# DWDM Training : *CSIR, South Africa*

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By

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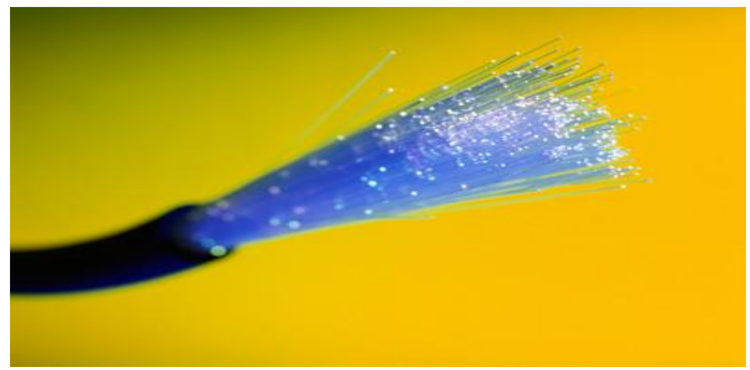
Nex-G Skills

# Day -1

The fiber optics is spread over worldwide having its uses in Different fields such as Telecommunication, Medical, Light based communication etc.

- ❖ Introduction Of fiber Optics
- ❖ Fiber Theory/Optical Fibers
- ❖ Test Equipment and Testing
- ❖ Light Sources(Lasers & LED description)
- ❖ Systems Overview- Evolution of DWM/CWDM/DWDM
- ❖ DWDM Introduction
- ❖ DWDM Components and Architecture (Optical Amplifiers and types)

# Fiber Optics Technology

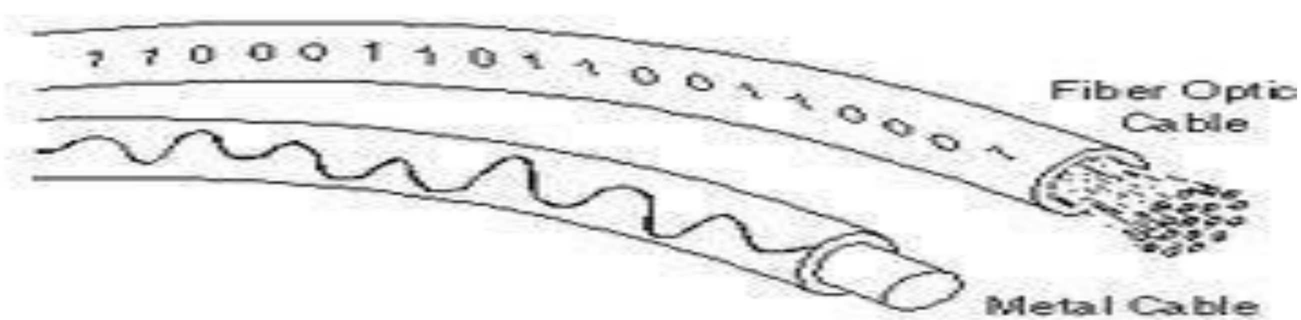


A Technology that uses glass (or plastic) threads (fibers) to transmit data.

A fiber optic cable consists of a bundle of glass threads, each of which is capable of transmitting messages modulated onto light waves.

I.e., it is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair.

Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber optic communications, where they permit transmission over longer distances and at higher bandwidth (data rates) than wire cables.



Optical fibers were first envisioned as optical elements in the early 1960s.

It was perhaps those scientists well-acquainted with the microscopic structure of the insect eye who realized that an appropriate bundle of optical waveguides could be made to transfer an image and the first application of optical fibers to imaging was conceived.

It was Charles Kao1 who first suggested the possibility that low-loss optical fibers could be competitive with coaxial cable and metal waveguides for telecommunications applications.

It was not, however, until 1970 when Corning Glass Works announced an optical fiber loss less than the benchmark level of 10 dB/km that commercial applications began to be realized.

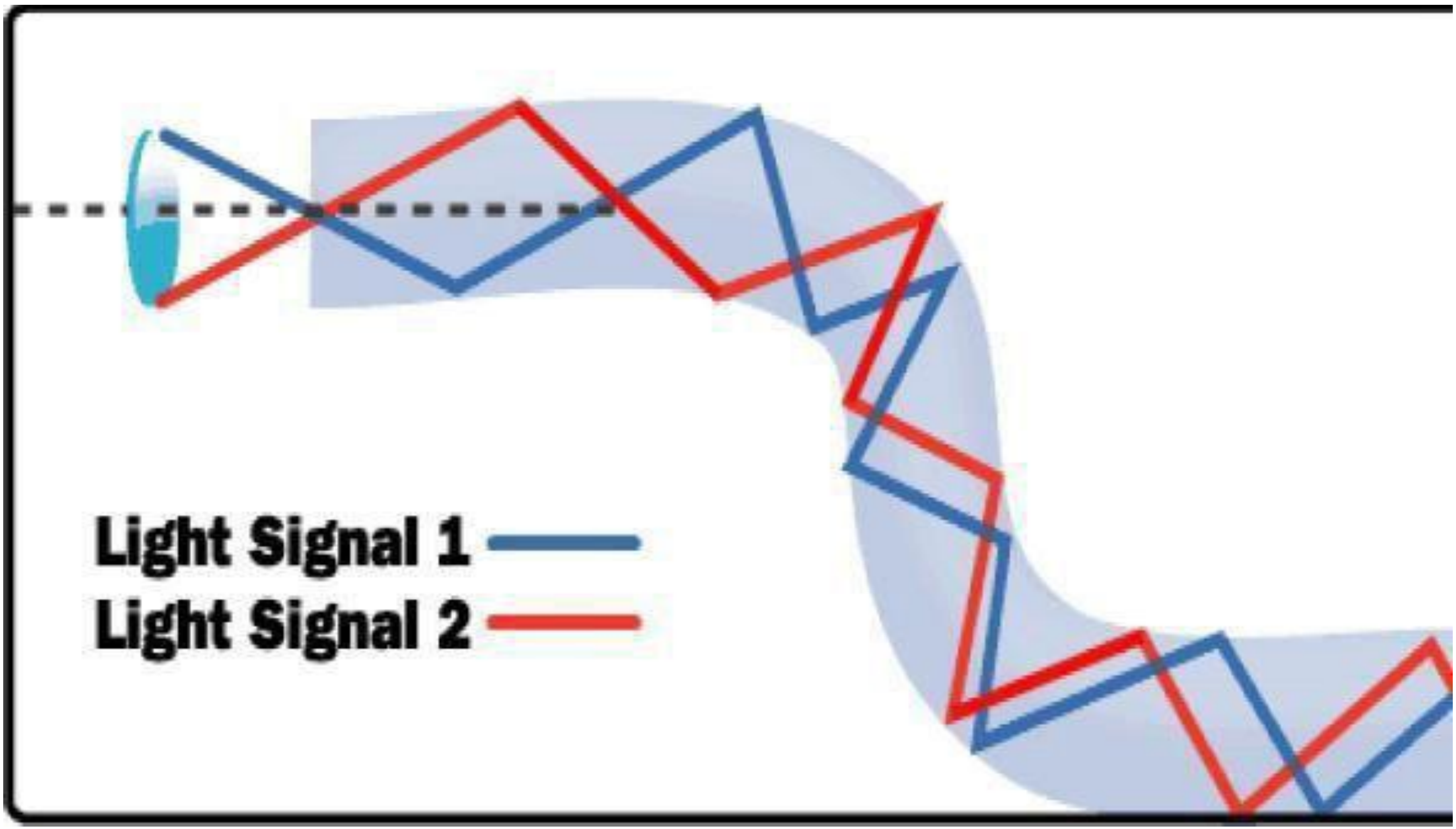
# Fiber Optic Communications

- fibers of glass
- Usually 120 micrometers in diameter
- Used to carry signals in the form of light over distances up to 50 km.
- No repeaters needed

- Thinner
- Less Expensive
- Higher Carrying Capacity
- Less Signal Degradation
- Light Signals
- Non-Flammable
- Light Weight

- Telecommunications
- Local Area Networks
- Cable TV
- CCTV
- Optical fiber Sensors

- Total Internal Reflection
- Fiber Optics Relay Systems
- Transmitter
- Optical fiber
- Optical Regenerator
- Optical Receiver


Light Signal 1
Light Signal 2

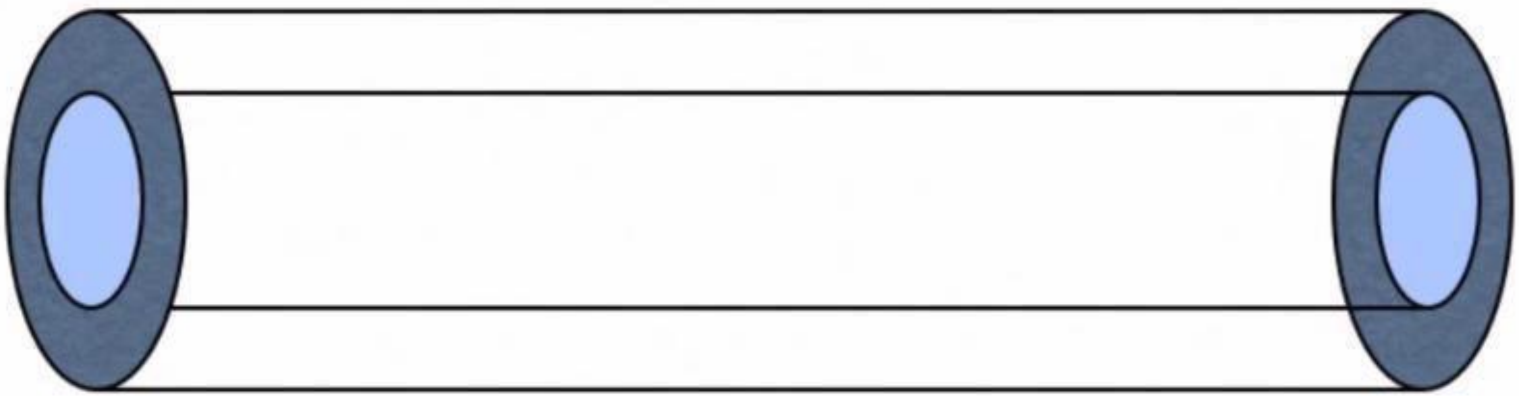
# Fiber Theory / Optical Fibers

- Uses Light Pulses to represent the Binary Data.
- Commonly used in high speed networks where distance requirement is too much.
- Two Types:

1. Multimode fiber(MMF)
2. Single Mode fiber(SMF)

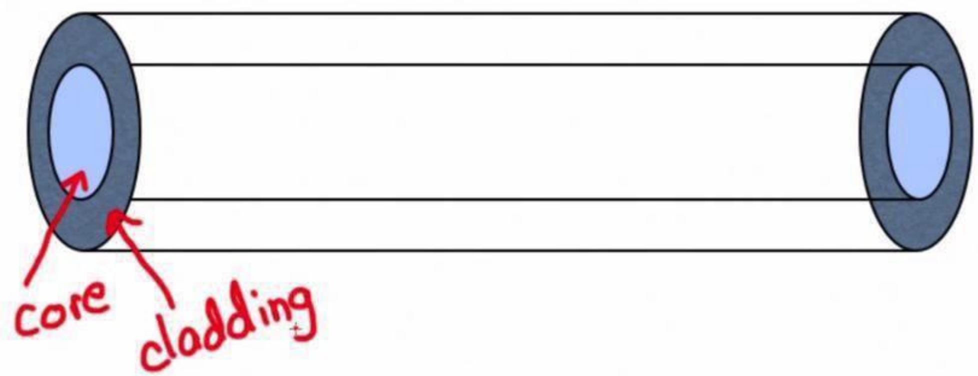
For ex, few pencils are put In a glass of water ,wher these pencils are looking differently above the water & below the water line due to refraction.

This is because air & water have different Refractive Index.



As we can see from the piece of fiber optic by zooming it, that it is having two sides.i,e,

Transmitter side & Receiver Side. This piece of fiber shows inner core and outside of the core is called Cladding as shown in the Figure.



- Now , considering the ray of light or LED coming into & hits the inner core, bounce off up & down inside the cladding as it bends of such as back and forth again and again the core.

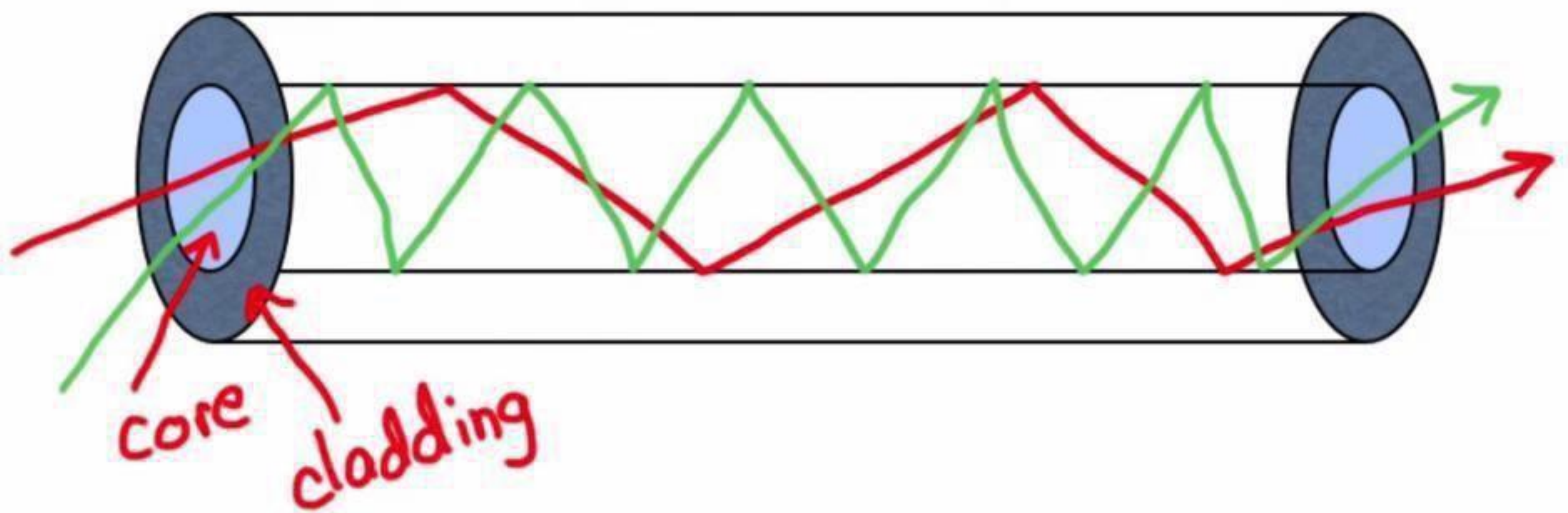
- But in case of multimode fiber, the core has a diameter *larger than the single mode* fiber to allow light to enter the core at different angles.

- If the light enters into the Steeper angle, it will bouncing more back and forth so much inside that it takes the longer time to travel out of the core, due to bouncing back and forth more *frequently.*

- Over a long distance for ex, 2 kms, we can have a issue with this, so if one bits coming with a longer steeps(Green) and other with less steep angle(red), then its possible that bits can get out of the order.

Hence , in Multimode, there is a *delay distortion* where bits get out of order as they are represented by different paths of Light at different angles.

Note: A mode is a path for propagation of light, so depending upon the Diameter of the optical fiber, there could be several modes.




So, if the diameter is so small say for one mode, then we can have a way of propagation that can only go down in the middle of the core as the diameter is not large enough to allow the light, so we call it single mode.

Hence the core has a diameter so small that light can only enter at one angle, which may cover larger distances for ex- 40 kms.

The role of the Optical Transmitter is to:

- Convert the electrical signal into optical form, and
- launch the resulting optical signal into the optical fiber.

The Optical Transmitter consists of the following components:

1. Optical source

2. Electrical Pulse Generator

3. Optical Modulator

The launched power is an important design parameter, as indicates fiber loss can be tolerated.

It is often expressed in units of dBm with 1 mW as the reference level.

# LED Modulation Response (Optical System)

The frequency response of an LED is determined by the dynamics (and therefore is limited by the carrier lifetime $T_n$) parasitic capacitance of the LED (described by the RC constant T).

If a small, constant forward bias is applied, the influence of the parasitic capacitance of the LED can be neglected.

For LED 3-dB modulation Optical Bandwidth is defined as the modulation Frequency at the LED power transfer function is reduced by 3 dB.

There are two main types of fiber optic transmitter that are in use today.
Both of them are *based on Semiconductor* Technology :

1. Light emitting diodes (LEDs)
2. Laser diodes

Semiconductor Optical Transmitters have many advantages as they are

- Small
- Convenient and
- Reliable.

However, the two different types of fiber optic transmitter have very different properties and they tend to be used in widely different applications.

*LED Transmitters* : These Fiber Optic Transmitters are cheap and reliable.

They emit only incoherent light with a relatively wide spectrum as a result of the fact that the light is generated by a method known as Spontaneous Emission.

A Typical LED used for optical communications may have its light output in the range 30 - 60 nm.

In view of this , the signal will be subject to Chromatic Dispersion, which will limit the distances over which data can be transmitted.

It is also found that the light emitted for a LED is not **particularly directional** and this means that it is only possible to **couple them to multimode fiber**, so that the overall efficiency is low because not all the light can be coupled into the fiber optic cable.

LEDs have significant *advantages* as fiber optic transmitters in terms of

1. Cost
2. Lifetime and
3. Availability.

They are widely produced and the technology to manufacture them is straightforward and as a result, costs are low.

**Laser diode Transmitters**: These fiber Optic Transmitters are **more expensive** and tend to be used for telecommunications links where the cost sensitivity is nowhere near as great.

