loss (Max., dB)	1.0 (grade P), 1.2 (grade A)
Channel Isolation (Typ., dB)	50
Channel Isolation (Min., dB)	40
Directivity (dB)	>50
PDL (dB)	<0.15
PMD(ps)	<0.1
Return Loss (dB)	>50
Power Handling (mW)	≤300
Operating Temperature (ºC)	0~+70
Storage Temperature(ºC)	-40~+85
Package Dimension (mm)	Φ5.5*L60 or L63

9.7.5 WDM filters

The function of the optical filters in optical communication system is to select a desired channel at the receiver. The filter bandwidth must be large enough to transmit the desired channel, but at the same time, block the neighboring channels.

The desirable properties of optical filters are:

- Wide tuning range to maximize the number of channels that can be selected
- Negligible crosstalk to avoid interference from adjacent channels
- Fast tuning speed to minimize the acsess time
- Low insertion loss
- Polarization insensitivity
- Stability against environment changes (humidity, temperature and vibrations etc.,)
- Low cost

Optical filters are categorized based on their working mechanisms. The working mechanisms are optical interference or diffraction. The commonly used optical filters are Fabry-Perot, Mach-Zender, Grating based Michelson and Acoustic-optic shown in figure 9.28 a, b, c and d respectively.

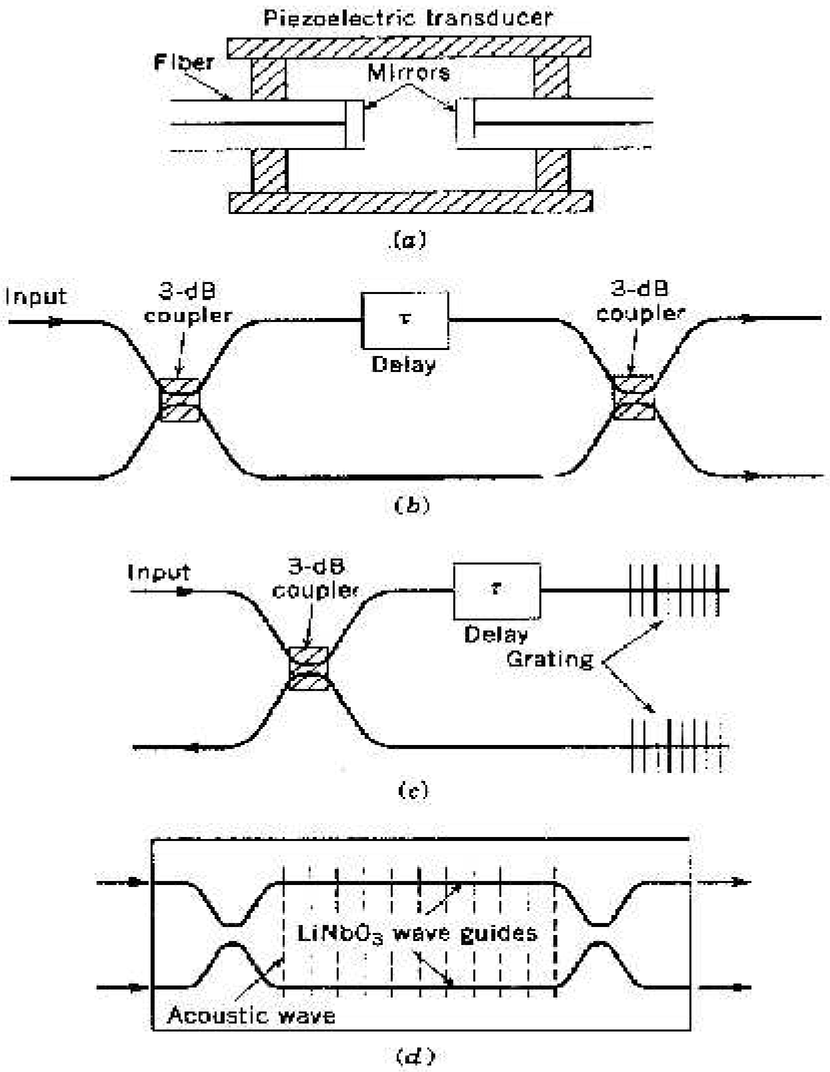


Figure 9.28 Optical filters

9.8 Optical Interfaces for STM equipment

In Optical communication equipment terminology there are certain standards as defined by ITU-T. They are as follows.

In general the interfaces are designated in the form ' X.Y.Z. ' where

X stands for length of the haul, they are

Code	Description	Length
I	Intra Station	2 km
S	Short haul	15 km
L	Long haul @ 1310 nm	40 km
L	Long haul @ 1550 nm	80 km
V	Very long haul @ 1310 nm	60 km
V	Very long haul @ 1550 nm	120 km
U	Ultra long haul @ 1550 nm	160 km

Ex:Intra Station: Within the station premises like YM, Crew Controller
Short haul: From station to station
Long haul: Between important junctions
Very long haul: Between important cities
Ultra long haul: Between Baseband Repeaters

Y stands for level of the STM (Synchronous Transport Module), they are

Code	Description
1	STM-1
4	STM-4
16	STM-16
64	STM-64

Z stands for fiber type, they are

Code	Description	Wavelength	Standard
1	NDSF - Non Dispersion Shifted Fiber	1310 nm	G.652
2	NDSF - Non Dispersion Shifted Fiber	1550 nm	G.652
3	DSF - Dispersion Shifted Fiber	1550 nm	G.653
4	* * * *	* * * *	* * * *
5	NZDSF - Non Zero Dispersion Shifted Fiber	1550 nm	G.655

A few examples of Optical Interfaces Nomenclature for STM-1, STM-4 & STM-16, and STM-64 are listed in the following tables.

9.8.1 Examples of Some OFC Interfaces:

Code	Description	Standard
I.16.1	Intra station STM-16 link on 1310 nm fiber	
S.16.2	Short haul STM-16 link on 1550 nm fiber	G.652
L.16.2	Long haul STM-16 link on 1550 nm fiber	G.652 & G.653
L.16.3	Long haul STM-16 link on 1550 nm fiber	G.652 & G.653
V.16.2	Very long haul STM-16 link on 1550 nm fiber	G.652 & G.653
V.16.3	Very long haul STM-16 link on 1550 nm fiber	G.652 & G.653
U.16.2	Ultra long haul STM-16 link on 1550 nm fiber	G.652 & G.653
U.16.3	Ultra long haul STM-16 link on 1550 nm fiber	G.652 & G.653
S.04.1	Short haul STM-4 link on 1310 nm fiber	
L.04.1	Long haul STM-4 link on 1310 nm fiber (40 km)	
L.04.2	Long haul STM-4 link on 1550 nm fiber (80 km)	G.652 & G.653
L.04.3	Long haul STM-4 link on 1550 nm fiber (80 km)	G.652 & G.653
S.01.1	Short haul STM-1 link on 1310 nm fiber	
L.01.1	Long haul STM-1 link on 1310 nm fiber (40 km)	

9.8.2 Examples of Some OFC Interfaces with STM-1

Code	l (nm)	Fiber	Transmitter	Dispersion (ps/nm)
I.1.1	1310	G.652	LED/MLM	18/25
S.1.1	1310	G.652	MLM	96
S.1.2	1550	G.652	MLM/SLM	296/NA
L.1.1	1310	G.652	MLM/SLM	246/NA
L.1.2	1550	G.652	SLM	NA
L.1.3	1550	G.652	MLM/SLM	296/NA

9.8.3 Examples of Some OFC Interfaces with STM-4

Code	l (nm)	Fiber	Transmitter	Dispersion (ps/nm)
I.1.1	1310	G.652	LED/MLM	14/13
S.4.1	1310	G.652	MLM	74
S.4.2	1310	G.652	SLM	NA
L.4.1	1310	G.652	MLM/SLM	109/NA
L.4.2	1550	G.652	SLM	Spec. under study
L.4.3	1550	G.653	SLM	NA
V.4.1	1310	G.652	SLM	200
V.4.2	1550	G.652	SLM	2400
V.4.3	1550	G.653	SLM	400
U.4.2	1550	G.652	SLM	3200
U.4.3	1550	G.653	SLM	530