- The *output from a laser diode is generally higher than that available from a LED*, although in the *power of LEDs is increasing*.

Often the light output from a laser diode can be the region of 100 mW.

- The light generation arises from stimulated emission which this generates coherent light.

In addition to this , *the output is more directional* than that of a LED and this enables much greater levels of *coupling efficiency into single mode fiber* which enables much *greater transmission distances* to be achieved.

- A further **advantage** of using a laser is that they have a coherent light output which means that the light is nominally on a **single frequency** and **modal dispersion** is considerably less.

- Also one more **advantage** of lasers is that they can be *directly modulated with high data rates* , apart from LEDS modulating directly, with a *lower modulation rate*.

Nevertheless laser diode fiber Optic Transmitters have some Drawbacks.

1. More **Expensive** than LEDs
2. Quite **Sensitive to Temperature** and
3. To obtain the **Optimum Performance** they need to be in a *stable environment*.

They also do not offer the same life as LEDs, although as much research has been undertaken into laser diode technology, this is much less of an issue than previously .

Fiber Optic Transmitter Summary :

In view of the different characteristics possessed by both LEDs and laser diode fiber optic transmitters are used in different applications.

The table below summarizes some of the chief characteristics of the two devices.

| CHARACTERISTIC | LED | LASER DIODE |
|---|---|---|
| Cost | Low | High |
| Data rate | Low | High |
| Distance | Short | Long |
| Fibre type | Multimode fibre | Multimode and single mode fibre |
| Lifetime | High | Low |
| Temperature sensitivity | Minor | Significant |

**NOTE :**

LEDs tend to be used for the more cost sensitive applications and ones where lower data rates and shorter distances are required. Local area networks with speeds up to a maximum of 100 Mbps and distances up to a kilometer or so represent the upper limits.

Long distance telecommunications fiber optic links with Gbps data rates require the use of the more expensive laser diode fiber optic transmitters.

Optical Receivers :

Once data has been transmitted across a fiber optic cable, it is necessary for it to be received and converted into electrical signals so that it can be processed and distributed to its final destination.

The fiber optic receiver is the essential component in this process as it performs the actual reception of the optical signal and converts it into electrical pulses. Within the fiber optic receiver, the photo detector is the key element.

A variety of semiconductor photo-detectors may be used as fiber optic receivers.

They are normally -

1. Semiconductor devices and
2. form of photo-diode.

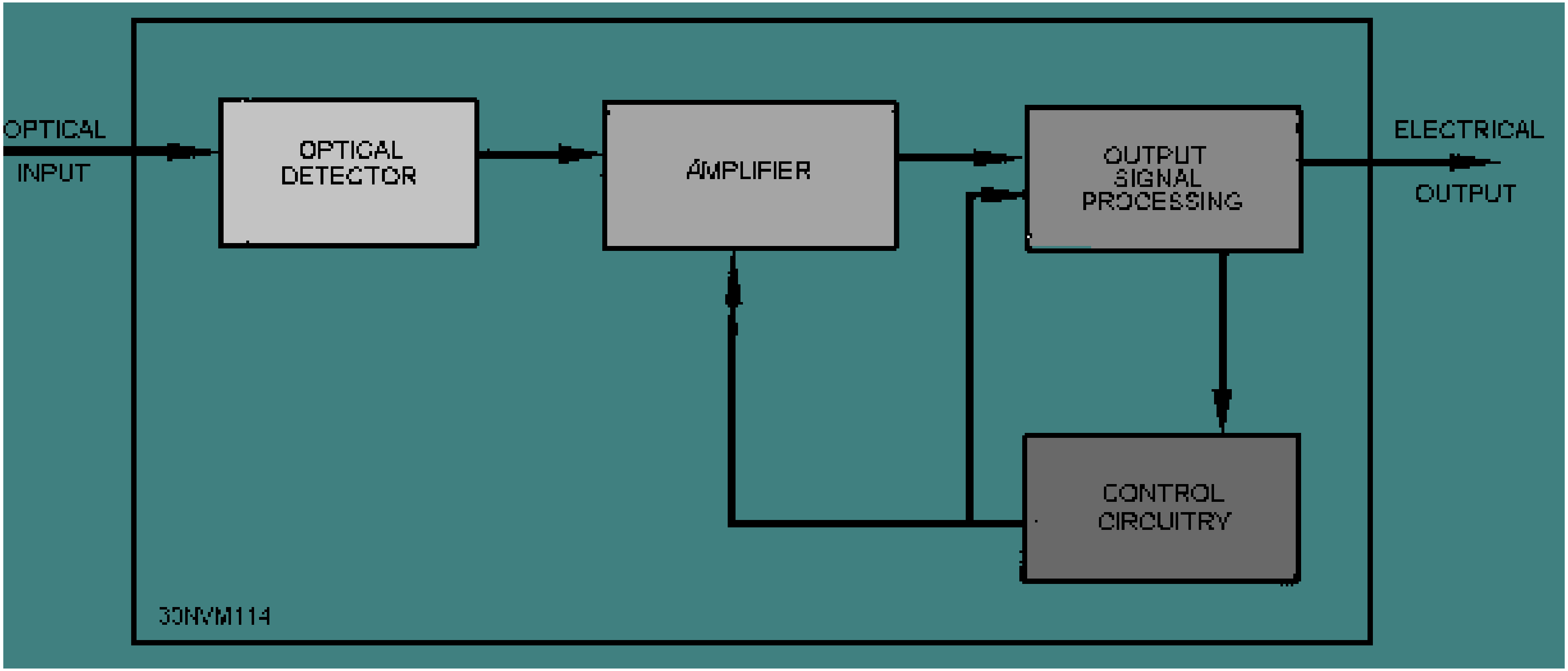
A variety of diodes may be used in fiber optic receivers, namely p-n photodiode , a p-i-n photodiode, or an avalanche photodiode. Metal-semiconductor-metal(MSM) photo detectors are also used in fiber optic receivers on occasions as well.

Fiber Optic Receivers uses –

1. Positive-Negative Junctions **(PN)**,
2. Positive-Intrinsic Negative **(PIN)** photodiodes, or
3. Avalanche Photodiodes (**APD**) as optical detectors.

The incoming light signal is sent by a fiber optic transmitter (or transceiver) and travels along single-mode or multi-mode optical cable, depending on device capabilities and a data demodulator converts the light signal back into its original electrical form.

So, for complex fiber optic systems, wavelength division multiplexing (WDM) components are also used.




fiber Optic Receiver Block Diagram

## Semiconductors and Photodiodes:

The Global Spec. database allows industrial buyers to select products by semiconductor type and photodiode type.

Two types of semiconductors are used in fiber optic receivers.

**Silicon semiconductors** are used in short-wavelength receivers with a range of 400 nm to 1100 nm.

**Indium gallium arsenide semiconductors** are used in long-wavelength receivers with a range of 900 nm to 1700 nm.

As described above, fiber optic receivers use three different types of photodiodes.

**P-N junctions** are formed at the boundary of a P-type and N-type semiconductor, typically in a single crystal via doping.

- **PIN photodiodes** have a large, neutrally-doped intrinsic region sandwiched between P- doped and N-doped semiconducting regions.
- **APDs** are specialized PIN photodiodes that operate with *high reverse bias voltages*.

**Optical Amplifier** :- is placed in front of the detector, acting as a Preamplifier.

- To increase the optical power reaching the amplifier
- Permitting it to detect Fainter signals.

The sensitivity of the detector & the receiver depends on the wavelength & also the Temperature.

- Optical Amplifiers : are the amplifiers which are employed in the DWDM systems used to build long transmission links, these, however, are only working well for the 3 and 4 optical window (about 1550nm to 1610nm) .

The Amplification can be done with an electrical repeater which converts the optical signal by means of a photodiode into an electrical signal, amplifies the electrical signal and converts it back to an optical signal.

Fig. shows a 1-channel system above and a DWDM system below with optical amplification.

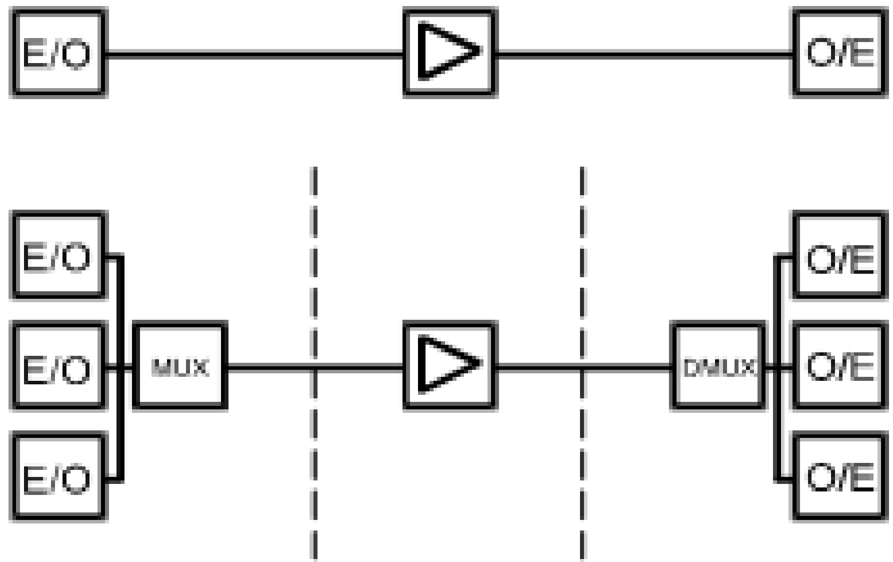
In comparing the two multi-channel DWDM systems the superiority of using an optical amplifier becomes obvious.

The Optical Amplification is independent of the bit rate as well as of the Transmission capacity and data protocol.

It operates without converting the signal into the electrical range.

Until now, Optical Amplifiers with appropriate features have been available for the 3. optical window only and suitable optical amplifiers for the 4. optical window are being Developed now.

Hence, DWDM systems can soon be realized in the 3. and the 4. optical window up to 1610nm (L-band, long wavelength).




transmission system with
optical signal amplification

It is disadvantageous that with a given repeater only a given protocol at a fixed data rate can be transmitted, therefore, it is more reasonable to use optical amplifiers in DWDM systems.

In Physics, two wave sources are coherent if they have a constant phase difference and the same frequency.

It is an ideal property of waves that enables stationary interference(i.e. temporally and spatially constant).

Coherent Light wave Systems provides 10 to 20 db performance improvement over more common direct detection technology.

In addition coherent systems offers -

1. Wide information Bandwidth
2. Excellent survivability against adverse environments &
3. Can replace/interface with the existing micro-wave / milli- meter wave systems.

Generally, Coherent systems are used to improve link distances and information capacity.

In coherent light wave system, the Amplitude, Frequency and Phase of the optical carrier are modulated in the same way that RF carrier in the microwave system is modulated.

Because the single –mode coherent Light wave system has an extremely wide operational bandwidth, it transmits/receive M/MMWRF signals (data & information) and can directly replace or interface with existing M/MMW RF systems.

Types of Coherent Light wave Systems:

- Heterodyne
- Homodyne

Common used fiber Optic Test Equipment includes :

- fiber optic power meter- is used for absolute optical fiber power measurement is used for absolute optical fiber power measurement
- fiber optic light source - is used with power meter to test the fiber system loss
- fiber multimeter- is an integrated unit of power meter
- Optical time domain reflectometer (OTDR) - it could test the whole system fiber length, joint point and loss.
- fiber fault locator - it could be regarded to be part of OTDR to find the faults in the Fiber.

When choose a fiber test equipment, besides the function and quality of the equipment, you have to consider the specifications of the fiber system that you are going to test, for example :-

1. The working wavelength (typical is 1310nm, 1550nm and 850nm)
2. fiber light source type
3. fiber optic glass type (single mode or multimode)
4. fiber connection interface (like FC, SC) , and
5. The system capacity and possible loss range

Fiber optic test equipment working environment is also the factor you should consider such as :

1. Whether you are going to use the fiber test equipment indoor or outdoor
2. The equipment working temperature.
3. Power supply.
4. Battery life

An **Optical Time-Domain Reflect meter** (**OTDR**) is an optoelectronic instrument used to characterize an optical fiber.

An OTDR is the optical equivalent of an electronic time domain reflect meter and it injects *a series of optical pulses into the fiber* under test and extracts, from the same end of the fiber, and the light that is scattered (Rayleigh backscatter) or reflected back from points along the fiber.

The scattered or reflected light that is gathered back is used to characterize the optical fiber.

The Strength of the return pulses is measured and integrated as a function of time, and plotted as a function of fiber length.

OTDR is applicable for the measurement of **fiber loss**, connector loss and for the determination of the exact place and the value of cable discontinuities.

By means of very short pulses it is also possible to measure the modal dispersion of multimodal fibers.

Working Principal of the OTDR Analyser is follows as –

I. A short light pulse is transmitted into the fiber under test and the time of the incidence and the amplitude of the reflected pulses are measured.

II. The commonly used pulse width ranges from nanosecs to microsecs, the power of the pulse can exceed 10 mW.

III. The repetition frequency depends on the fiber length, typically is between 1 and 20 kHz, naturally it is smaller for longer fibers which is naturally smaller for longer fibers.

The components of the fiber loss and their importance in the OTDR measurements :

There are three reasons for the fiber loss:

- Absorption
- Radiation loss
- Rayleigh scattering

The Absorption creates 10-20% of the fiber loss and mainly originates from the OH- ions inside the fiber material (impurities) , so the loss can be kept at relatively low level.

The fiber loss increases dynamically for wavelengths above 1700 nm, thus this is the lowest frequency for optical telecommunications.

In practice the 1300 and 1550 nm wavelengths are used as the insertion loss shows minimal values at these wavelengths. (Note that Insertion Loss is the difference in power at the input and the output of the device under test.It is usually expressed in decibels.(This is per channel loss on a DWDM system)

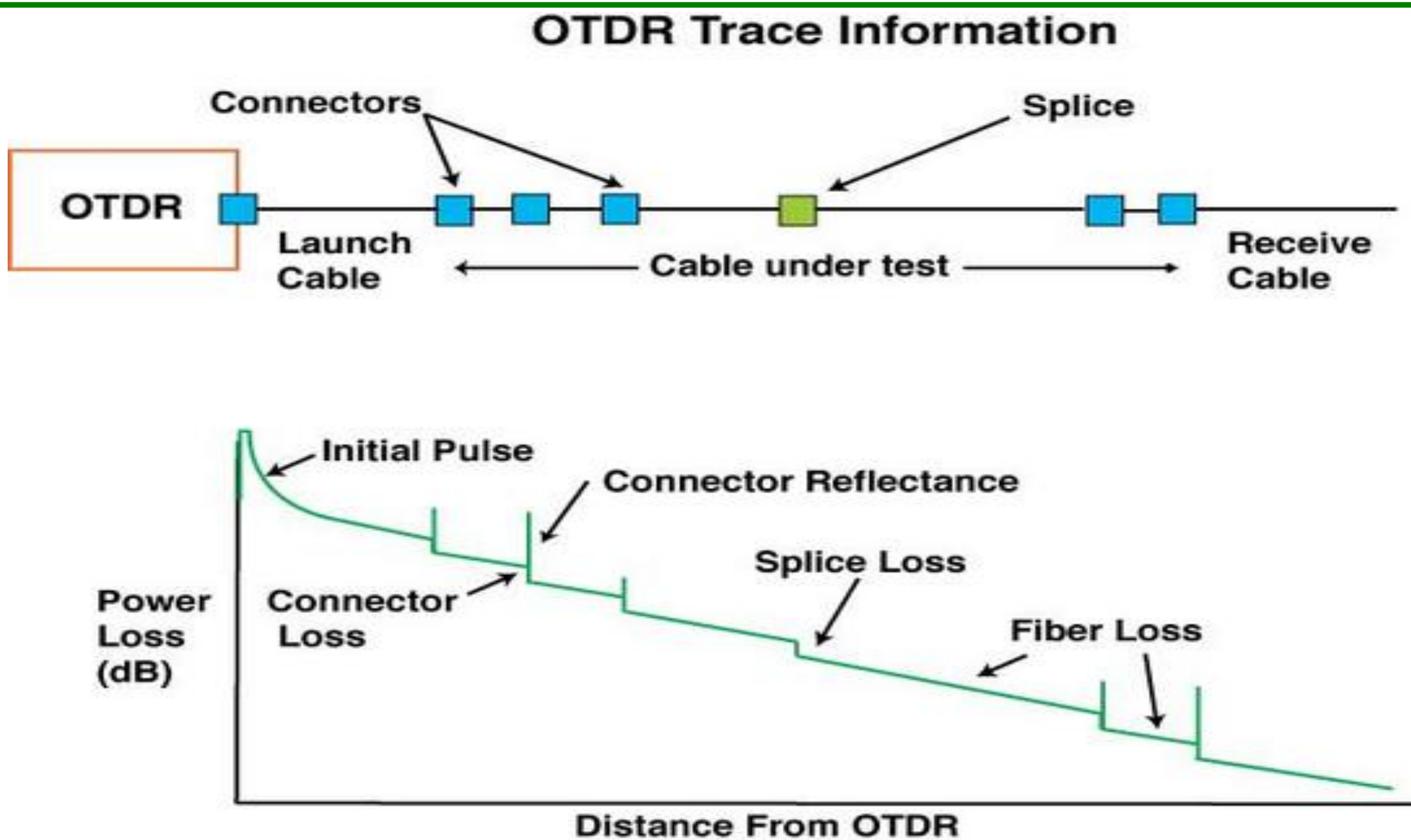
Naturally, Absorption does not induce reflection, so if this would be the only physical phenomena, the fiber loss could be measured by the means of OTDR only with a well known, calibrated termination.

**Radiation loss** occurs when the geometrical parameters of the fiber *abruptly change*, or a *mechanical tension is present* in the fiber material due to fabrication failure or mechanical impact.

During OTDR measurements ,the most important loss is the one caused by **Rayleigh scattering**.

It generates the 80-90% of the total loss.

The scattering is induced by the microscopic inhomogenity of the refractive index of the fiber.


OTDR Trace Information
Connectors
Splice
OTDR
Launch Cable
Cable under test
Receive Cable
Initial Pulse
Connector Reflectance
Splice Loss
Fiber Loss
Power Loss (dB)
Connector Loss
Distance From OTDR


ShinewayTech


RS800 Mini–OTDR
Read
Save
Delete
CleanUp
Transmit
Return
B
Rayscience

Most light sources and detectors are electronic devices built from the same semiconductor materials as are used in transistors and integrated circuits.

**Lasers -** The most commonly form of the Laser is called as ***Injection Laser Diode (ILD).***

A laser provides a light of fixed wavelength which can be in the visible region around 635 nm or in any one of the three infrared windows.

The light has a very narrow bandwidth, typically only a few nanometres wide.

This ensures that Chromatic Dispersion is kept to a low value and this, together with fast switching, allows high Data Transmission rates.

As the laser device itself is barely visible to the unaided eye, it must be contained in some form of package.

Two typical examples are shown in Figure 14.1.

Lasers for visible light - The light is launched via a lens system to allow it to be concentrated into a beam.

Visible laser light finds applications in bar code readers, CD players, medical and communication systems.

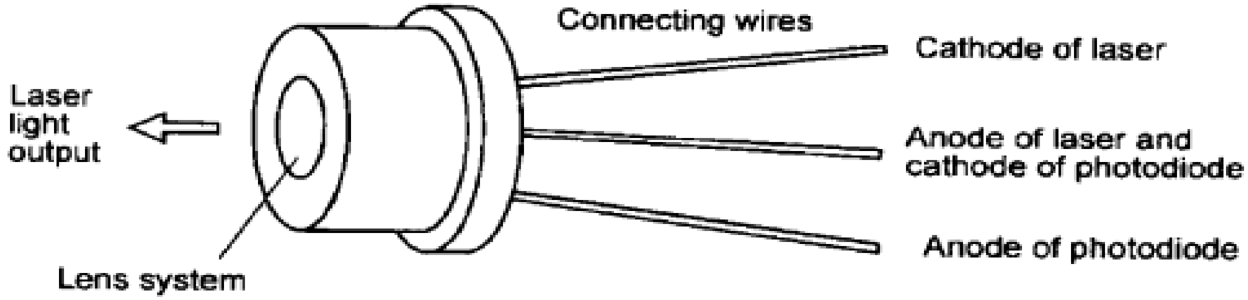
They are usually fitted with a built-in light detector so that they can receive reflected information as in the case of the barcode reader.

***Lasers for 850 nm use*** **:** These can be packaged in either of the ways illustrated in Figure 14.1 depending on their application.

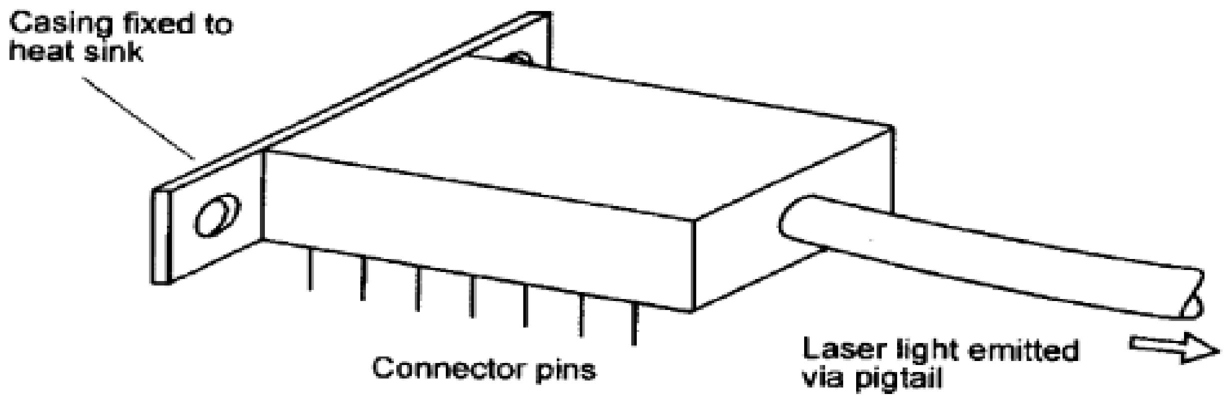
The fact that their output is not visible allows for use in

- Security
- Ranging
- Automotive and industrial and
- Military Applications.

They also provide the light source for short and medium range fiber communications.




A typical package for visible light lasers and for 850 nm lasers




A laser for singlemode use

*Lasers for Single mode communications* :

Successful launching into single mode fibers requires very high precision and this is achieved by optimizing the position of an attached pigtail which can be connected to the main fiber run by any desired method.

A Photoelectric cell is also included as a monitoring device to measure the output power providing feedback to allow for automatic control of the laser output power.

As the output power of a laser is affected by "***any change in its temperature***", generally *decreasing in power as the temperature increases* , some laser modules include a temperature sensor to combat this problem.

It provides internal temperature information which is used to control a thermo-electric cooler like -a small refrigerator, to maintain the temperature.

Laser Safety - Both visible and infrared light can cause immediate and permanent damage to the eyes.

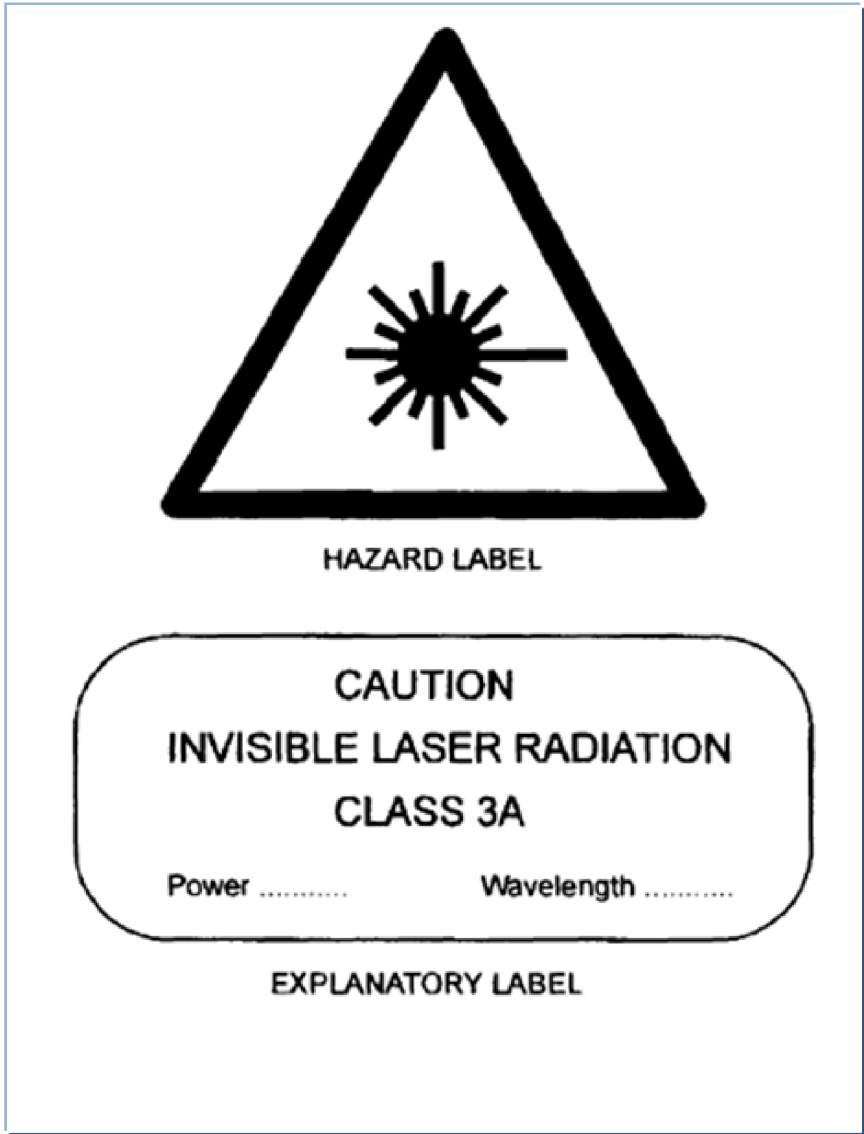
The shorter wavelengths cause damage to the retina and the longer wavelengths attack the cornea, in neither case can medical science offer remedy once the damage is done.

**Precautions :**

1. Never look into:
2. A live laser source
3. An unknown light source
4. Any fiber until you have ascertained that it is safe.

Check it yourself even if trusted colleagues say ‘its OK we’ve just checked it out’.

They may be talking about a different fiber or they may have made a mistake.




Laser warning labels

## Laser Specifications

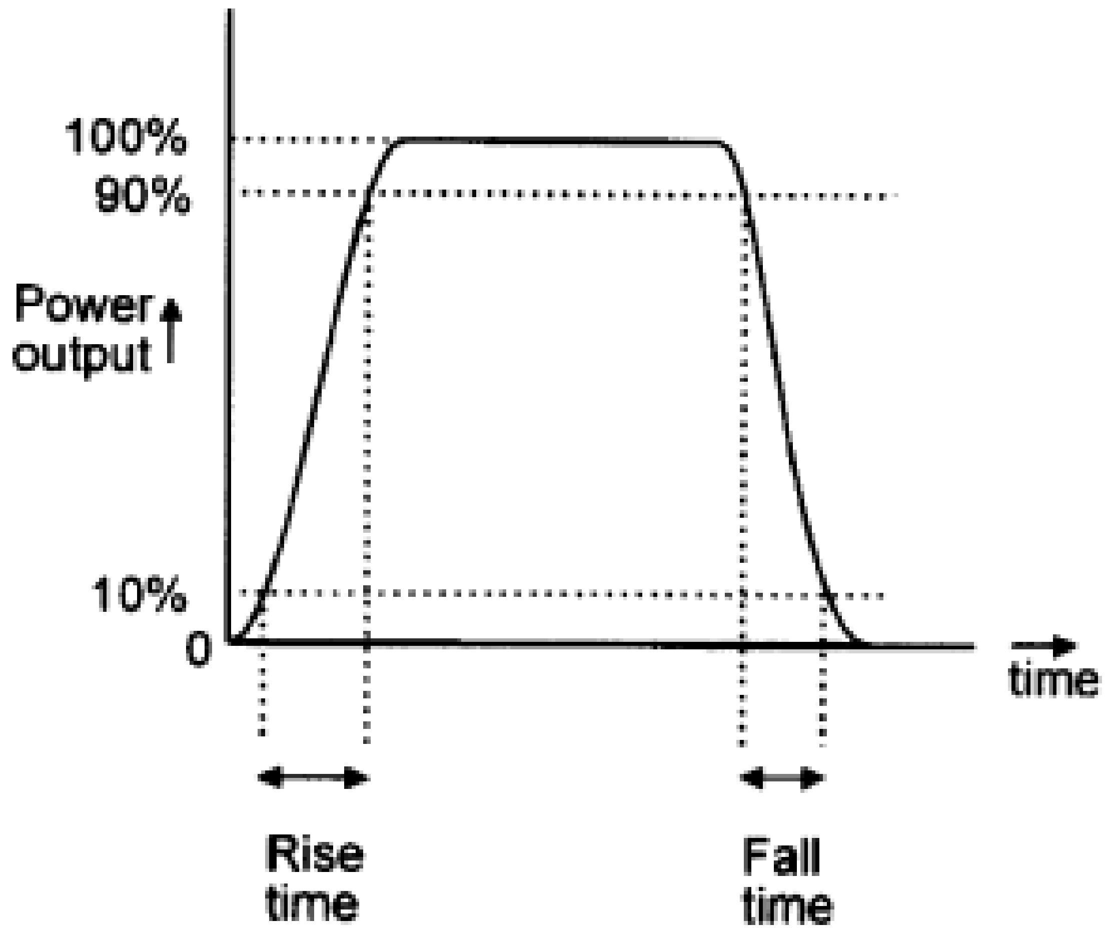
Wavelength - The wavelength quoted is only a typical value.

So if we want to buy a laser for the 1300 nm window, the one offered may well be quoted as 1285–1320 nm and the actual frequency will fall somewhere between these limits.

Sometimes it would just be sold as 1300 nm (nominal).

This is a measure of how quickly the laser can be switched on or off measured between the output levels of 10% to 90% of the maximum.

A Typical value is 0.3 ns.

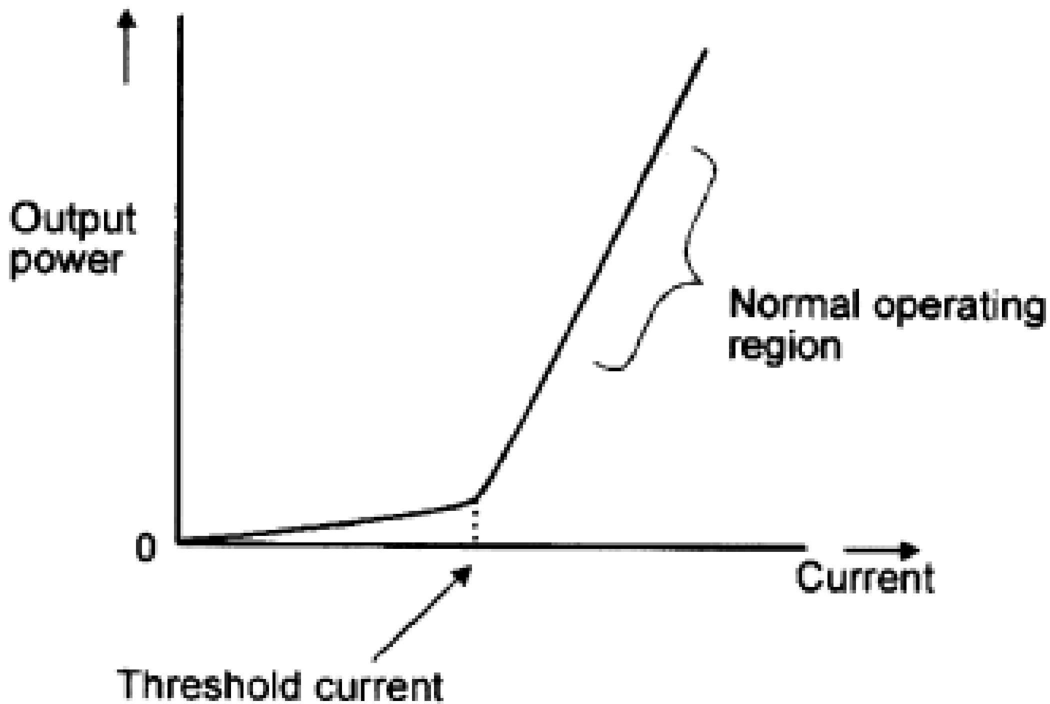



Rise and Fall time

**Threshold current — as shown in Figure 14.4**

This is the lowest current at which the laser operates.

A Typical value is 50 mA , and the normal operating current would be around 70 mA.

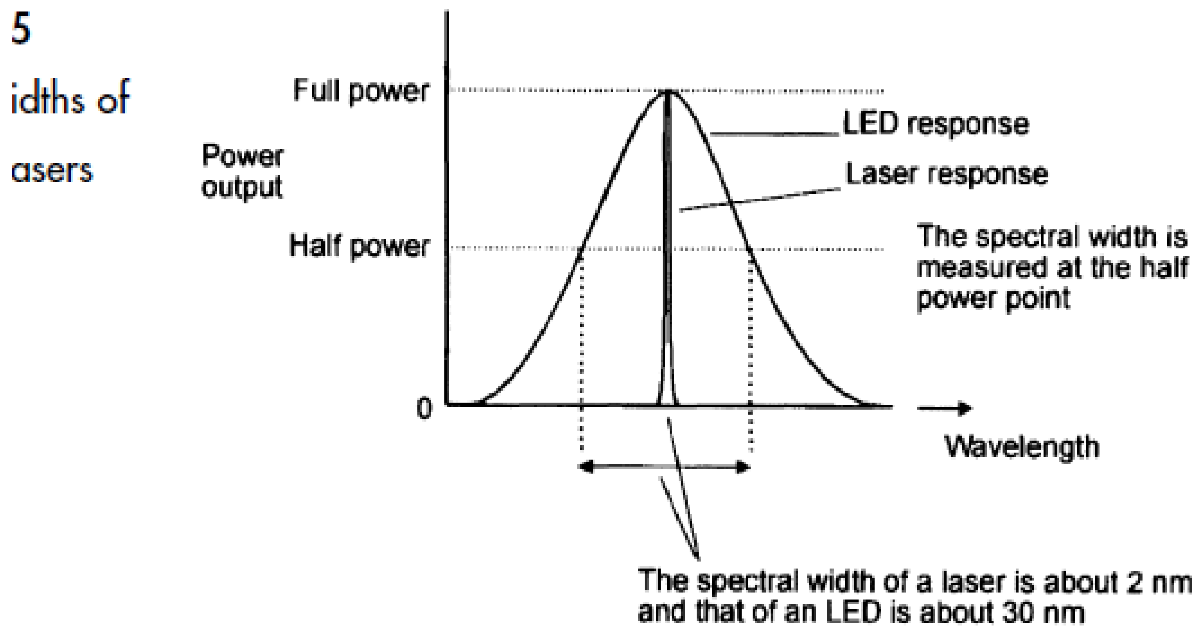


**Spectral Width —** as shown **Figure 14.5**

This is the bandwidth of the emitted light.