9.8.4 Examples of Some OFC Interfaces with STM-16

Code	l (nm)	Fiber	Transmitter	Dispersion (ps/nm)
I.16.1	1310	G.652	MLM	12
S.16.1	1310	G.652	SLM	NA
S.16.2	1550	G.652	SLM	Spec. under study
L.16.1	1310	G.652	SLM	NA
L.16.2	1550	G.652	SLM	1600
L.16.3	1550	G.653	SLM	Spec. under study
V.16.2	1550	G.652	SLM	2400
V.16.3	1550	G.653	SLM	400
U.16.2	1550	G.652	SLM	3200
U.16.3	1550	G.653	SLM	530

9.8.5 Examples of Some OFC Interfaces with STM-64

Code	l (nm)	Fiber	Transmitter	Dispersion (ps/nm)
I.64.1	1310	G.652	MLM	6.6
I.64.2	1550	G.652	SLM	500
I.64.3	1550	G.652	SLM	80
I.64.5	1550	G.655	SLM	Spec. under study
S.64.1	1310	G.653	SLM	70
S.64.2	1550	G.652	SLM	800
S.64.3	1550	G.653	SLM	130
S.64.5	1550	G.655	SLM	130
L.64.2	1550	G.652	SLM	260
L.64.3	1550	G.653	SLM	Spec. under study
V.64.2	1550	G.652	SLM	400
V.64.3	1550	G.653	SLM	Spec. under study

Objective:

1. The bandwidth is limited in optical transmitter with internal modulator due to relaxation frequency of laser diode. (T/F)
2. The feedback loop using photo diode in optical transmitter using external modulator provides a very stable level of power radiated by the laser diode. (T/F)
3. The optical amplifiers employed in optic fiber communication have made it possible to amplify all the wavelengths at once without optical-electrical-optical conversion. (T/F)
4. The regenerators employed in optical fiber links are specific to bit rate and modulation format. (T/F)
5. The optical amplifiers employed in optic fiber communication are independent of bit rate and modulation format. (T/F)
6. The system up gradation in optical fiber links does not require change in amplifiers. (T/F)
7. The system up gradation requires replacement of regenerators in optical fiber links, which are employing regenerators. (T/F)
8. EDFAs are typically capable of providing a gain of about 30 dB to the input optical signals. (T/F)
9. The important parameters that are to consider while selecting an EDFA are low noise and flat gain. (T/F)
10. A WDM system sends signals from various sources over a single fiber on different wavelengths closely spaced as a single beam. (T/F)
11. Multiplexers and demultiplexers used in WDM systems can be passive or active. (T/F)
12. No conversion of the signal from optical to electrical takes place in OADMs. (T/F)
13. Dynamic selection of wavelengths to add or drop is possible with an OADM. (T/F)
14. The OXC in an optical network is an optical switch. (T/F)
15. A device that combines the functionality of a star coupler with multiplexing and demultiplexing of optical signals is called as optical router. (T/F)
16. A device in which routing topology is not dynamically reconfigurable in optical networks is called as static router. (T/F)
17. An optical coupler is a device which split the input optical signal into two and combine two optical signals into one. (T/F)
18. An optical coupler is a passive device. (T/F)
19. An optical coupler is bi-directional device. (T/F)
20. In a 1X2 optical coupler, the input signal can be split between the two outputs in any desired ratio. (T/F)

Objective:

1. List out the names of basic blocks of transmitter.
2. Write the functions of major sections of optical receiver.
3. Explain in brief about Optical amplifiers.
4. Write short notes on Optical multiplexing techniques.
5. List out Passive fiber optic components. Write in brief about each component.
6. Explain Optical interface nomenclature with examples.

CHAPTER-10

OPTICAL LINK ENGINEERING

10.1 An Optical Link

An optical transmission system (see figure 10.1) in its most basic form include the following components:

- An optical source such as a Light Emitting Diode (LED) or a laser diode.
- An optical link consisting of one or several segments of cable (held together by connectors).
- Optical amplifiers.
- An optical receiver that consists of a photodetector (photon counter) such as an avalanche
- Photodiode or a *pin* photodiode followed by an amplifier, decision circuitry and other signal processing hardware such as equalizers.

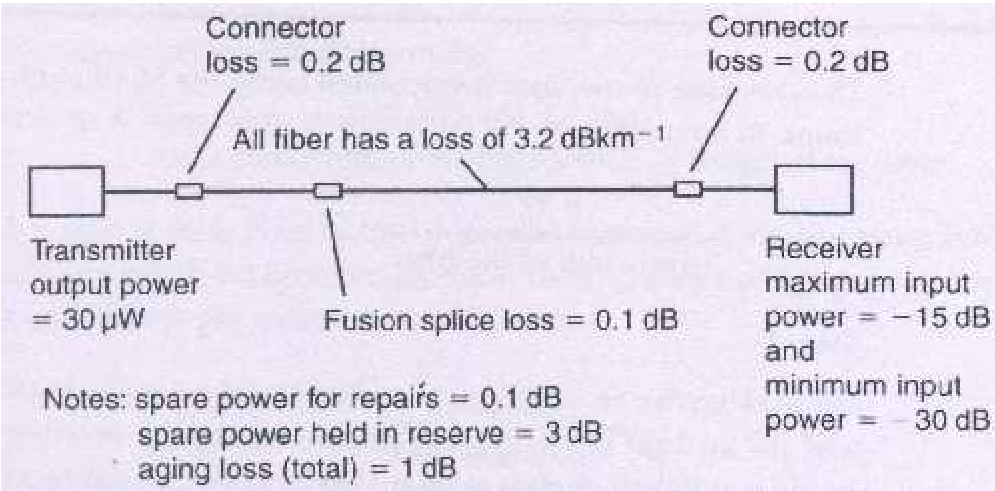


Figure 10.1 Basic components of OFC system with losses

The design of an optical link basically consists of selection of devices required for ensuring a given probability of error and bit rate for a distance between transmitter and receiver. The probability of error is a function of the modulation technique, the received power and channel noise. Therefore, for a given modulation scheme, in order to ensure that a probability of error is achieved, one needs to develop a link budget taking into consideration the power launched into the cable as well as all the gains, losses, noise between the transmitter and the receiver.

The maximum bit rate supportable by an optical link, on the other hand, is limited by the dispersion of the light in the fiber as well as the rise times of the transmitter and receiver. We need to perform a rise time budget calculation in order to find the maximum bit rate that a link can support.

The rest of the chapter we discuss the factors to be considered to design an optical network, link budget and rise time budget with examples.

10.2 Factors to be considered in optical link design

- The topology of link

  The simplest transmission link is a point to point link having transmitter at one end and receiver on the other.

This type of link forms the basis for more complex system architectures. The complex type of network architecture is distributed, local and wide area network. The design of an optical link involves many interrelated variables among the fiber, source, and photo detector, so that the actual link design and analysis may require several iterations before they are finalized.

- System performance criteria

  The system performance criteria depend upon the desired transmission distance, data rate (channel bandwidth) and bit error rate (BER). System performance should be ensured over the expected system life time.

- Selection of Components

  First decide the wavelength of operation i.e short distance 800-900nm and longer distances 1300-1500nm. Once wavelength is decided the system performance is depends upon the three major components. They are receiver, transmitter and fiber. Generally, characteristics of two of these elements are chosen and then the characteristics of the 3rd one is computed to meet the system performance requirement

The first component is Optical receiver i.e. Pin or avalanche photodiode. The responsivity, operating wavelength, speed and sensitivity of the detector as per requirement must be decided by designer.

Generally, a suitable photo detector is chosen which can detect successfully the optical signals at the highest operating speed. Then suitable optical source is chosen to suit the transmission speed (band width). Optical power level is estimated using a particular fiber. Introduction of booster amplifier is also examined at this stage.

The minimum optical power level that must fall on the photo detector to satisfy the BER requirement at the specified data rate. When we compare the pin photo diode with APD, complexity of receiver design is very simple, more stable with variation in the temperature and less expensive than APD. Pin photo diode bias voltages are normally less than 5 V and APD's bias voltage ranges from 40 V to several hundred volts. APDs are more sensitive to low optical power levels.

The second component is optical source i.e LED or Laser. The emission wavelength, spectral line width, output power, effective radiating area, emission pattern, number of emitting modes of the sources must be considered by designer.