Typical spectral widths lie between 1 nm and 5 nm.

A laser with an output of 1310 nm with a spectral width of 4 nm, would emit infrared light between 1308 nm and 1312 nm



## Operating Temperature

Typical values ***are –10°C to +65°C*** and therefore match the temperature ranges of fibers 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 are generally only of interest to the equipment designer or the repair technician.

## Output Power

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

**LEDs — light emitting diodes :**

LEDs can provide light output in the visible spectrum as well as in the 850 nm , 1350 nm and the 1500 nm windows.

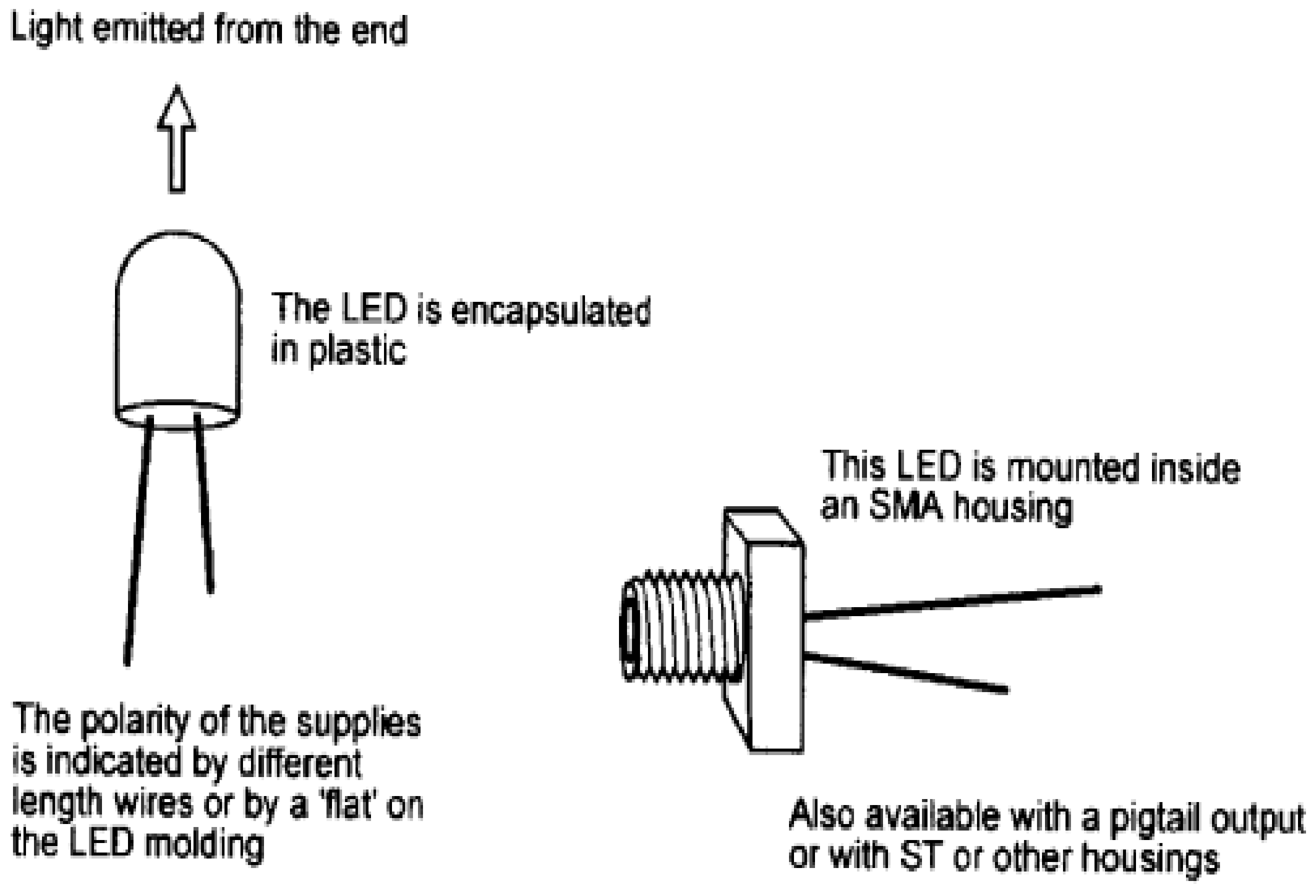
Compared with the laser, the LED has –

1. A lower Output Power
2. Slower Switching Speed and
3. Greater Spectral Width, hence more dispersion.

These deficiencies make it inferior for use with high speed data links and telecommunications.

However ,it is widely used for short and medium range systems using both glass and plastic fibres because it is simple, cheap, reliable and is less Temperature Dependent.

Although the lower power makes it safer to use, it can still be dangerous when the light is concentrated through a viewing instrument.




Typical packages are shown in Figure 14.6.

An **Optical Communications Repeater -** is used in a fiber-optic communications system to regenerate an optical signal by –

1. Converting it to an Electrical Signal
2. Processing that Electrical Signal and,
3. Then Retransmitting an Optical Signal.

Such Repeaters are used to extend the reach of optical communications links by overcoming loss due to attenuation of the optical fibre and distortion of the optical signal.

Such repeaters are known as optical-electrical-optical (OEO) due to the conversion of the signal.

Repeaters are also called **Regenerators** for the same reason.

Optical Regenerations are classified into 3 categories by the 3 R's scheme.

R : Re amplification of the data pulse alone is carried out.
2R : in addition to Re amplification, pulse reshaping is carried out. E.g.: Mamyshev 2R regenerator
3R : in addition to Re amplification and reshaping, retiming of data pulse is done.

In case of using Optical Amplifiers , the cost efficiency has led to repeaters being largely replaced in long-haul systems by optical amplifiers since one (broadband) amplifier can be used for many wavelengths in a *Wavelength Division Multiplexing (WDM)* system.

Note -- 1. That this class of device is sometimes called "Optical Amplifier Repeater".
2. In contrast, an *Optical Amplifier can amplify all of the wavelengths in a single device.*

***An Amplifier does not provide the regeneration ability of a repeater***, rather than distortion is generally the limiting factor in the design of communications system.

**Passive Components:**

Those devices or components which do not required external source to their operation is called Passive Components. **For Example**: Resistor, Capacitor, Inductor etc…

Like a Diode, Resistor does not require 0.3 or 0.7 V. i.e., when we connect a resistor to the supply voltage, it starts work automatically without using a specific voltage.

**Passive Components:**

Those devices or components which store or maintain Energy in the form of Voltage or Current are known as Passive Components

**For Example**: Resistor, Capacitor, Inductor etc…

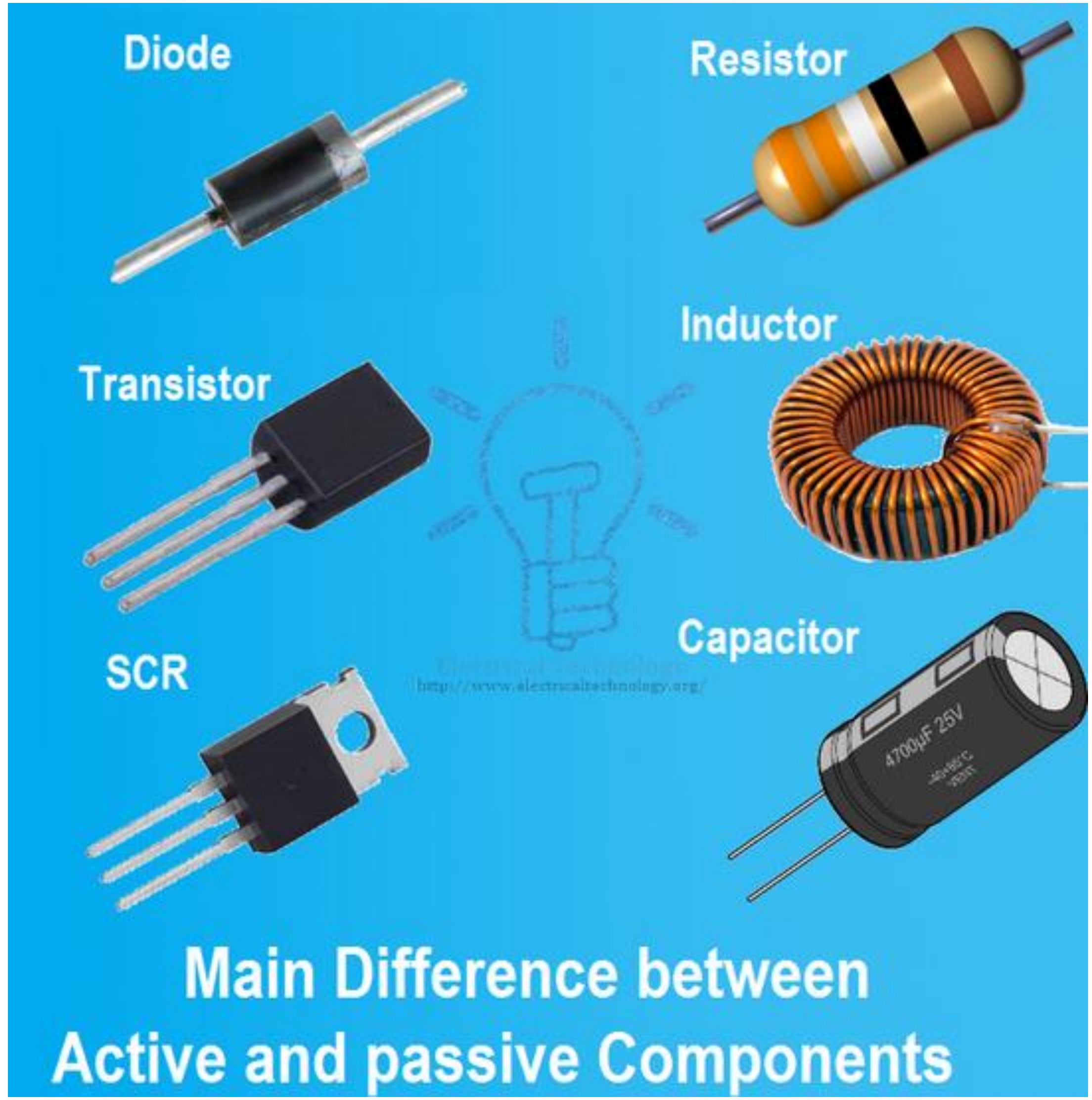
***In very Simple words;***

**Active Components: Energy Donor**

Passive Components: Energy **Acceptor**

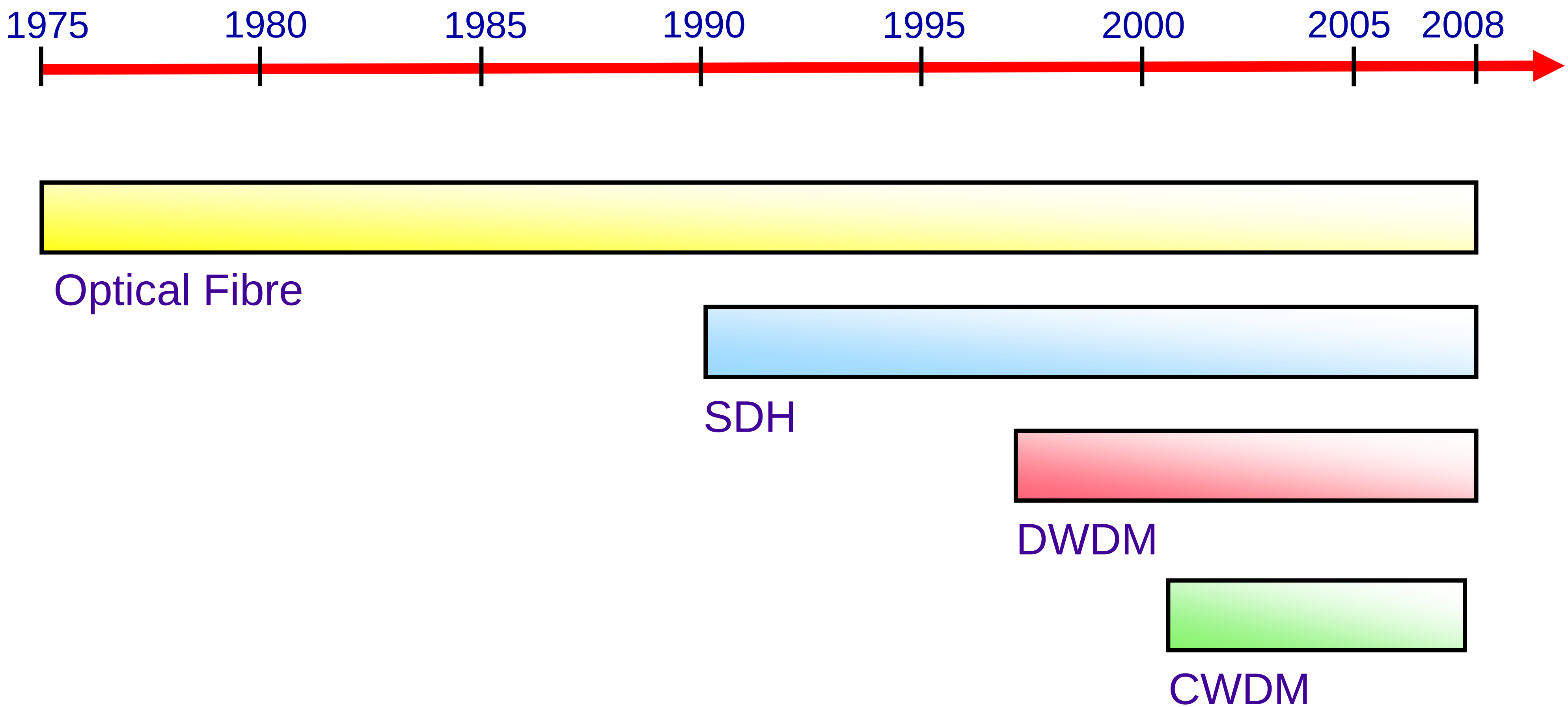
**Also** Passive Components are in linear and Active Components are in non linear category.

In DWDM system, the Passive devices are Splitters, WDM systems, Attenuators etc.



# Evolution of WDM/CWDM/DWDM

# Timeline



1975
1980
1985
1990
1995
2000
2005
2008
Optical Fibre
SDH
DWDM
CWDM

| | **Coarse WDM** (includes WWDM) | **WDM** | **DWDM** (includes ultra dense WDM) |
|---|---|---|---|
| Channel Spacings | Large, from 1.6 nm (200 GHz) to 25 nm | 1310 nm lasers used in conjunction with 1550 nm lasers | Small, 200 GHz and less |
| Number of bands used | O,E,S,C and L | O and C | C and L |
| Cost per channel | Low | Low | High |
| Number of channels delivered | 17-18 at most | 2 | Hundreds of channels possible |
| Best Application | Short-haul, Metro | PON | Long-haul |

As Data transmission gets more and more "**heavy,**" it requires *stronger and stronger* fibers on which to travel.

In the world of technology, there's stronger and denser density is needed rather than building more and more fibers.

So, Researchers make it possible to move greater and greater amounts of data on existing fibers.

One way to do this is to use DWDM, which stands for **Dense Wavelength Division Multiplexing.**

The concept was first published in **1970, and by 1978** WDM systems were being realized in the laboratory.

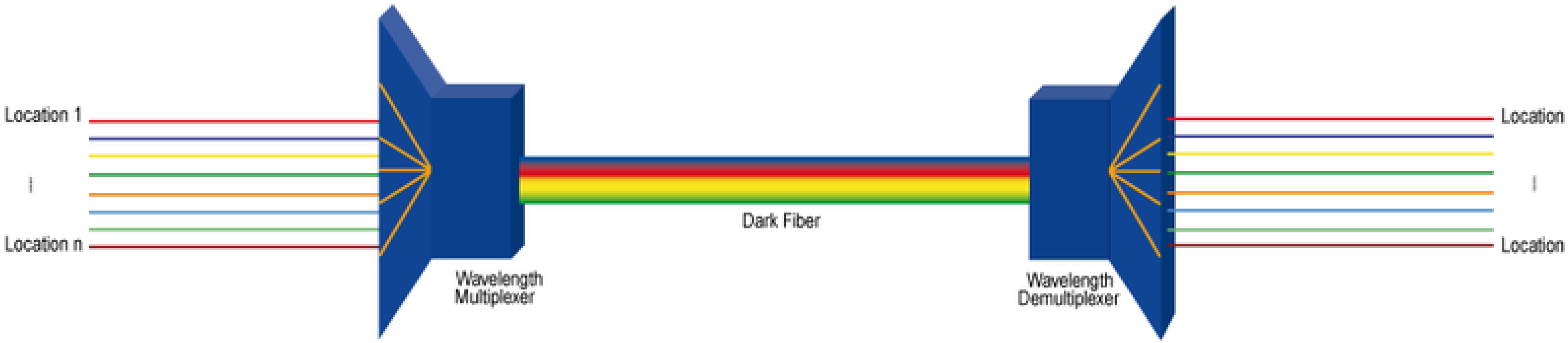
The first WDM systems only combined two signals whereas modern systems can handle up to 160 signals and can thus expand a basic 10 Gbit/s fiber system to a theoretical total capacity of over 1.6 Tbit/s over a single fiber pair.

Capacity of a given link can be *expanded* by simply **upgrading** the Multiplexers and Demultiplexers at each end for overhaul the backbone network by using Optical Amplifiers.

These, however, are only working well for the 3. and 4. optical window (about 1550nm to 1610nm) today.