The design engineer must compare next between the optical sources (LED verses Laser diode). The system parameters involved in deciding between LED and laser diode are signal dispersion, data rate, transmission distance and cost. LED source in 800 - 900 nm regions can work up to data rate - distance of 150 Mbps – km

Single mode fiber with LD source can provide ultimate bit rate at data rate distance product of over 500 Gbps - km with 1550 nm. Laser diodes are capable of coupling 10 - 15 dB more optical power into a fiber than an LED. The disadvantages of LD are its cost and its complexity of transmitter circuit.

At last the selection of fiber, choice is either Multimode or single-mode optical fiber. The choice depends upon on type of light source and the amount of dispersion that can be tolerated. The size of the core, core refractive index profile, bandwidth, dispersion, attenuation, numerical aperture or mode field diameter of the fiber must be decided by designer.

LEDs (edge emitting type) with multimode fibers, 500Mbps data rates are possible. The losses offered by fiber, connector and joints (Splice) also to be considered.

10.3 Link power Budget

If the signal is too weak when it reaches the far end of the system, it will be difficult to separate data from the noise. Then number of errors increases in the received data bits. If an error occurs once in every thousand million bits it would be said to have a bit error rate (BER) of 10^{-9} and is the lower limit of acceptability.

The limitations on the receive power are, the received power must be high enough to keep the BER to a low value. And received power must be low enough to avoid damage to the receiver.

Similarly the limitations on the transmitted power are, on cost and safety grounds. It is better to keep the transmitter power to the minimum acceptable value.

We discuss the Link Power Budget in considering the following scenarios.

Scenario:1 The receiver and Optic fiber system is decided, then what transmitter Minimum power would be needed?

Scenario: 2 Maximum receiver power under minimum loss conditions.

Scenario: 3 In existing system, how much we could lengthen the fiber without changing the transmitter, receiver and still meet the minimum power requirement of receiver.

Let us proceed step by step and we work out an example relevant to the above scenarios.

Scenario : 1 The receiver and Optic fiber system is decided, then what transmitter minimum power would be needed ?

Step: 1 Find the minimum power losses due to the:

1. fiber
2. connectors and
3. splices

These figures are obtained from the catalog.

Step: 2 Find the maximum likely losses. This will include:

1. Minimum losses calculated above
2. Aging losses. Many components of a system deteriorate during their lifetime and it is important to know how much to allow for this, otherwise the system will crash in future. The aging loss is slight in fibers but the transmitter and the connectors, mechanical splices, couplers, etc. will need to be counted. Manufacturers will supply the data.
3. Repairs. This stage is really a guess based on the experience and advice.
4. Additional margin 3 dB loss added extra.

Step: 3 Selection of transmitter light source with enough power and checking the maximum receive power of receiver.

Select transmitter light source with enough power to enable the system to operate under the worst-case conditions, with the maximum losses considered above. Then check whether it would damage the receiver in the condition of minimum loss.

- An example to scenario : 1

  Calculate the minimum transmitter power necessary in the system shown in figure 10.2.

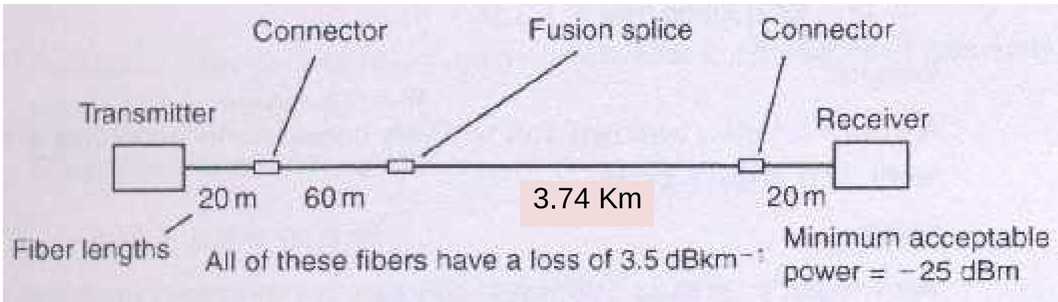


Figure 10.2 Optical link for minimum transmitter power

Step: 1 Minimum power loss

1. The fiber:

Total length of the fiber is = 20m+60m+3.74km+20m = 3.84km

Total loss = total length X loss per unit length.

= 3.84X3.5 = 13.44dB

2. The connectors:

As per the catalog the loss for the type of connector used is 1dB per mated pair. There are two mated pairs used, so the total loss is: =2X1=2 dB

3. The splices:

The fusion splice will be assumed to be 0.2 dB.
Total power loss: The minimum value of power loss i.e sum of the above
Losses = 13.44+2+0.2 = 15.64dB.

Step: 2 Finding the maximum power loss

The minimum power loss is 15.64dB to which the losses due to aging and repair must be added to know the maximum power loss.

Aging:

The aging losses used in this scenario are:

Loss due to fiber aging is negligible.
Loss due to Connectors=0.1dB per mated pair.
Therefore for two pairs = 0.2dB.

Splice loss = negligible
Transmitter loss = 1dB
Total aging loss = 1.2dB

Repairs: A loss of 1.5dB is assumed. This will vary considerably according to the environment. This is a guess based on the experience.

Margin: 3dB loss to take care of unforeseen situations.

The maximum power loss is = (minimum loss + loss due to aging + loss due to repairs + margin)
= 15.64+1.2+1.5+3=21.34dB

Step 3: Selection of transmitter light source with enough power and checking the maximum receive power of receiver.

Transmitter must supply enough power to overcome the worst-case losses and should meet minimum power requirements of the receiver (see figure 10.3).

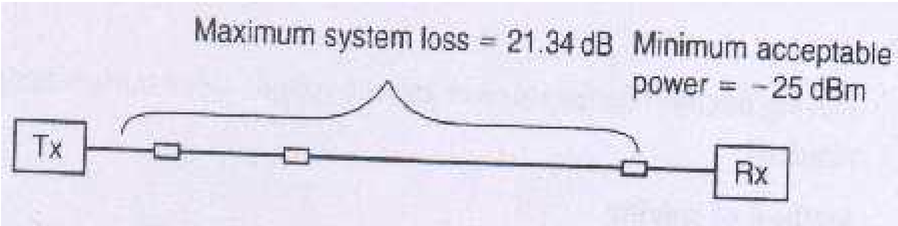


Figure 10.3 minimum power requirements of receiver

The minimum transmitter power = -25+21.34= -3.66dBm or 430.5µw

Observe the figure 10.3, the receiver minimum power level (-25dBm) is a large negative number of decibels. This means that the power level is very small. The transmitter must be greater than this and therefore the numerical value of power must be less negative (-3.66dBm).

The light source with the nearest value of output power available is 500µw (-3.0dBm) .

Scenario: 2 Maximum receiver power under minimum loss conditions.

The maximum input power to the receiver occurs when the system losses are at their minimum level as shown in figure 10.4.

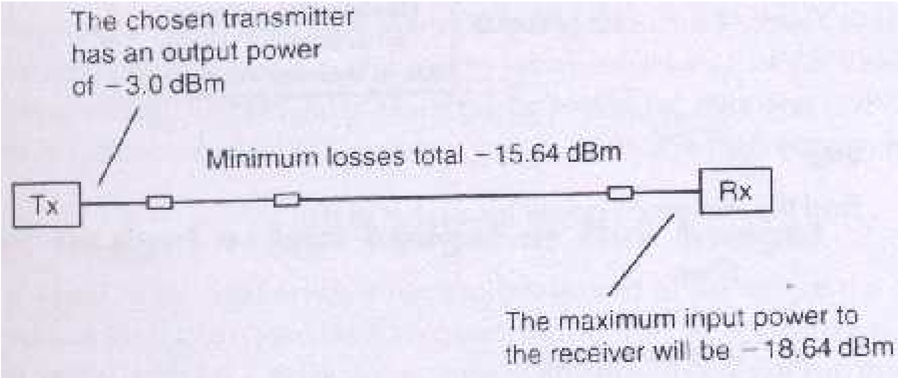


Figure 10.4 maximum input power without overloading the receiver

So maximum receiver power = (transmitter power – minimum losses)
= (-3.0 – 15.64) = -18.64dBm

The maximum receiver power (- 18.64dBm) not higher than the minimum acceptable power level (-25dBm) of the receiver. So certainly receiver is not overloaded.