Most WDM systems operate on single mode fiber optical cables, which have a core diameter of 9 µm and in multimode fiber cables (also known as premises cables) which have core diameters of 50 or 62.5 µm.

Using WDM systems, the fiber optic links can be utilized for data transmission more efficiently.




The wavelength multiplexing technology provides the ability to transmit more light beams, each having different wavelengths, using the same optical link.

Due to the fact that wavelengths do not interfere, single light beams can be separated from each other using simple filters.

A laser serves as the source of light and light-sensitive diode as receiver unit.

Each application is allocated to a *dedicated colour (wavelength) to communicate with a remote station*.

The advantage is that different colours can be simultaneously transmitted using one pair of fiber.

For this purpose a multiplexer combines all different colours which will then be transmitted to the remote station over one pair of fiber.

At the remote site the combined signal is separated again into different colours by a Demultiplexers.

Generally only one light beam with one wavelength is transferred over a pair of fiber.

## Choosing of the appropriate wavelength

By the use of appropriate Transceivers (SFP, XFP etc.) with different Power budget ranges from a few 100 m up to 160 km can be achieved.

A major factor in the range is next to the power budget of the Transceiver .

The used wavelength as a fiber has a specific Attenuation behaviour for each wavelength.

By employing Wave Division Multiplexing (WDM) two signals at two different wavelengths of 1310nm and 1550nm, can be conveniently carried on the same fiber as seen in Fig. 4.

The first WDM combines the two signals while a second WDM at the other end of the link, separates the two wavelengths again.

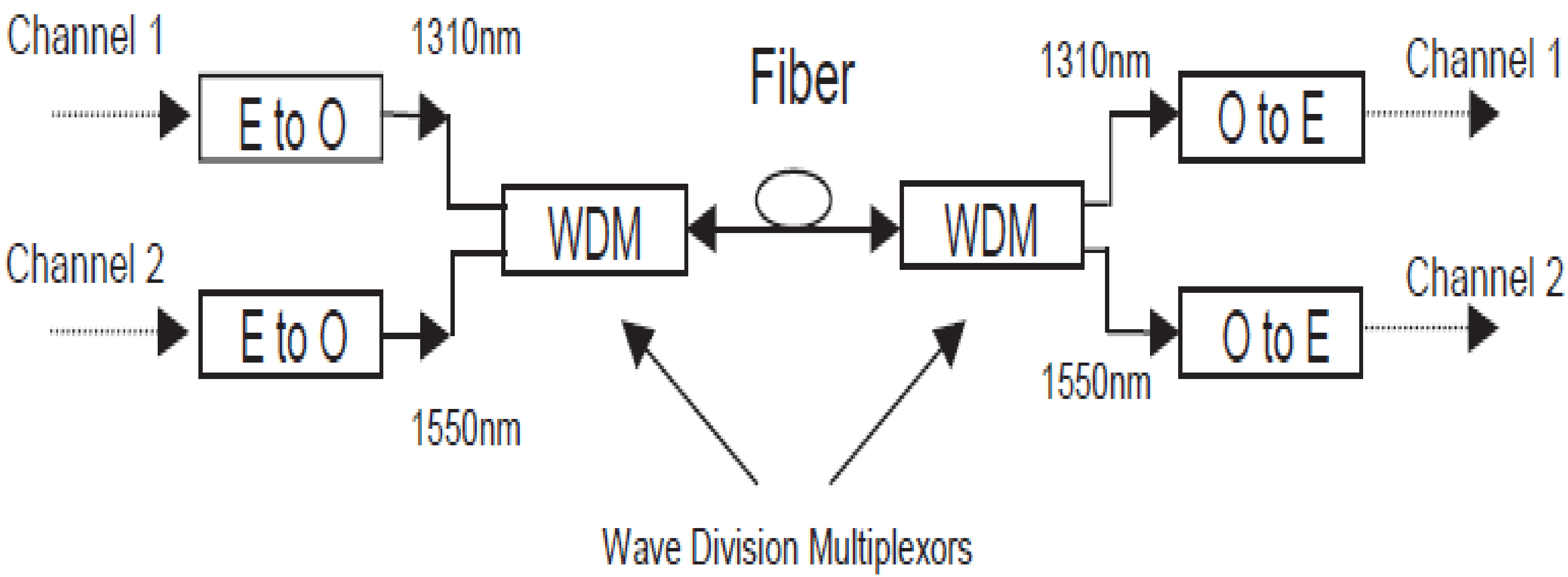



Fig 4. Combining two signals onto one fiber

## Going both ways

If we want our fiber link to be bi-directional, we need to employ lasers at both ends.

As the lasers will be transmitting towards each other, we need to ensure that they do not affect each other's performance.

The best solution is to utilize optical isolators built into each laser, to prevent the light coming from the other end, from affecting the **center wavelength stability** and Performance characteristics of the local Transmitting laser.

Some laser types, (e.g. DFB lasers) are more susceptible to interference than other laser types (e.g. FP).

Laser types will be explained in a later section.

Evertz uses built-in optical isolators on any laser type which could be affected by reverse transmission effects or back reflections, in bi-directional fiber links.

A key component in bi-directional fiber links is the combiner device, which combines and separates the bi-directional signals at each end, as shown in Figure 5.

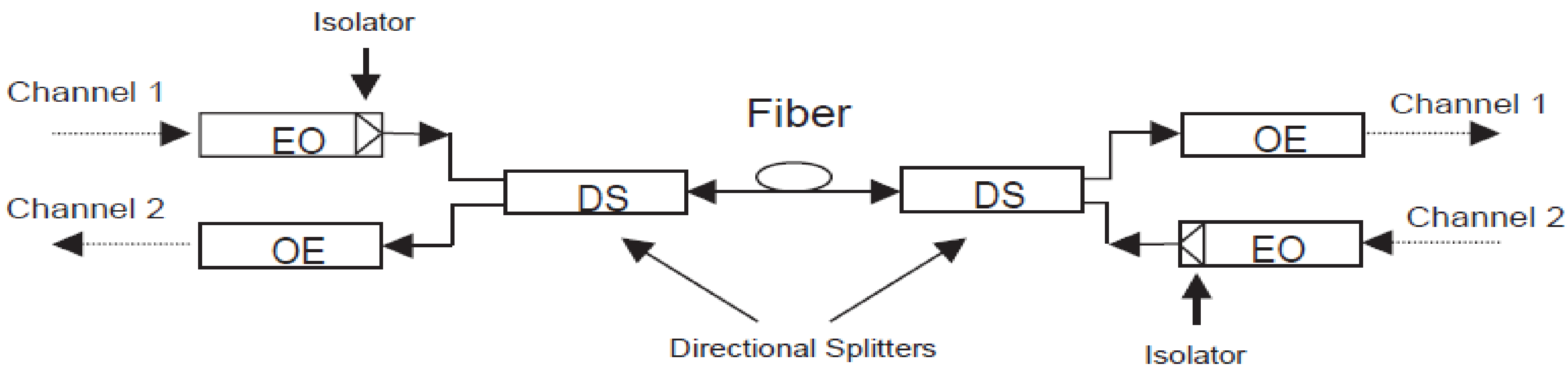



Fig 5. Bi-Directional Video

These devices route the source light from the lasers directly to the fiber line, without permitting it to get back into the local lasers.

Some systems, which are specifically designed for bi-directional applications, may have built-in directional couplers.

Note that a bi-directional system should only be built with directional splitters, if the optical path loss is less than 14dB.

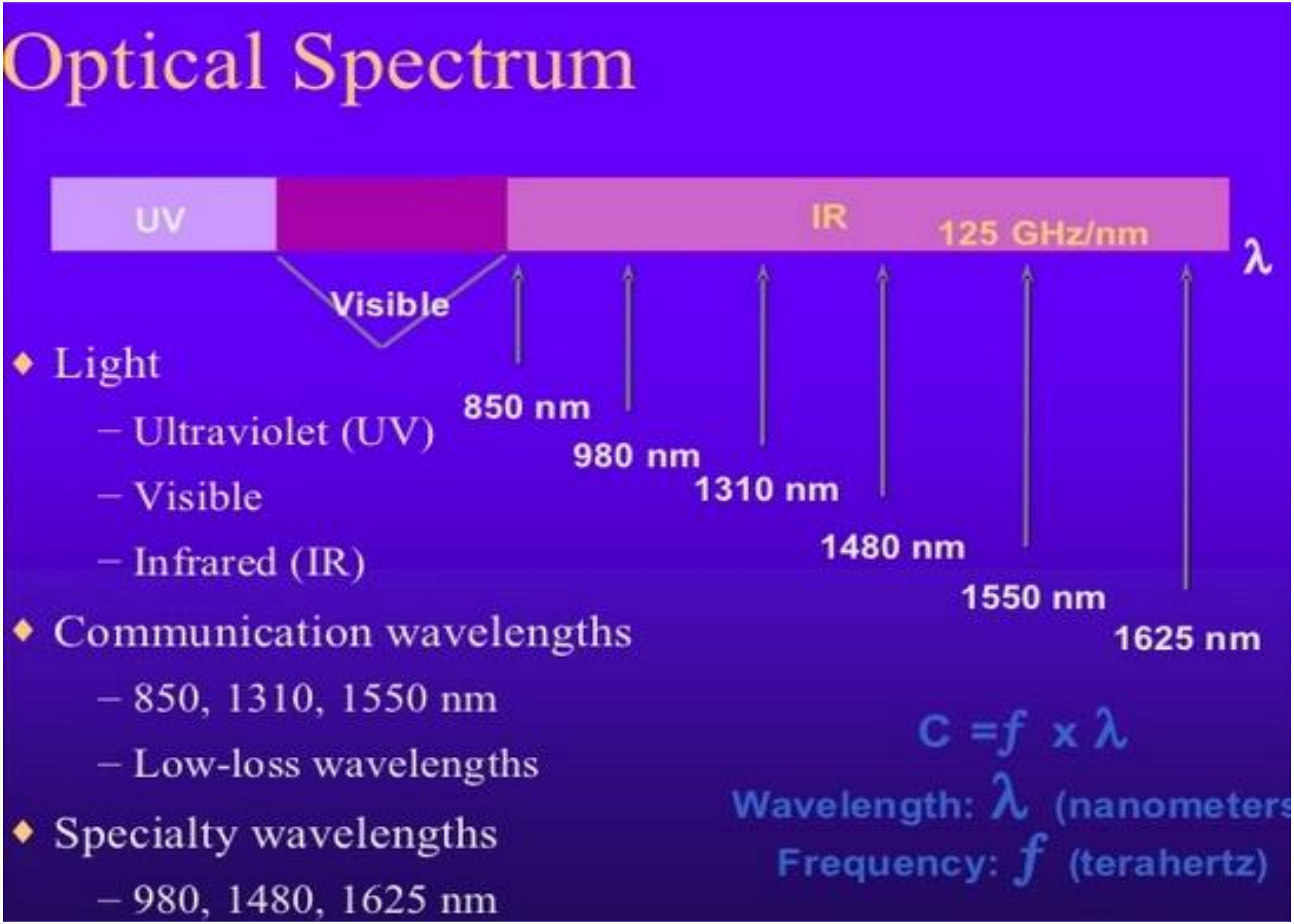
Otherwise, it is possible that the output of the local laser will be reflected back into the local receiver.

Evertz publishes tables for bidirectional system, to help the designer choose whether to employ a single fiber, dual fibers or WDM techniques using two or more fibers.

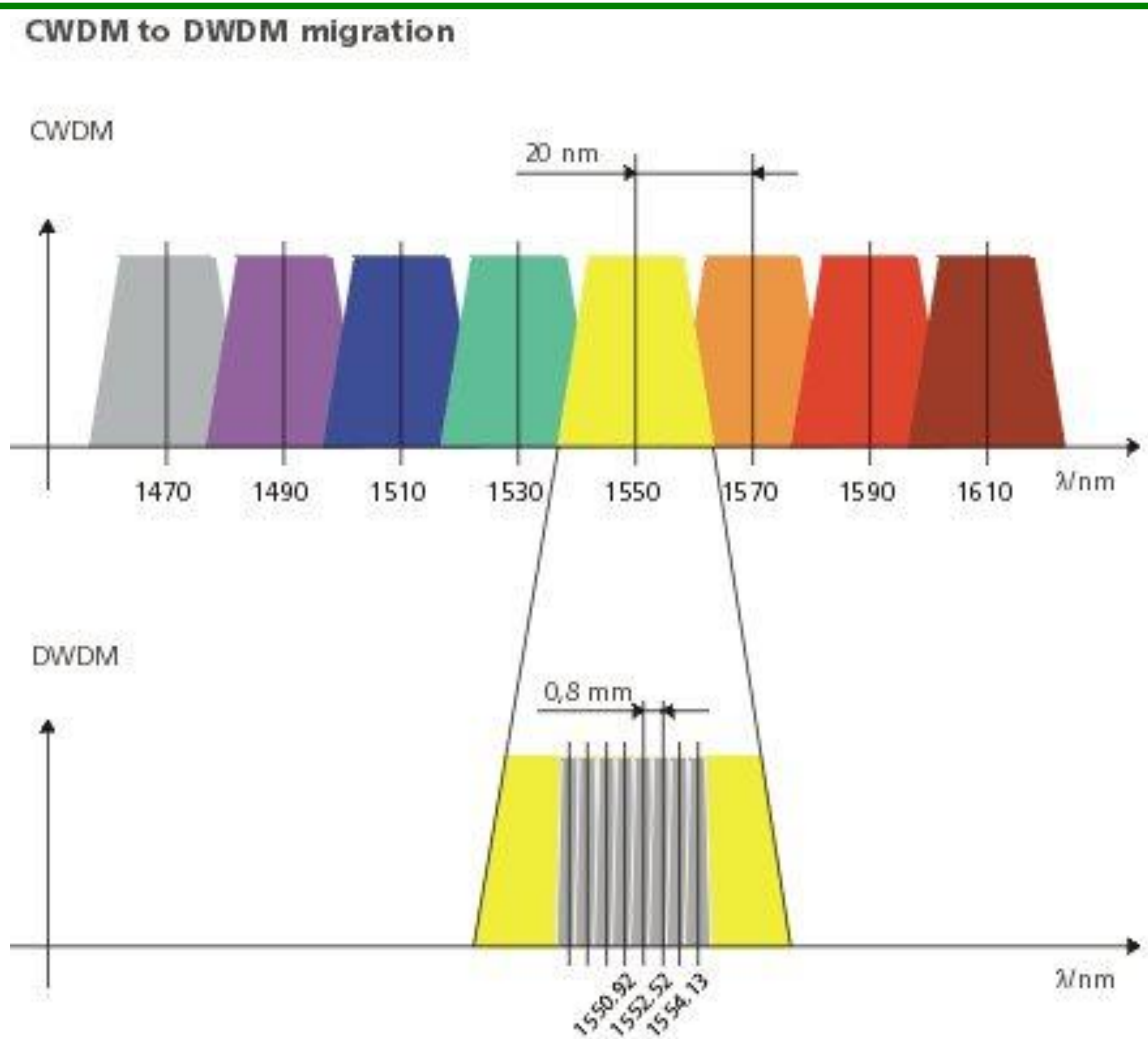
The higher the attenuation, the lower the overall distance.

With a careful selection of the wavelength a higher range and better signal quality can be achieved.