In order to maintain tolerant system, Attenuator can be used to avoid damage to receivers due to excess power.

Scenario: 3 In existing system, how much we could lengthen the fiber without changing the transmitter, receiver and still meet the minimum power requirement of receiver.

The existing OFC system is shown in figure 10.5 .

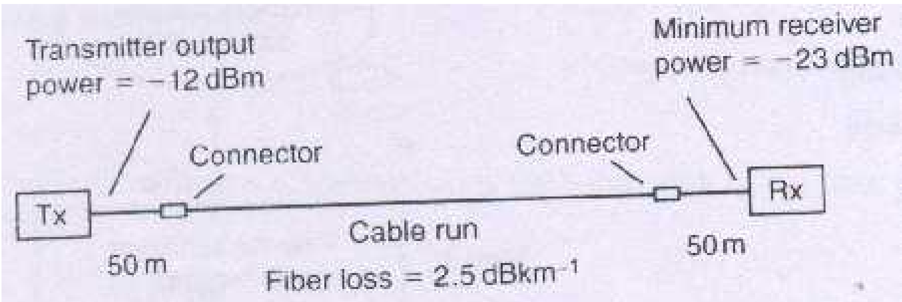


Figure 10.5 Existing OFC system

Step 1: Find the total loss of the existing system.

Total length of the patch chords: 100 meters
Assume fiber used has a loss of 2.5dB/Km, fiber loss = 0.25dB

The mated pairs of connectors loss = 0.2dB per connector
Total connector loss is = 0.2 X 2 = 0.4dB

Therefore existing losses = (0.25 + 0.4) = 0.65dB

Step 2: Find worst case losses for the proposed system.

Aging loss:

Coupler loss (0.1dB per pair) = 0.2dB
Transmitter = 1.0dB
Repair loss : 2dB assumption

safe Margin : 3dB (as practice)

Total losses = (existing losses + aging loss + repair loss+ safe margin)
= 0.65 + 1.2 + 2.0 + 3.0 = 6.85dB

Step 3: Find the power available for the required cable

Transmitter output power is (- 12dBm) and minimum receiver input power is (-23dBm), so there is total of 11dB available for the whole system. Out of available power (11dB), we have already accounted for 6.85dB for total losses (see Step 2)

The spare power for the link is = 11 – 6.85 = 4.15dB

Step 4: The fiber in use has a loss of 2.5dB/Km, so the maximum length of the cable that can be used in existing system is = (spare power)/ (fiber loss)
= (4.15 / 2.5) = 1.66 Km as shown in figure 10.6.

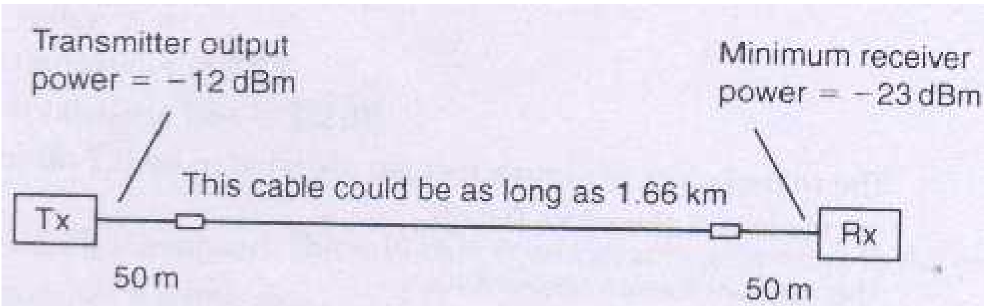


Figure 10.6 existing OFC system with maximum length of cable

10.4 Rise time Budget

The performance of the optical fiber system is also depends on the data transfer rate, which means sufficient bandwidth on demand. The multimode graded index fibers have a bandwidth of 100MHz to 1GHz. The single mode fiber is even better, have a bandwidth of 500MHz to 10GHz.

But the dispersion phenomenon limits the data transfer rate. The magnitude of the dispersion problem increases with the length of the cable and so the transmission rate. Hence the bandwidth decreases with fiber length.

To develop a real OFC system we also need a light source and a receiver. They both have a finite switching speed and limit the transmission rate. There is no use in using a fiber able to deliver a bandwidth of 10GHz if the receiver at the far end can only switch at 5MHz.

It is very clear that it is system bandwidth in which we are interested, not just on fiber bandwidth. So we need to investigate the effect of dispersion and the switching speed of the transmitter and the receiver.

The multimode and single mode fiber responds differently. We study rise time budget with multimode and single mode fibers in a system separately.

10.4.1 Rise time budget with multimode fiber

Let us study with an example. Our aim is to find the usable bandwidth in the fiber optic system shown in figure 10.7.

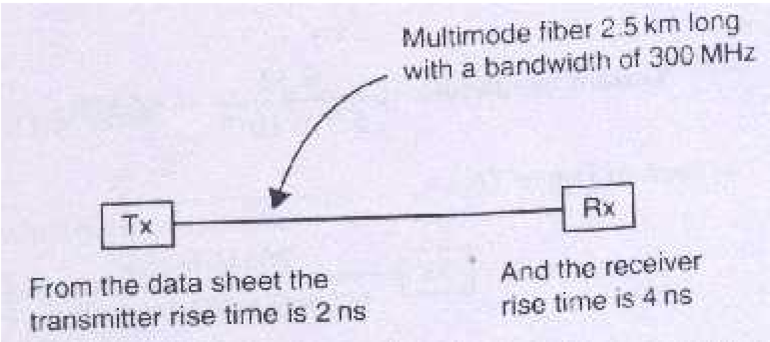


Figure 10.7 OFC systems with multimode fiber to find bandwidth

Step: 1 Find the bandwidth of the fiber

We can get the fiber bandwidth from the data sheet or catalog. The specification will appear as 300MHz-Km. Observe the units (MHz-Km), this means that the bandwidth multiplied by the distance in kilometers results to 300MHZ. So this particular fiber has a bandwidth of 150MHz if it is length of 2 km. If we use 10Km length of cable, the bandwidth reduces to 30MHz. Notice the variations in bandwidth as the length of cable increases.

So fiber bandwidth = (quoted bandwidth)/(length in km)

= $(300 \text{ X}10^6)/(2.5)$ = 120 MHz

Step: 2 Find the fiber rise time

The rise time taken for the light to increase from 10% to 90% of its final value. The higher the frequency of a waveform the shorter will be the rise time as shown in figure 10.8. It is linked to the bandwidth as this is a measure of the highest frequency component in the signal transmitted along the fiber.

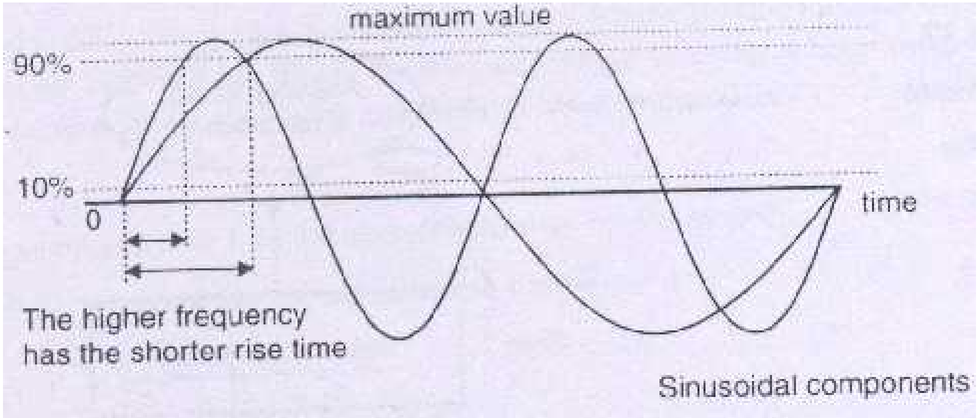


Figure 10.8 signals with different risetimes

The rise time (t_r) the fiber is = (0.35 / bandwidth of the fiber)

So Rise time $(t_r)_{Fiber}$ = (0.35) / ($120X10^6$) = 2.9 ns

Step: 3 Find the rise time of the light source and the receiver from the data sheets

Observer the figure 10.7 the rise time for transmitter and receiver are 2ns and 4ns respectively.