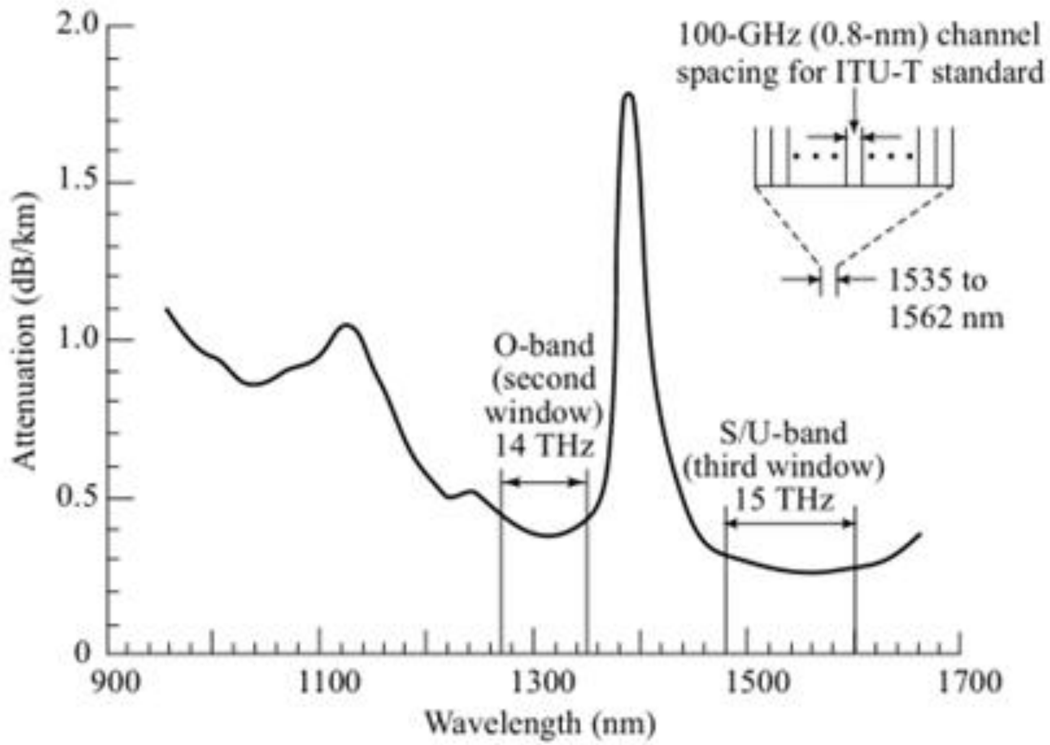
| | Optical band | Wavelengths |
|---|---|---|
| O | (Original)-Band | 1260 nm – 1360 nm |
| E | (Extended)-Band | 1360 nm – 1460 nm |
| S | (Short)-Band | 1460 nm – 1530 nm |
| C | (Conventional)-Band | 1530 nm – 1565 nm |
| L | (Long)-Band | 1565 nm – 1625 nm |
| U | (Ultralong)-Band | 1625 nm – 1675 nm |



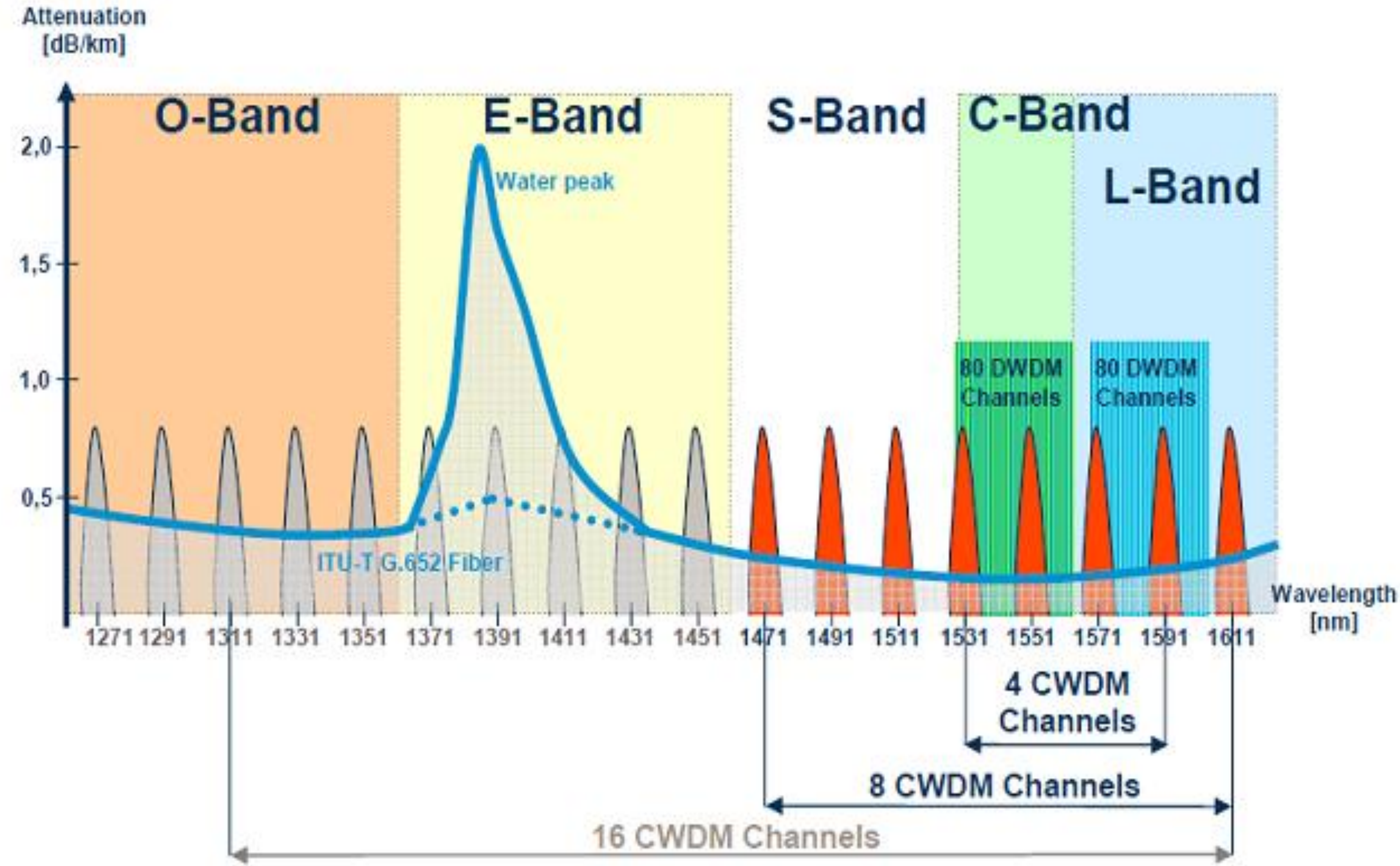
Optical Spectrum
UV
IR
125 GHz/nm
λ
Visible
850 nm
980 nm
1310 nm
1480 nm
1550 nm
1625 nm
◆ Light
– Ultraviolet (UV)
– Visible
– Infrared (IR)
◆ Communication wavelengths
– 850, 1310, 1550 nm
– Low-loss wavelengths
◆ Specialty wavelengths
– 980, 1480, 1625 nm
C = f x λ
Wavelength: λ (nanometers
Frequency: f (terahertz)


CWDM to DWDM migration
CWDM
20 nm
1470
1490
1510
1530
1550
1570
1590
1610
λ/nm
DWDM
0,8 mm
1550,92
1552,52
1554,13
λ/nm

*Implementation of a typical WDM network containing various types of optical amplifiers*




*The transmission-band widths in the O- and C-bands (the 1310-nm and 1550-nm windows) allow the use of many simultaneous channels for sources with narrow spectral widths. The ITU-T G.692 standard for WDM specifies channels with 100-GHz spacings*


Attenuation [dB/km]
2,0
1,5
1,0
0,5
O-Band
E-Band
S-Band
C-Band
L-Band
Water peak
80 DWDM Channels
80 DWDM Channels
ITU-T G.652 Fiber
Wavelength [nm]
1271 1291 1311 1331 1351 1371 1391 1411 1431 1451 1471 1491 1511 1531 1551 1571 1591 1611
4 CWDM Channels
8 CWDM Channels
16 CWDM Channels

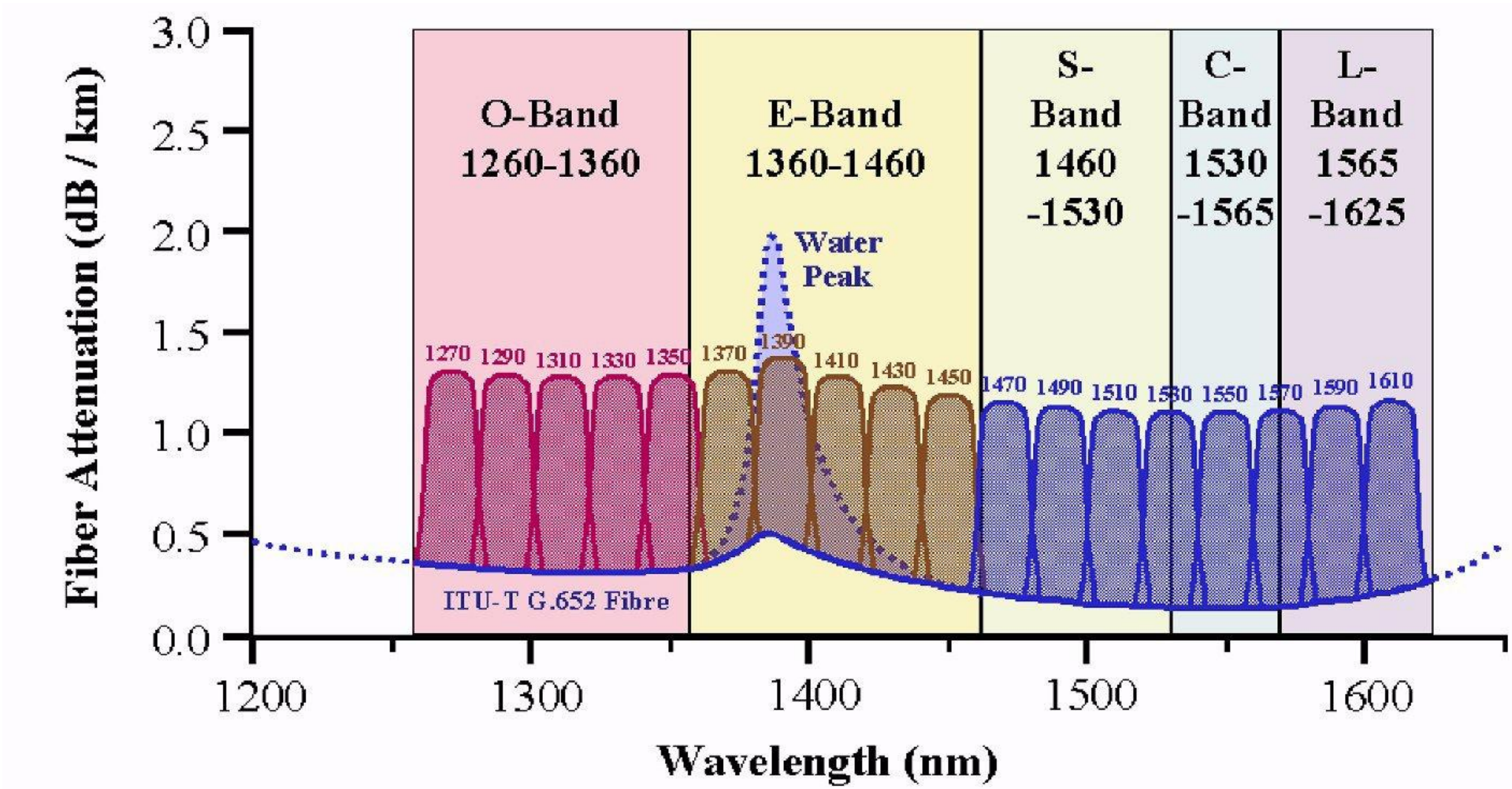
## CWDM (Coarse Wavelength Division Multiplexing)

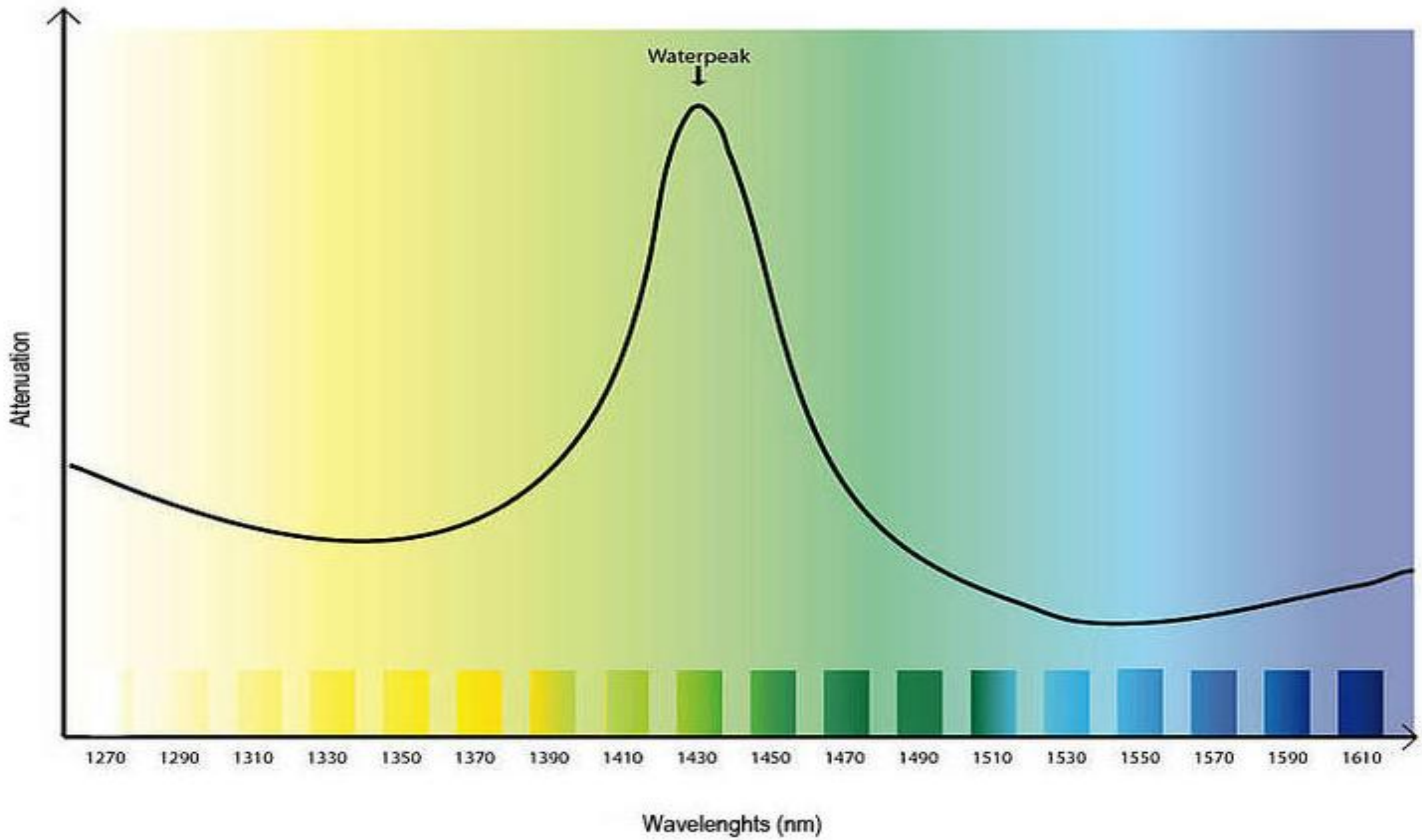
**CWDM highlights :**

Up to 16 CWDM wavelength over one pair of fiber,
CWDM channel spacing 20 nm
Distances up to 120 km
Cost-effective WDM solution
Scalable by hybrid CWDM/DWDM - perfect solution for your investment.

**CWDM Principle :** As shown in the Figure:

- In principle installation possible on existing single-mode G.652 optical fibres and on the recent 'water peak free' versions of the same fibre.
- Issues remain about viability of full capacity because of water peak issue at 1383 nm





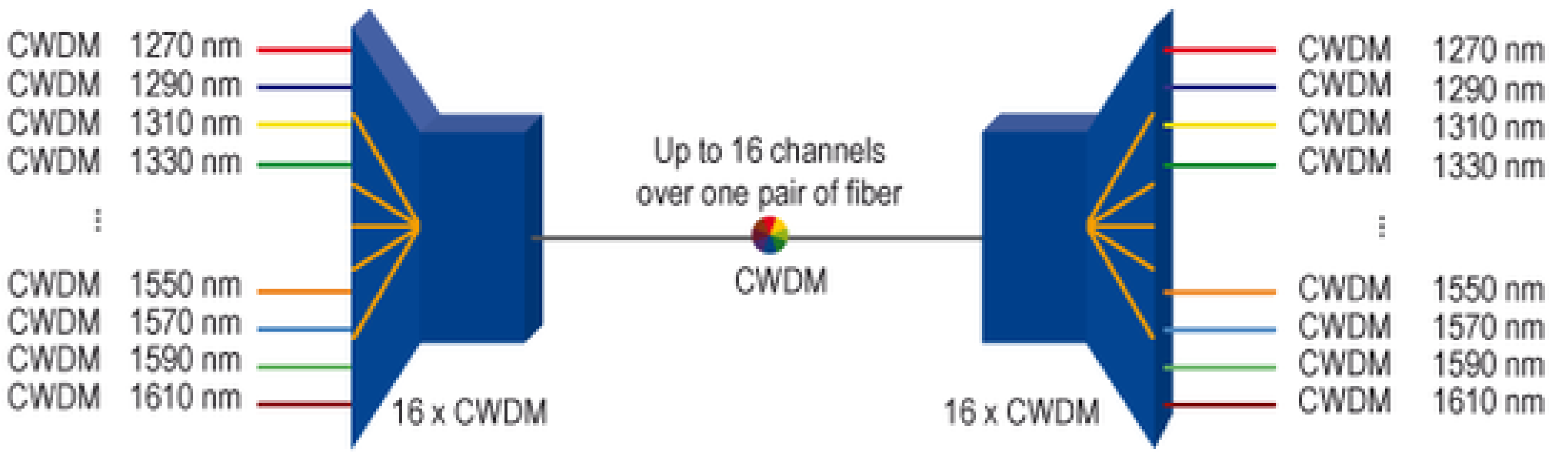
Waterpeak
Attenuation
1270
1290
1310
1330
1350
1370
1390
1410
1430
1450
1470
1490
1510
1530
1550
1570
1590
1610
Wavelenghts (nm)

**(CWDM)** is a wavelength multiplexing technology for city and access networks.

Transmission is realized using 16 channels with wavelengths between 1270 nm and 1610 nm.

Due to the channel spacing of 20 nm cost-effective lasers can be used.

The channel width itself is 13 nm. The remaining 7 nm is designed to secure the space to the next channel.