Step: 4 Find the system rise time and then the bandwidth of the whole system

We have three different components, the light source, the fiber and the receiver, each with their own switching speed. When the electronic pulse is applied to the light source it will start to increase its light output power. The fiber follows at its own rate and finally the receiver electrical output starts to rise.

So total rise time of the system :

$(t_r)_{SYSTEM} = [\{t_{r\,(Tx)}\}^2 + \{t_{r\,(fiber)}\}^2 + \{t_{r\,(Rx)}\}^2]^{1/2}$

$= [\{2\}^2 + \{2.9\}^2 + \{4\}^2]^{1/2} = 5.3\text{ns}$

System bandwidth = (0.35 / rise time of the system)

$= 0.35/(5.3 \times 10^{-9}) = 66$ MHz

It is very clear to understand that the total bandwidth of the system is only 66MHz , even though fiber supports 300MHz as shown in figure 10.9.

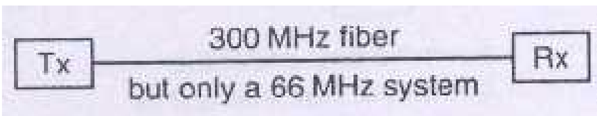


Figure 10.9 OFC system with useful bandwidth

10.4.2 Rise time budget with single mode fiber

The data sheet gives the value of the dispersion characteristics instead of the bandwidth, from this we must calculate the bandwidth. Because the dispersion depends on the spectral width of the light source and the length of the fiber.

Let us study with an example. Our aim is to find the usable bandwidth in the fiber optic system shown in figure 10.10.

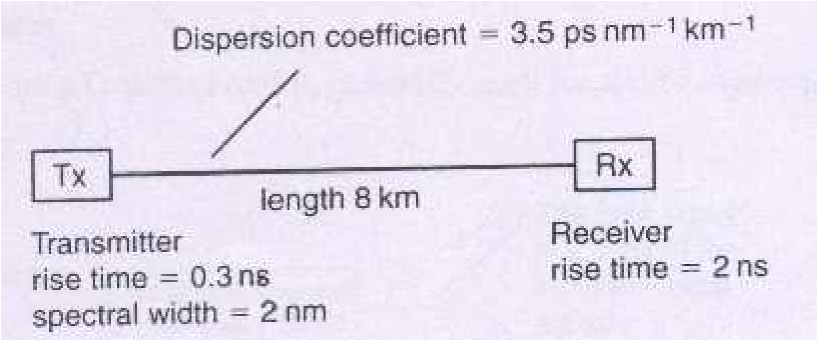


Figure 10.10 Optic fiber systems with single mode fiber

Step: 1 Find the dispersion

The dispersion depends on the dispersion specification of the fiber, the spectral width of the light source and the fiber length.

Dispersion = (Dispersion specification for the fiber) X (Spectral width of the light source) X (Length of the fiber)

= 3.5 X 2 X 8 = 56 psnm^{-1}km^{-1}

Step: 2 Find the fiber bandwidth

Fiber bandwidth = (0.44)/(dispersion figure)

= (0.44)/(56 X 10^{-12}) = 7.86 GHz

Step: 3 The rise time (t_r) the fiber is = (0.35 / bandwidth of the fiber)

So Rise time $(t_r)_{Fiber}$ = (0.35) / (7.86X10^9) = 44.53 ps

Step: 4 Find the rise time of the light source and the receiver from the data sheets

Observer the figure 10.10 the rise time for transmitter and receiver are 0.3 ns and 2ns respectively.

Step: 5 Find the system rise time and then the bandwidth of the whole system

We have three different components, the light source, the fiber and the receiver, each with their own switching speed. When the electronic pulse is applied to the light source it will start to increase its light output power. The fiber follows at its own rate and finally the receiver electrical output starts to rise.

So total rise time of the system :

$$(t_r)_{SYSTEM} = [\{t_{r\,(Tx)}\}^2 + \{t_{r\,(fiber\,)}\}^2 + \{t_{r\,(Rx\,)}\}^2]^{1/2}$$
$$= [\{ 0.3 \}^2 + \{ 0.0445 \}^2 + \{ 2 \}^2]^{1/2} = 2.02\text{ns}$$

System bandwidth = (0.35 / rise time of the system)

= 0.35 / (2.02 x 10^{-9}) = 173.3 MHz

Just look at the system rise time formula, the receiver response time (2ns) is higher than the transmitter (0.3ns) and fiber (0.0445ns) rise times.

It would be better to change the receiver with rise time of 1ns, the system bandwidth increases to 335MHz.

Objective:

1.Complexity of the optical receiver design is simple in case of PIN photodiode. (T/F)

2.APDs used in optical receivers are very sensitive to optical power input levels. (T/F)

3.PIN photo diode is more stable with temperature variations. (T/F)

4.Laser diodes are capable of coupling 10-15 dB more optical power into a fiber than an LED. (T/F)

5.The complexity of the transmitter circuit is more in case of Laser diode. (T/F)

6.APD as an optical detector is more sensitive to variations in temperature. (T/F)

7.The received optical power must be high enough to keep the BER to a low value. (T/F)

8.The optical receive power must be low enough to avoid damage to the receiver. (T/F)

Subjective:

1. Redraw the figure 10.1 and write your observations.
2. List out the factors to be considered in Optical link design.
3. Why the Link Power and Rise time budget are to be assessed in optical link design?
4. What is difference between the procedure in estimating the rise time budget for multimode and single mode fiber?
5. Write a summary for this chapter.

CHAPTER-11

DENSE WAVELENGTH DIVISION MULTIPLEXING (DWDM)

Dense wavelength division multiplexing (DWDM) is a fiber-optic transmission technique that employs light wavelengths to transmit data parallel-by-bit or serial-by-character WDM is a concept that describes combination of several streams of data, Video or voice on the same physical fiber-optic cable by using several wavelengths (frequencies) of light with each frequency carrying a different type of data.

11.1 DWDM Evolution

- Early WDM (late 80s)
  - Two widely separated wavelengths (1310, 1550nm)
- "Second generation" WDM (early 90s)
  - Two to eight channels in 1550 nm window
  - 400+ GHz spacing
- DWDM systems (mid 90s)
  - 16 to 40 channels in 1550 nm window
  - 100 to 200 GHz spacing
- Next generation DWDM systems
  - 64 to 160 channels in 1550 nm window
  - 50 and 25 GHz spacing

11.2 Issues with the existing systems

The solution to overcome the short comings of exponential increase in user demand for bandwidth led to increase the channel capacity by TDM and WDM techniques, Statistical multiplexing, multiple optical fibers etc. Further, the limitations of TDM systems were the dependency of Mux - Demux on bit rate limitations. The bit rates decide how fast can we go and how small the time slots can be made. Inefficient usage of full capacity of the optical fiber and capability of carrying signals efficiently over short distances also were to be overcome. All this led to the improvements in optical fibers and narrowband lasers gave birth to Dense WDM (DWDM).

11.3 Advantages of DWDM over TDM

a) Overcome fiber exhaust / lack of fiber availability problems (Better utilization of available fiber)
b) Space & Power savings at intermediate stations
c) Easier capacity expansion
d) Cost effective transmission
e) No O-E-O conversion delays
f) Wave length leasing instead of Bandwidth leasing
g) Better Scalability as it utilizes abundance of dark fibers in metropolitan areas and enterprise networks

11.4 Basic Components & Operation:

Transmitting Side

- Lasers with precise stable wavelengths, Optical Multiplexers

On the Link

- Optical fiber, Optical amplifiers, OADM (Optical add drop filter)

Receiving Side

- Photo detectors, Optical De multiplexers / Optical add/drop multiplexers

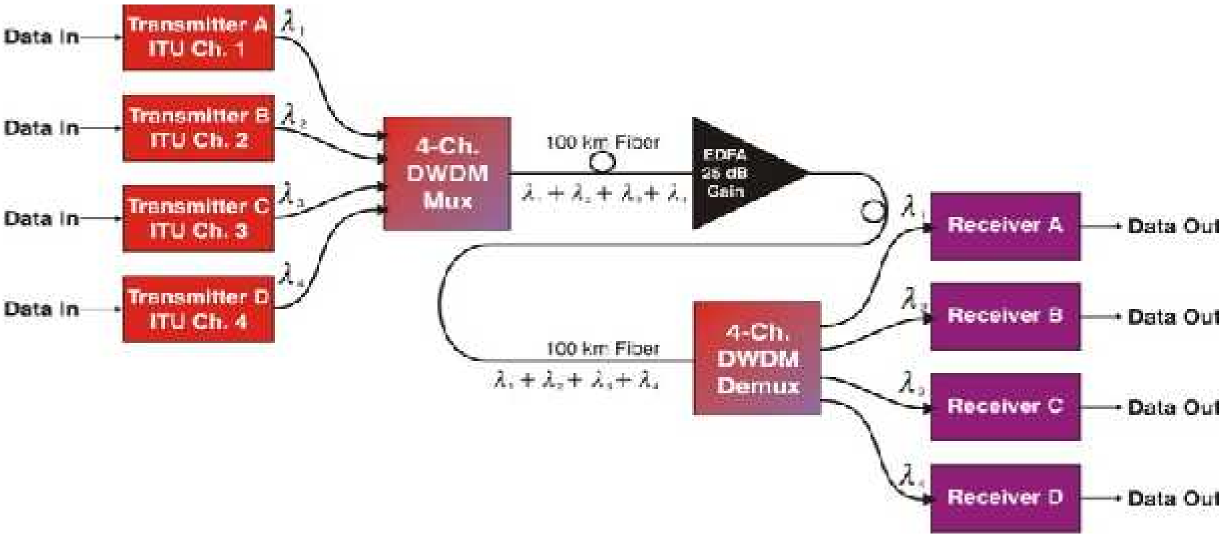


Fig No 11.1: Basic DWDM system

11.5 WDM Classification

WDM Classification is based on the Channel spacing between 2 Wave lengths

Channel spacing > 200GHz is called CWDM
Channel spacing > 100 GHz is called WDM
Channel spacing < 100GHz is called DWDM
Channel spacing < 25GHz is called UDWDM

11.6 Infrared Spectrum

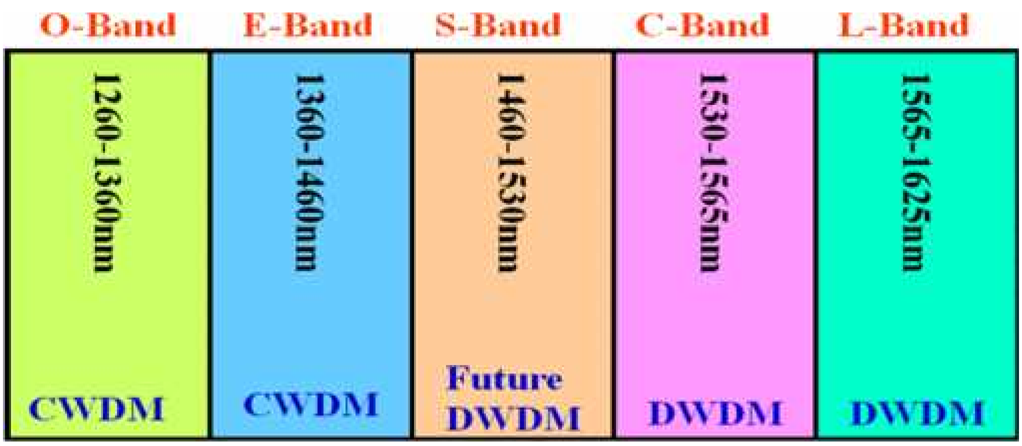


Fig No 11.2 Infrared Spectrum

11.7 Wavelength allocation for DWDM (ITU-T G.692)

C-Band (1530 – 1562nm): Also called conventional band or 1550 band
L-Band (1574 – 1608nm): Also called Long wavelength band or 1580nm band

The channel central frequencies are allocated in equal to frequency spacing of 100 GHz or 0.1 THz. All the channel central frequencies are anchored to the 193.1 THz reference. The channel central wavelength the corresponding to the reference frequency is 1552.52 nm.

Wavelength allocation in C-Band

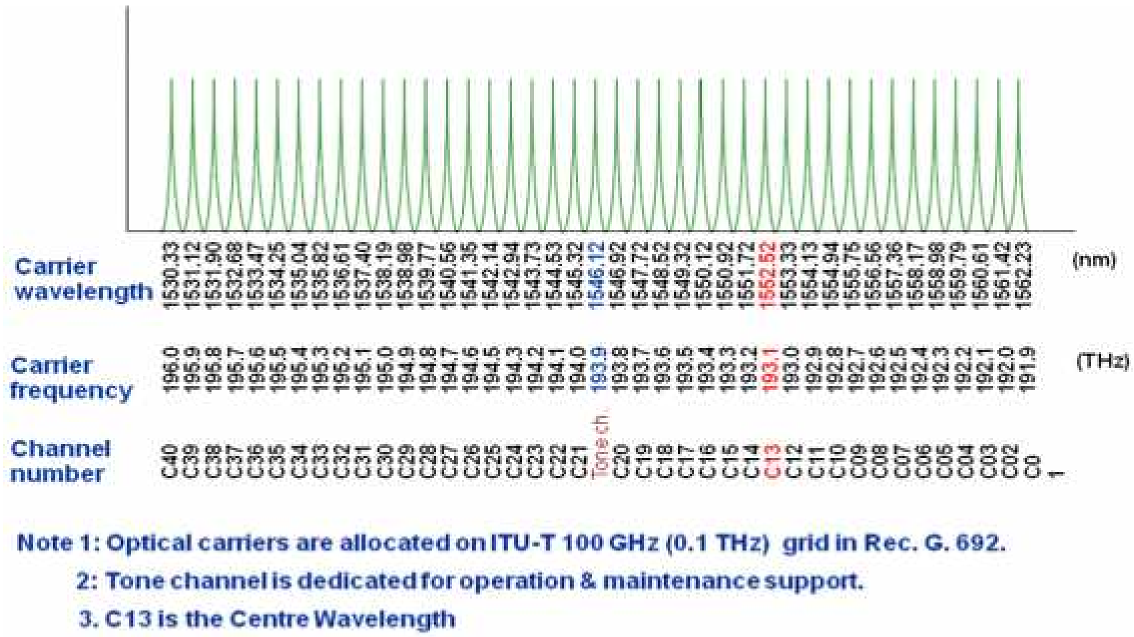


Fig No 11.3 : Wavelength allocation in C-Band

Wavelength allocation in L-Band

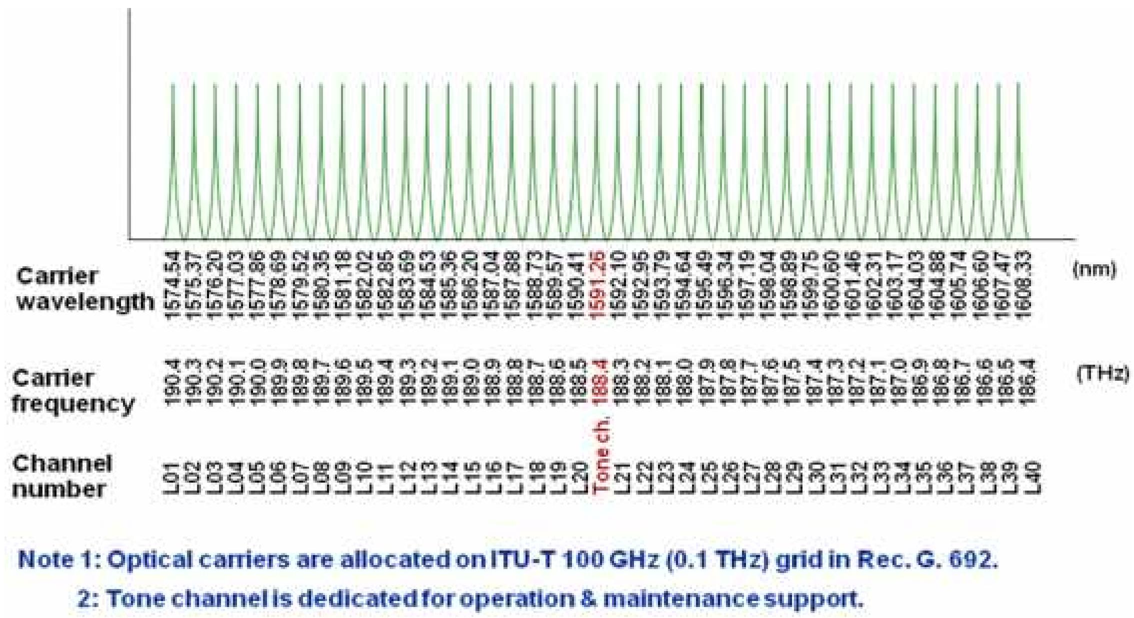


Fig No 11.4 : Wavelength allocation in L-Band

11.8 Comparaison of CWDM and DWDM Technologies

Feature	CWDM	Metro DWDM
Wavelengths per fiber	8-16 (O, E, S, C, L bands)	40-80 (C, L bands)
Wavelength spacing	2500 GHz (20 nm)	100 GHz (0.8 nm)
Wavelength capacity	Up to 2.5 Gpbs	Up to 10 Gbps
Aggregate fiber capacity	20-40 Gbps	100-1000 Gbps
Laser transmitter types	Uncooled DFB	Cooled DFB, external mod.
Filter technology	Thin film	Thin film, AWG, Bragg grating
Transmission distances	Up to 70 km	Up to 900 km
Overall cost	Very low	Medium
Applications	Enterprise, metro-access	Access, metro-core, regional