**Technical Details :**

ITU-T G.694.2

$\lambda$: 1271 nm - 1611 nm

Max. 18 channels can be used because of the water peaks

Channel spacing: 20 nm

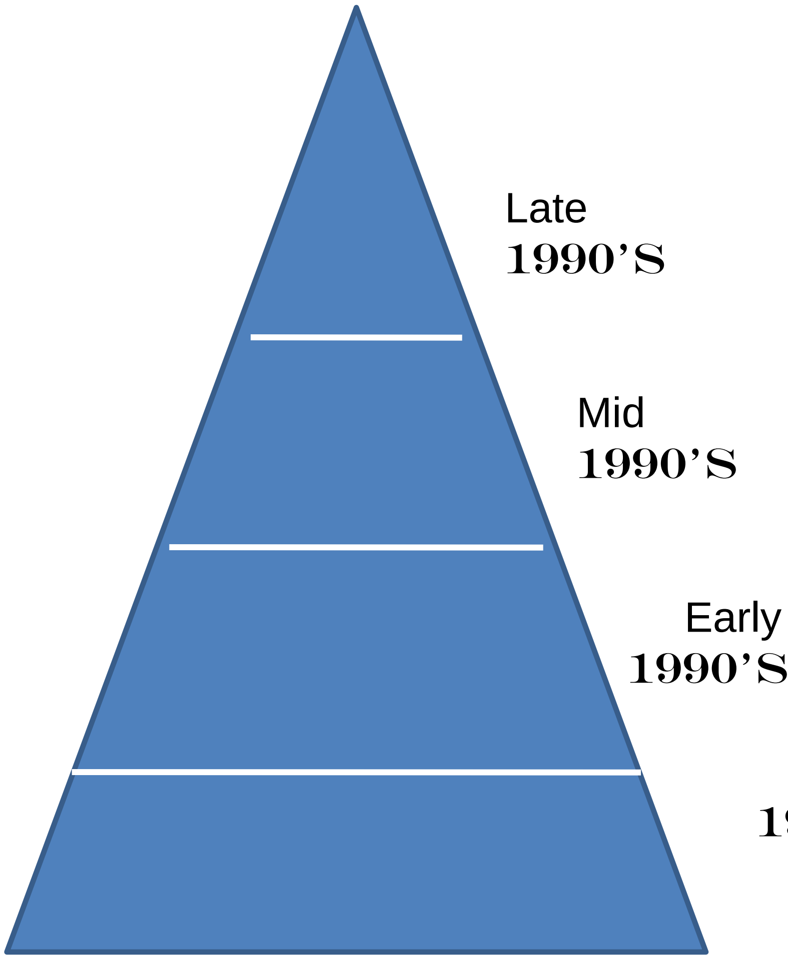
# ITU-T Standard for 100GHz Spacing in C Band

| Nominal Frequencies Allocation Plan (Red Band) | | |
|---|---|---|
| Channel number | Central wavelength (nm) | Central frequency (THz) |
| 20 | 1561.42 | 192.000 |
| 21 | 1560.61 | 192.100 |
| 22 | 1559.79 | 192.200 |
| 23 | 1558.98 | 192.300 |
| 25 | 1557.36 | 192.500 |
| 26 | 1556.55 | 192.600 |
| 27 | 1555.75 | 192.700 |
| 28 | 1554.94 | 192.800 |
| 30 | 1553.33 | 193.000 |
| 31 | 1552.52 | 193.100 |
| 32 | 1551.72 | 193.200 |
| 33 | 1550.92 | 193.300 |
| 35 | 1549.32 | 193.500 |
| *36* | 1548.51 | *193.600* |
| 37 | 1547.72 | 193.700 |
| 38 | 1546.92 | 193.800 |

| Nominal Frequencies Allocation Plan (Blue Band) | | |
|---|---|---|
| Channel number | Central wavelength (nm) | Central frequency (THz) |
| 42 | 1543.73 | 194.200 |
| 43 | 1542.94 | 194.300 |
| 44 | 1542.14 | 194.400 |
| 45 | 1541.35 | 194.500 |
| 47 | 1539.77 | 194.700 |
| 48 | 1538.98 | 194.800 |
| 49 | 1538.19 | 194.900 |
| 50 | 1537.40 | 195.000 |
| 52 | 1535.82 | 195.200 |
| 53 | 1535.04 | 195.300 |
| 54 | 1534.25 | 195.400 |
| 55 | 1533.47 | 195.500 |
| 57 | 1531.90 | 195.700 |
| 58 | 1531.12 | 195.800 |
| 59 | 1530.33 | 195.900 |
| 60 | 1529.55 | 196.000 |

| Channel | Wavelength | Frequency | Channel | Wavelength | Frequency |
|---|---|---|---|---|---|
| **1** | 1470nm | 203.94THz | **5** | 1550nm | 193.41THz |
| **2** | 1490nm | 201.20THz | **6** | 1570nm | 190.95THz |
| **3** | 1510nm | 198.54THz | **7** | 1590nm | 188.55THz |
| **4** | 1530nm | 195.94THz | **8** | 1610nm | 186.21THz |

# History of DWDM




64 to 160 channels in 1550 nm window
Next generation DWDM system
Channel spacing of 0.2 to 0.4 nm

16 to 40 channels in 1550nm window
DWDM (Dense wdm)
Channel spacing of 0.8 to 1.6

2 to 8 channels in 1550nm window
Passive (or) 2nd generation WDM
Channel spacing of~ 3.2nm

2 channels WWDM (Wideband WDM)
1310nm & 1550nm

DWDM definition:

Up to 96 DWDM wavelength over one pair of fiber

**DWDM Highlights :**

Up to 96 DWDM wavelength over one pair of fiber
DWDM channel spacing 0.8 nm (100 GHz grid) or 0.4 nm (50 GHz grid)
Distances over 1,000 km can be achieved with the use of optical amplifier
DWDM wavelength : 1528 nm (channel 61) to 1563 nm (channel 17)

**DWDM principle**
The functionality of **DWDM (Dense Wavelength Division Multiplexing)** resembles to the one of CWDM.

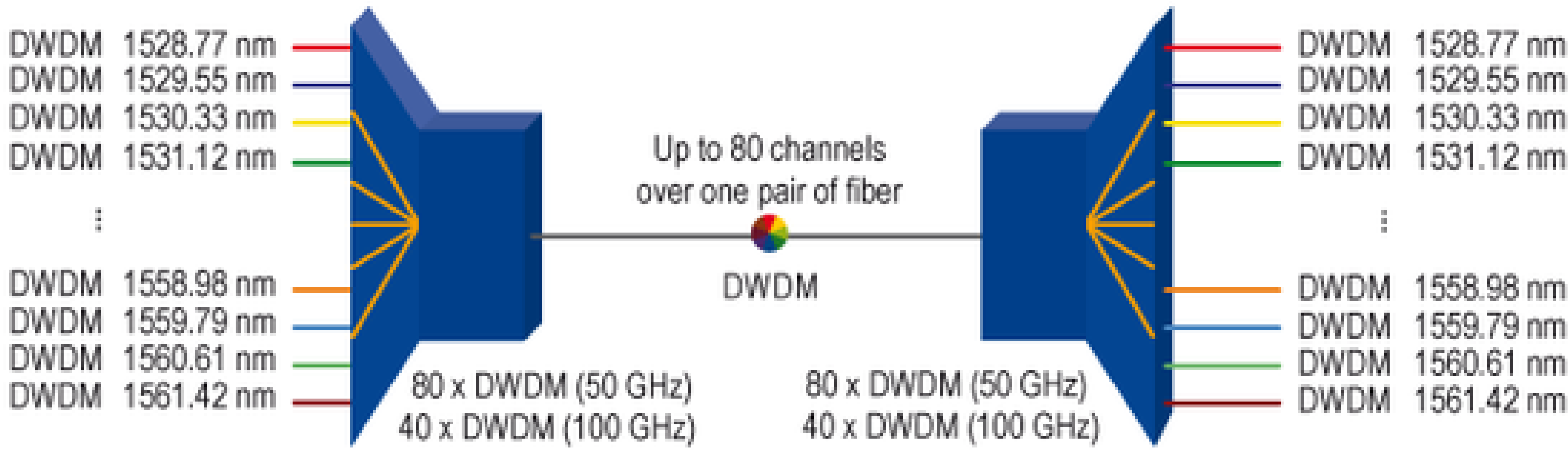
The DWDM channel spacing is 0.8/0.4 nm (100 GHz/50 GHz grid).

This small channel spacing allows to transmit much more information simultaneously.

Currently a restriction on wavelengths between 1530 nm and 1625 nm exists which corresponds to the C and L band.

In this connection DWDM ,
wavelengths are more expensive compared to CWDM caused by the need of more sophisticated transceivers.

**Technical Details:**
ITU-T G.694.1
C-Band $\lambda$: 1530 nm - 1565 nm
max. 360 channels (12,5 GHz Grid)
L-Band $\lambda$: 1565 nm - 1625 nm
max. 560 channels (12,5 GHz Grid)




## Theoretically available DWDM channels in the C and L-band depending on the channel spacing

| Channel spacing in GHz | 200 | 100 | 50 | 25 | 12,5 |
|---|---|---|---|---|---|
| Channel spacing in nm | 1.6 | 0.8 | 0.4 | 0.2 | 0.1 |
| Number of available channels (C-Band) | 22 | 45 | 90 | 180 | 360 |
| Number of available channels (L-Band) | 35 | 70 | 140 | 280 | |

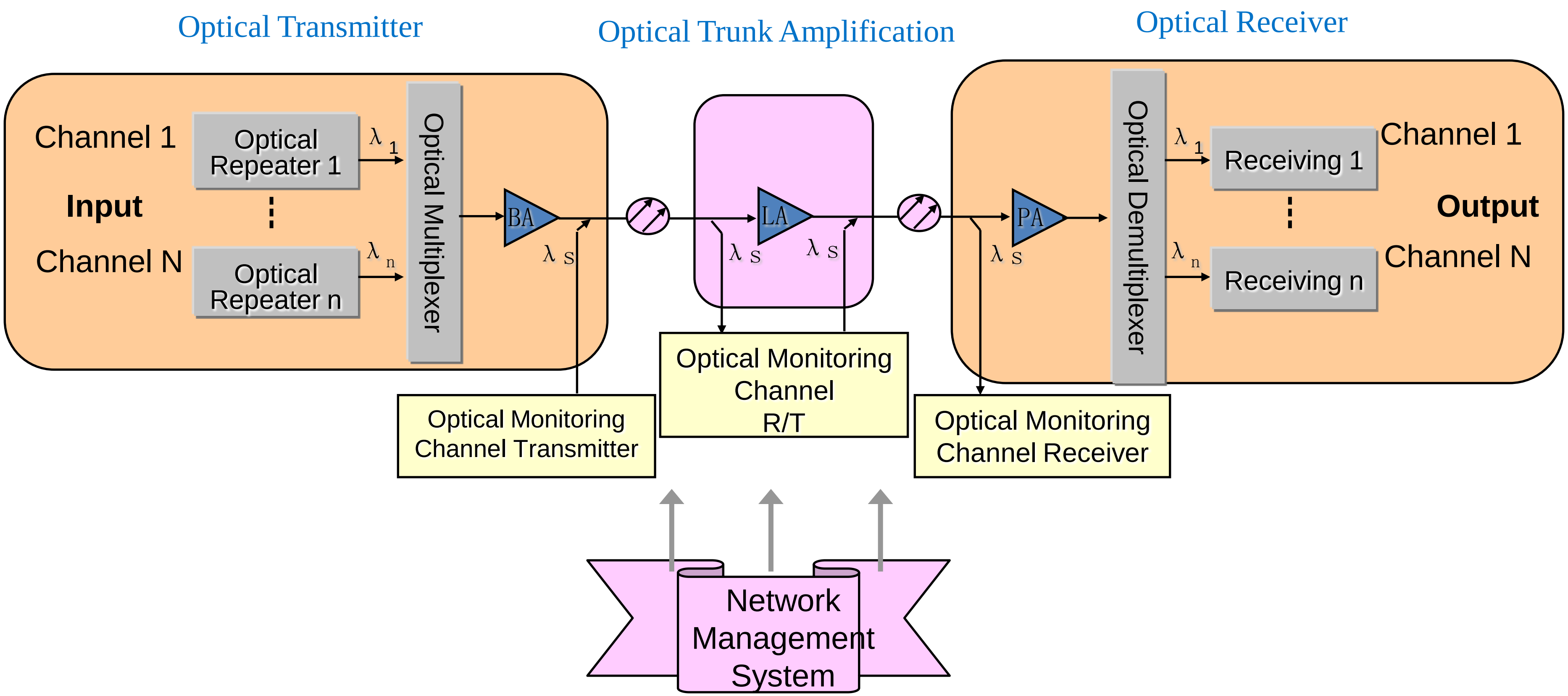
Dense Wave Division Multiplexing (DWDM) is a technology that uses more than eight multiplexed signals to transmit many wavelengths of light simultaneously over a single optical fiber .

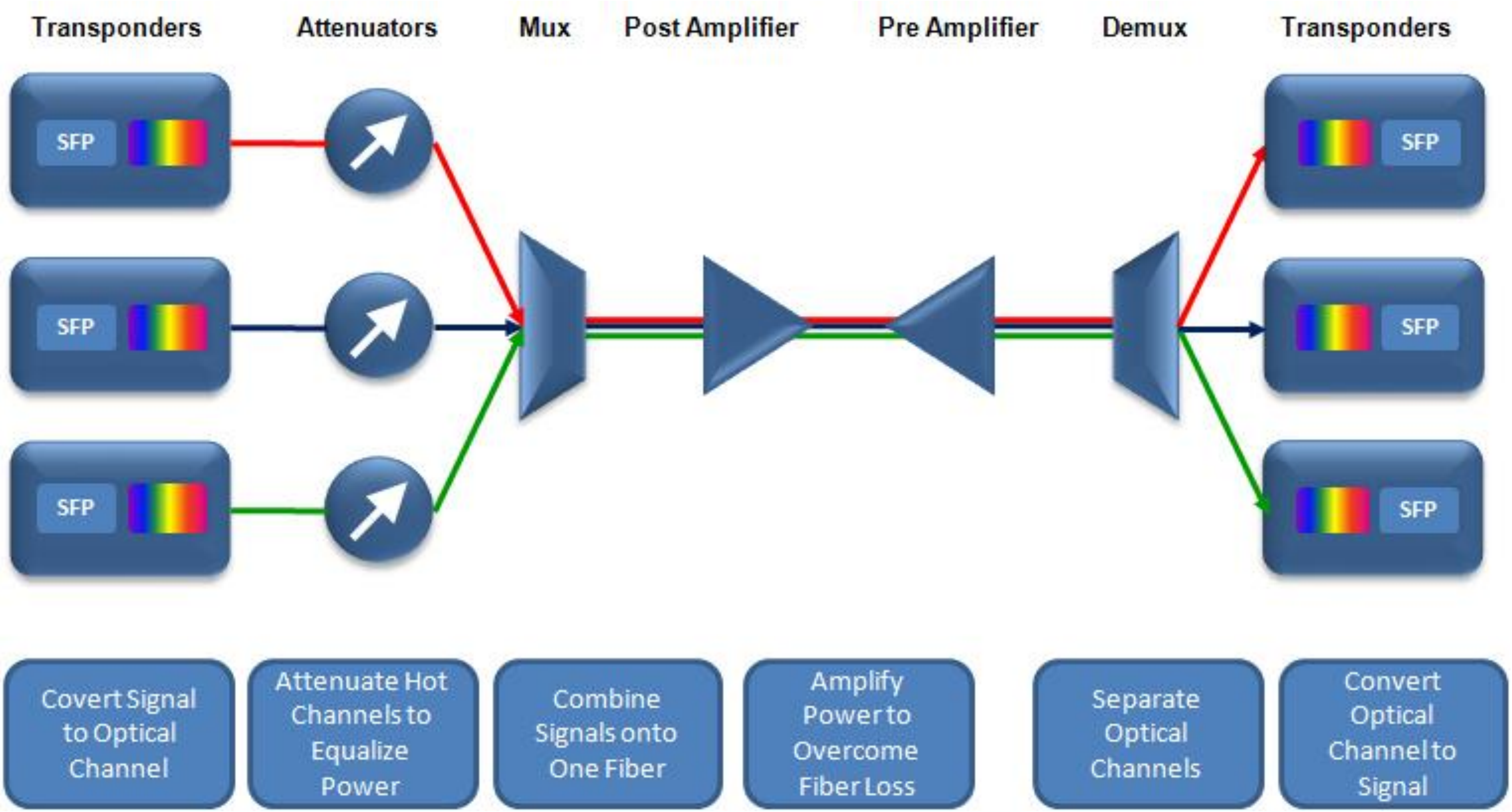
It is a crucial component of Optical networks that allows the :-

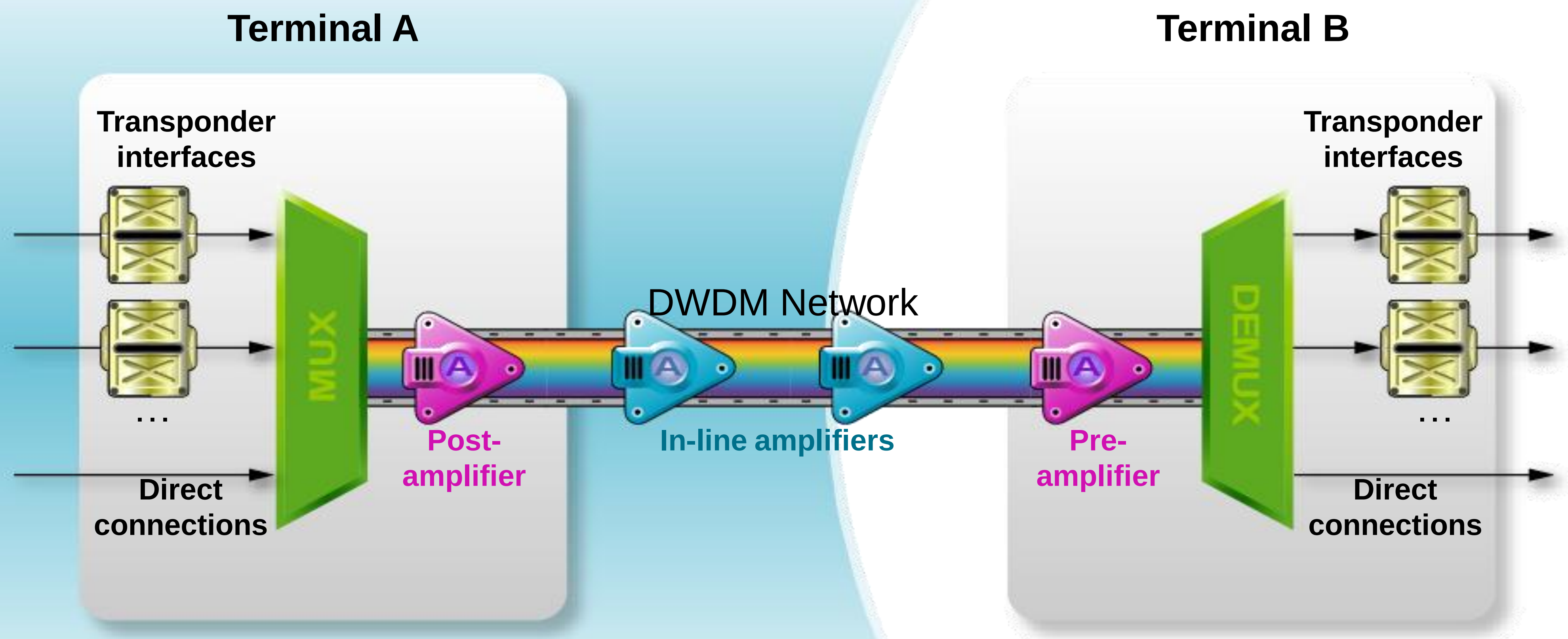
a. Transmission of e-mails
b. Videos
c. Multimedia
d. Data (etc. all carried in –