Table No 1: Comparaison of CWDM and DWDM Technologies

11.9 CWDM Channel Grid (ITU-T G.694.2)

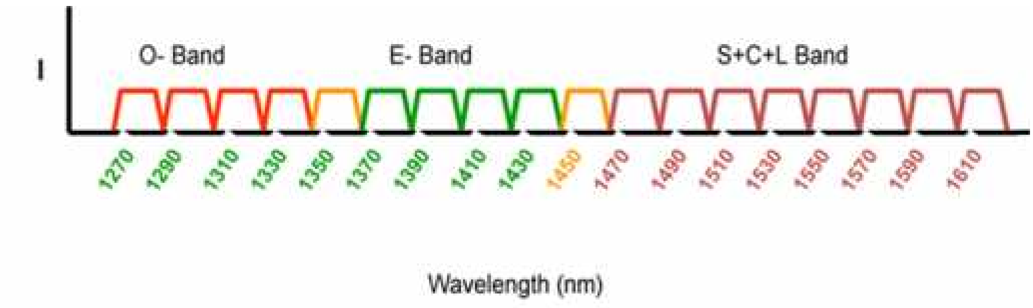


Fig No 11.5: CWDM Channel Grid

11.10 Main Components in DWDM

1) **Transponder**
2) **Omux/Odmux**
3) **Optical Amplifier**
4) **OADM**
5) **Regenerator**

1) **Transponder:** A device that takes an optical signal, performs electrical 3R regeneration & re-transmits the signal in optical form In to Wavelength grid as per G.192

For every input Wavelength, one transponder is required Its very useful for Wavelength leasing, as customer can Send any wavelength

2) **Omux/Odmux:** Various Transponder outputs (Wavelengths) will be provided as Inputs to Mux. Each input is equipped with A selective filter of certain Wavelength. The output of these filters are coupled to a Single Mode fiber

At the Receiver end, these Wavelengths are separated again by a Demux & directs them to individual Transponders

3) Optical Amplifier

a) **Booster/Post Amp:** Boosts the signal at Transmitter end to compensate relatively low output power of laser transmitters

b) **Line Amp:** Used at regular intervals to compensate fiber transmission loss

c) **Pre Amp:** Boosts signal prior to Optical detectors to increase the Rx sensitivity

- Booster amplifiers for boosting optical power into the fiber
- Preamplifiers for increasing receiver sensitivity
- In line amplifiers for periodic compensation of loss
- For overcoming losses at cross connect, add/drop etc.

11.11 Types of Optical Amplifiers

Two Types of optical amplifiers available

1. Solid state Optical Amplifiers
   - Semiconductor Optical Amplifiers
2. Fiber Amplifiers
   - Erbium Doped Fiber Amplifiers (EDFAs)
   - Raman Amplification (RA)

Erbium Doped Fiber Amplifiers

- An Erbium Doped Fibre Amplifier consists of a short length of optical fibre doped by small controlled amount of the rare earth element erbium
- This rare earth element contributes in the amplification process in presence of pump signal
- Pump laser excites erbium ions which give extra energy to signal
- Principle of operation is similar to principle of a laser
- Pumping with 980nm laser is more effective than 1480nm pumping
- Commonly used in submarine systems, and increasingly on land
- Amplification possible at many wavelengths around 1550nm
- Gain profile is not flat from the EDFA and need some flatting mechanism

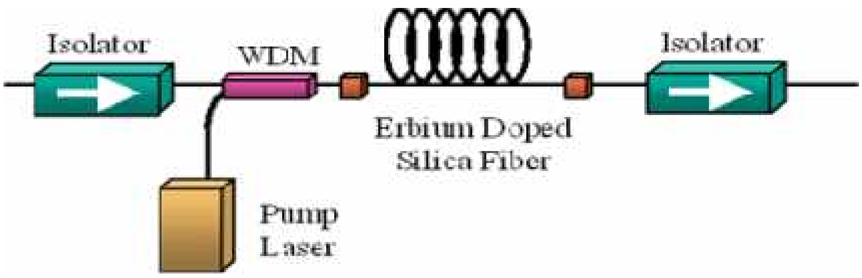


Fig 11.6 : Configuration of EDFA

Raman Fiber Amplifier

- Basic principle of Raman fiber amplifier is Stimulated Raman Scattering (SRS)
- When stronger optical pump interacts with the medium generates new signal (a Stokes wave) in same direction
- New generated frequency is lesser then the pump frequency by13.2 THz
- In normal fiber this effect is very small and it takes a relatively long length to have significant amplification

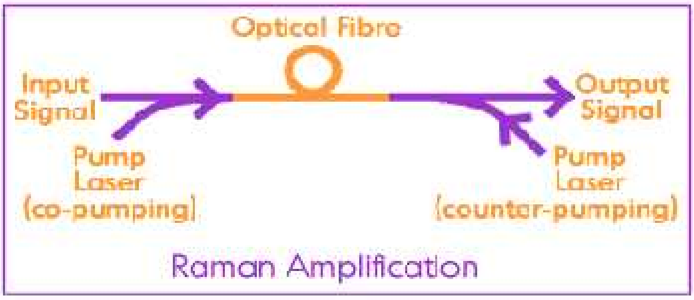


Fig 11.7 : Raman Amplification

11.12 Advantages of Raman Amplifier over EDFA

Low Noise Build up, Simple design, as direct amplification is achieved in the optical fiber and no special transmission medium is required

Flexible assignment of signal frequencies, as Raman gain depends on the pump wavelength and not on a wavelength sensitive material parameter, such as emission cross section of dopant in the Erbium Doped Fiber (EDF)

Broad gain bandwidth is achievable by combining Raman amplification effect of several pump waves that are placed carefully in wavelength domain

Not only specially launched pump waves but also but also some of the WDM channels may provide power to amplify the other channels this would result in power to amplify other channels and thus cross talk leading to de-gradation

Degrading effects like Raman scattering and backward Rayleigh scattering also affects the performance

11.13 Limitation:

The serious problem is Dispersion as Chromatic dispersion, Polarization mode dispersion, Attenuation Intrinsic, Scattering, Absorption, & Extrinsic Manufacturing Stress, Environment, etc. The Non-linear nature of refractive index of optical fiber Limits channel capacity of the DWDM System

DWDM SYSTEMS on Indian Railways

11.14 Introduction

RailTel has created country wide state of the art SDH/DWDM backbone optical transport network using latest cutting edge technology. More than 400 cities covering over 37,000 RKMs across the country are connected on the network with multiple STM-16 connectivity and has also implemented ultra high capacity DWDM network over 10,000 RKM to provide 400 Gbps which is further up gradable to 800 Gbps in future with PAN India DWDM network. The whole network is managed by centralized network management/operation system (NMS) located at New Delhi with back up facilities at Secunderabad / Kolkata/Mumbai.

RailTel has implemented ultra high capacity DWDM network using ADVA FSP 3000 systems. The Optical Networking equipment provides flexibility in multiplexing, transporting and protecting high-speed data, and video applications.

11.15 ADVA FSP 3000 system

The FSP 3000 is a scalable WDM transport solution specifically designed for service providers and large enterprises looking for flexibility and cost-efficiency in multiplexing, transporting and protecting high-speed data, storage and video applications.

The FSP 3000 facilitates bandwidth scale and service flexibility in access, backhaul, metro and long-haul networks, while supporting the creation of new revenue opportunities for high-speed OTN, Ethernet and storage services. The modular architecture of the FSP 3000 comprises a family of hot-swappable modules to meet network application requirements and make convergence practical. It supports DWDM & CWDM. Up to 120 wavelengths per fiber pair and a wide range of fully integrated transponder options optimize the spectral efficiency in the transmission fiber, eliminate fiber exhaust and reduce power and space consumption

11.16 Feature & Benefits of ADVA FSP 3000 system

1. Fixed or reconfigurable optical layer for long-haul, metro and access applications supporting DWDM, CWDM, WDM-PON
2. Multi-service capability supporting Ethernet, OTN, SONET/SDH, storage and video services up to 100Gbit/s
3. Erbium and Raman amplification option for non-regenerated transmission over distances exceeding 2,000km and up to 50dB single span loss.
4. High-density design for smallest footprint and lowest power consumption, resulting in operational cost savings.
5. Network Flexibility: It supports static and configurable photonic components, including tunable lasers and multi-degree ROADM (**reconfigurable optical add-drop multiplexer**) technology for colorless, directionless and contention less wavelength routing. The Flexible Remote Node concept allows network operators to deploy WDM-PON (**passive optical network** (**PON)** extensions that enable a unified access and backhaul architecture.
6. Network Automation: The FSP Network Manager and FSP Service Manager, operates through remote system operation and service-centric provisioning. The embedded RAY control GMPLS control plane enables automated on-demand delivery and management of any mix of services, therefore simplifying network operations and improving network resiliency. It enables service providers and enterprises to introduce new levels of efficiency in the operation of optical transport networks.
7. The FSP 3000 provides increased distance support by means of end point optical amplifiers. Distances of up to 103km route (approx 50-55km radial) will be supported. It has been agreed that planning rules will be introduced so that 4Gig cards can be deployed with a shorter reach.

11.17 ADVA FSP 3000 system with 1 U Chassis (Slim line 1U chassis)

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Fig No 11.8 ADVA FSP 3000 system (1 U)

Features of Slim line 1U chassis

1. 1U has a double card slot capability. This can run either without filters (max 1 wavelength) or with an additional 1U passive filter shelf (max 4 wavelengths)
2. The equipment comprises Slim line 1U chassis covering Route distance up to 100km
3. Ideal to deliver higher volumes of 1Gig services
4. It is having a capacity of 12 channels, & the capacity can be enhanced to 32 optical channels.
5. Future developments include midpoint amps, and Rings & Chains

11.18 ADVA FSP 3000 7U high chassis

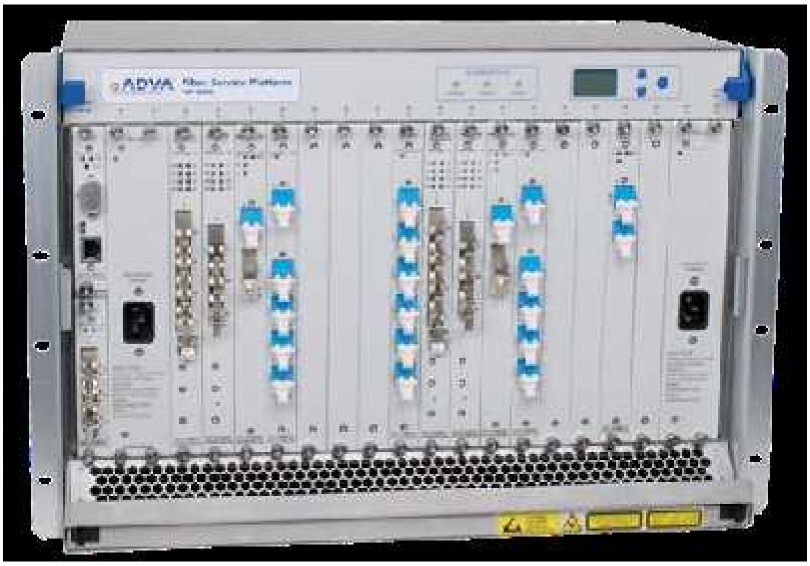

Fig No 11.9 : ADVA FSP 3000 system (7U)

1. It is fully featured, high capacity chassis which provides the flexibility to meet an extensive range
2. 16 slots available for all card types including transponders, filters, protection cards and optical supervisory cards
3. It is having a capacity of 12 channels, & the capacity can be enhanced to 32 optical channels
4. Future developments include midpoint amps, and Rings & Chains

ITU- T Recommendation for reference:

Recommendation ITU-T G.709

It Deals with Interfaces for the optical transport network

It describes a means of communicating data over an optical network. It is a standardized method for transparent transport of services over optical wavelengths in DWDM systems. It is also known as Optical Transport Hierarchy (OTH) standard

Recommendation ITU-T G.709/Y.1331 defines the requirements for the optical transport module of order n (OTM-n) signals of the optical transport network, in terms of:

- Optical transport hierarchy (OTH)
- Functionality of the overhead in support of multi-wavelength optical networks
- Frame structures
- Bit rates
- Formats for mapping client signals.

The interfaces defined in this Recommendation can be applied at user-to-network interfaces (UNI) and network node interfaces (NNI) of the optical transport network. It is recognized, for interfaces used within optical sub networks, that aspects of the interface are optical technology dependent and subject to change as technology progresses. Therefore, optical technology dependent aspects (for transverse compatibility) are not defined for these interfaces to allow for technology changes. The overhead functionality necessary for operations and management of optical sub networks is defined. G.709 offers advanced OAM&P capabilities such as Tandem Connection Monitoring (TCM), End to End performance monitoring, connectivity monitoring, signal quality supervision and General Communication Channel (GCC).

ITU-T Recommendation G.694.1

It Deals with Spectral grids for WDM applications: DWDM frequency grid

The purpose of this Recommendation is to provide the definition of a frequency grid to support dense wavelength division multiplexing (DWDM) applications

Frequency grid: A frequency grid is a reference set of frequencies used to denote allowed nominal central frequencies that may be used for defining applications.

Frequency slot: The frequency range allocated to a slot and unavailable to other slots within a flexible grid. A frequency slot is defined by its nominal central frequency and its slot width.

The full width of a frequency slot in a flexible grid. The frequency grid defined by this Recommendation supports a variety of fixed channel spacings ranging from 12.5 GHz to 100 GHz and wider (integer multiples of 100 GHz) as well as a flexible grid. Uneven channel spacings using the fixed grids are also allowed.The current steps in channel spacing for the fixed grids have historically evolved by sub-dividing the initial 100 GHz grid by successive factors of two.

For details please refer ITU website: http://www.itu.int/rec/T-REC-G.694.1-201202-I/en

REFERENCES

Books from British Library on Fiber Optics

1.	IRISET PPT FILES	:	P V Sreekanth, Prof./IRISET
2.	Maintenance Hand-Book on OFC	:	CAMTECH
3.	Plastic Optical Fiber: Practical Applications	:	Jean Marcon
4.	Introduction to Fiber Optics	:	John Crisp
5.	Optical Networking Crash Course	:	Steven Shepard
6.	WDM Technologies : Optical Networks	:	Achyut K Dutta & Others
7.	Fiber-Optic Communication Systems	:	Govind P Agrawal
8.	Opto Electronics & Fiber Optic Technology	:	Ray Tricker

Websites relating to Optical Fiber System

1. http://www.hsc.csu.edu.au
2. http://www.aoe-expo.com/english
3. http://www.cbi.co.za
4. http://www.fe.up.pt/si/web_page.inicial
5. http://www.connectworld.net
6. http://optical-components.globalspec.com
7. http://www.science.org.au
8. http://portal.acm.org/portal.cfm
9. http://www.nationmaster.com/index.php
10. eeclass.stanford.edu
11. http://www.visionscopetechnologies.co.uk
12. http://www.bikudo.com
13. http://www.j-fiber.com
14. http://www.lanutil.com
15. http://misgroup2.blogspot.com
16. http://www.howstuffworks.com
17. http://networks.cs.ucdavis.edu
18. fiber-optics-cable.blogspot.com
19. http://www.lucidos.co.uk
20. http://www.lascomm.com
21. http://www.cisco.com