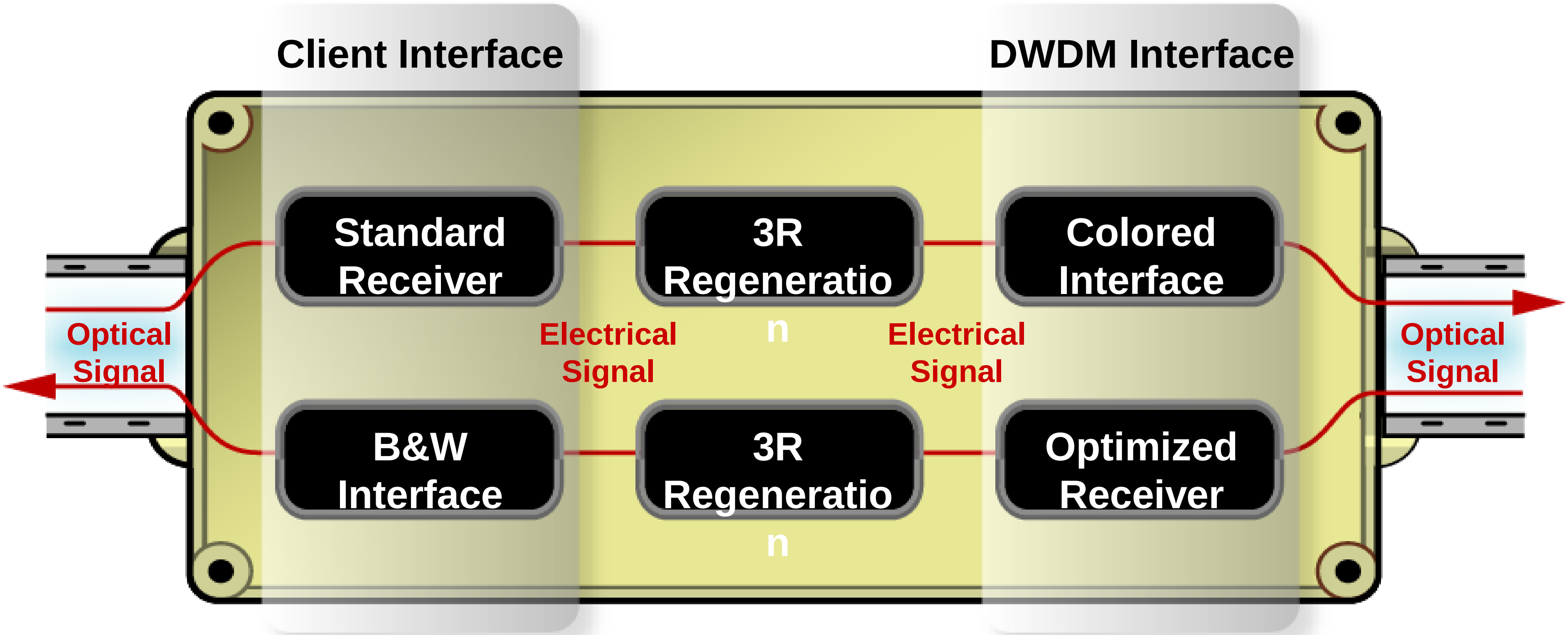
a. Internet Protocol
b. Asynchronous transfer mode (ATM)
c. Synchronous Optical Networks Synchronous Digital Hierarchy(SONET/SDH), respectively over the Optical Layer.

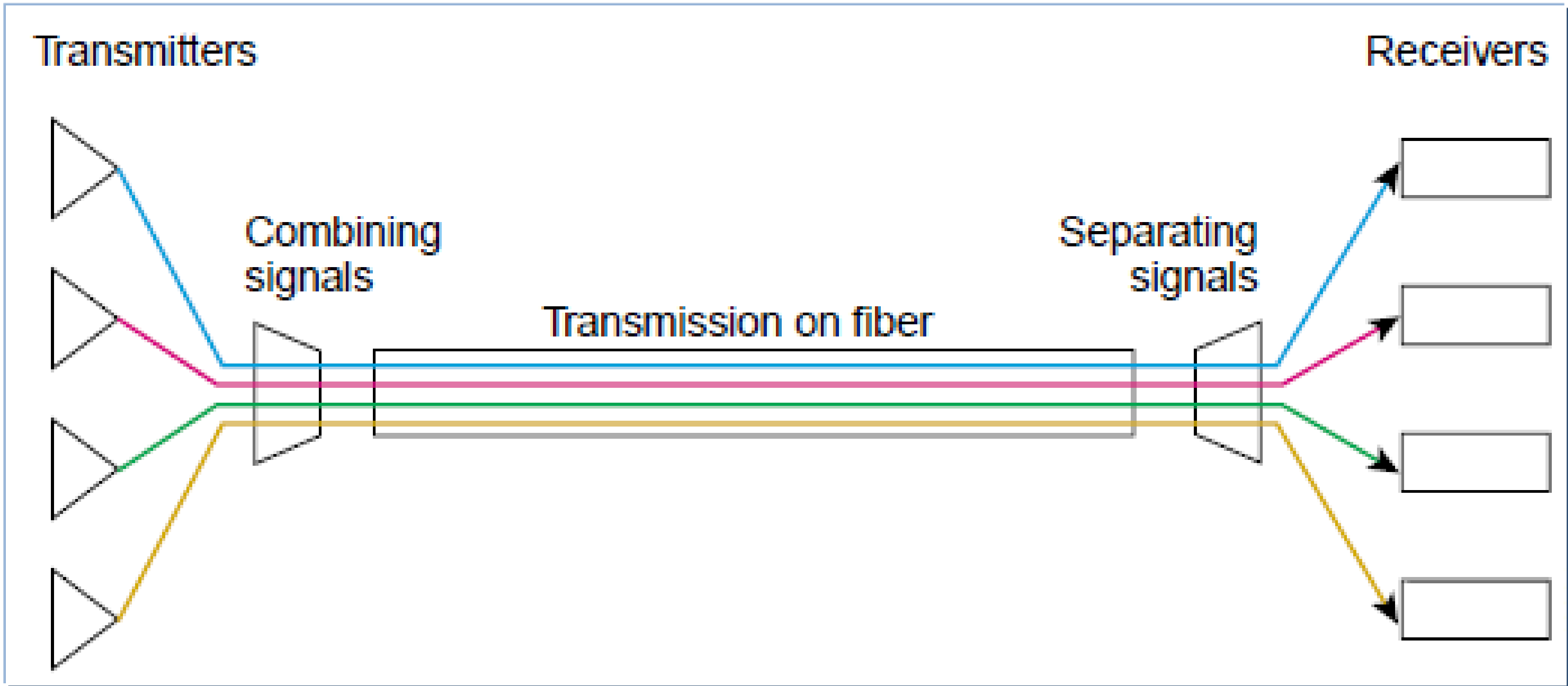
Therefore, DWDM-based networks can carry *different types of traffic at different speeds* over an optical channel.


Optical Transmitter
Optical Trunk Amplification
Optical Receiver
Channel 1
Input
Channel N
Optical Repeater 1
Optical Repeater n
λ 1
λ n
Optical Multiplexer
BA
λ S
LA
λ S
λ S
PA
λ S
Optical Demultiplexer
λ 1
λ n
Receiving 1
Receiving n
Channel 1
Output
Channel N
Optical Monitoring Channel Transmitter
Optical Monitoring Channel R/T
Optical Monitoring Channel Receiver
Network Management System


Transponders
Attenuators
Mux
Post Amplifier
Pre Amplifier
Demux
Transponders
SFP
SFP
SFP
SFP
SFP
SFP
Covert Signal to Optical Channel
Attenuate Hot Channels to Equalize Power
Combine Signals onto One Fiber
Amplify Power to Overcome Fiber Loss
Separate Optical Channels
Convert Optical Channel to Signal


Terminal A
Terminal B
Transponder interfaces
Transponder interfaces
MUX
DEMUX
DWDM Network
Post-amplifier
In-line amplifiers
Pre-amplifier
Direct connections
Direct connections


Client Interface
DWDM Interface
Standard Receiver
3R Regeneration
Colored Interface
Optical Signal
Electrical Signal
Electrical Signal
Optical Signal
B&W Interface
3R Regeneration
Optimized Receiver


Transmitters
Receivers
Combining signals
Separating signals
Transmission on fiber

**The system performs the following main functions:**

- **Generating the signal—The source, a solid-state laser, must provide stable light within a specific,**
narrow bandwidth that carries the digital data, modulated as an analog signal.

- **Combining the signals—Modern DWDM systems employ multiplexers to combine the signals.**

There is some inherent loss associated with multiplexing and demultiplexing.
This loss is dependent upon the number of channels but can be mitigated with optical amplifiers, which boost all the wavelengths at once without electrical conversion.

- **Transmitting the signals—The effects of crosstalk and optical signal degradation or loss must be** reckoned with in fiber optic transmission.

These effects can be minimized by controlling variables such as channel spacings, wavelength tolerance, and laser power levels.

Over a transmission link, the signal may need to be optically amplified.

- **Separating the received signals—At the receiving end, the multiplexed signals must be separated**
out. Although this task would appear to be simply the opposite of combining the signals, it is actually more technically difficult.

- **Receiving the signals—The demultiplexed signal is received by a photo detector.**

In addition to these functions, a DWDM system must also be equipped with client-side interfaces to receive the input signal.

Further developments in fiber optics are closely tied to the use of the specific regions on the optical spectrum where optical attenuation is low.

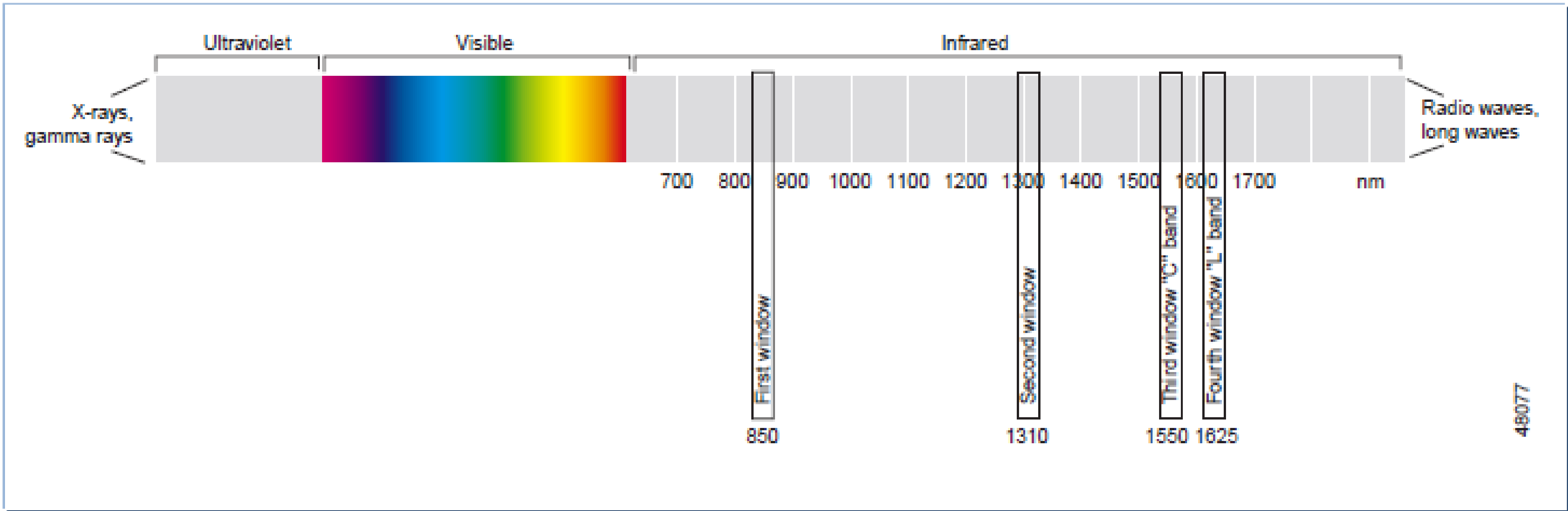
These regions, called *windows, lie between areas of high* absorption.

The earliest systems were developed to operate around 850 nm, the first window in silica-based optical fiber.

A Second window (S band), at 1310 nm, soon proved to be superior because of its lower attenuation, followed by a third window (C band) at 1550 nm with an even lower optical loss.

Today, a fourth window (L band) near 1625 nm is under development and early deployment.

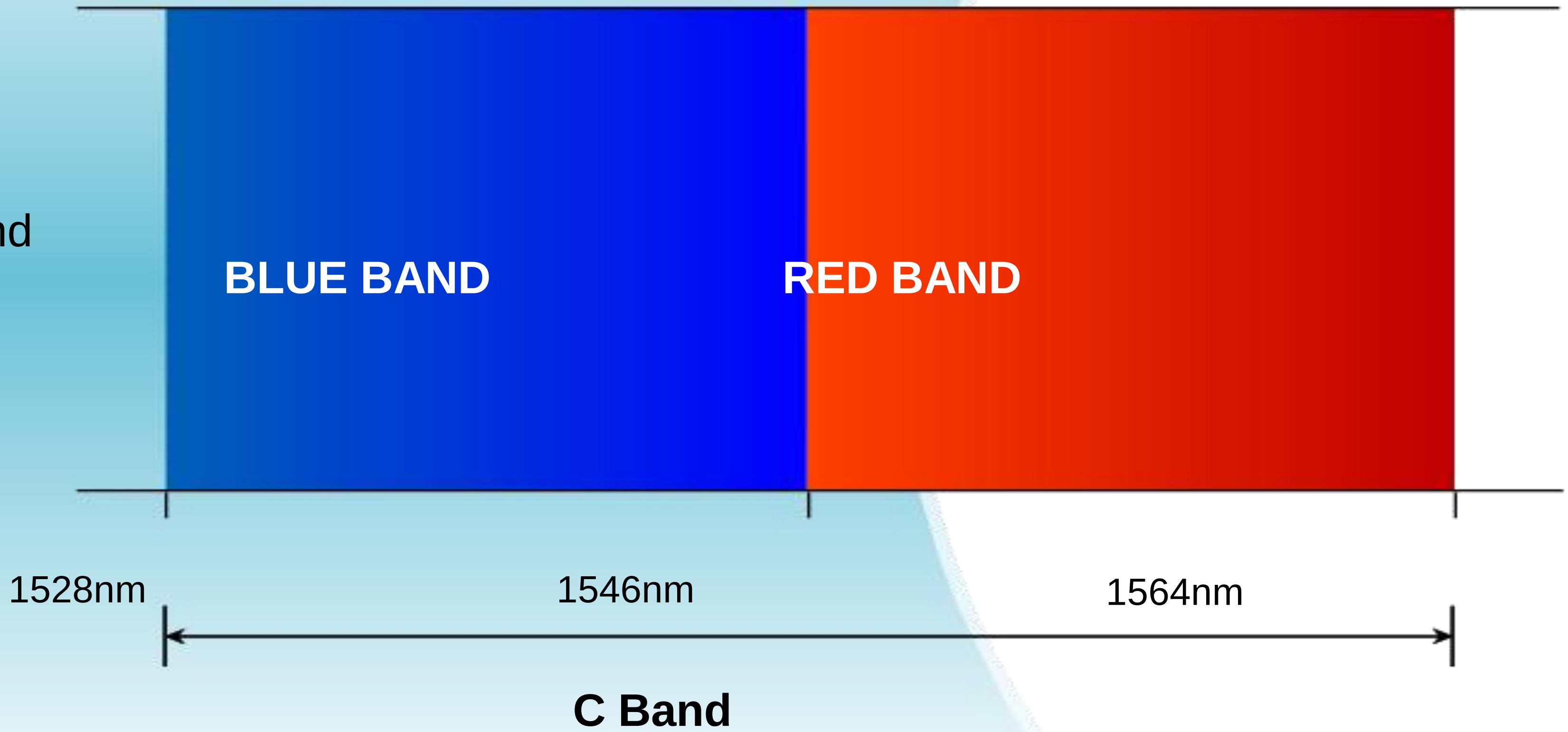
These four windows are shown relative to the electromagnetic spectrum in Figure



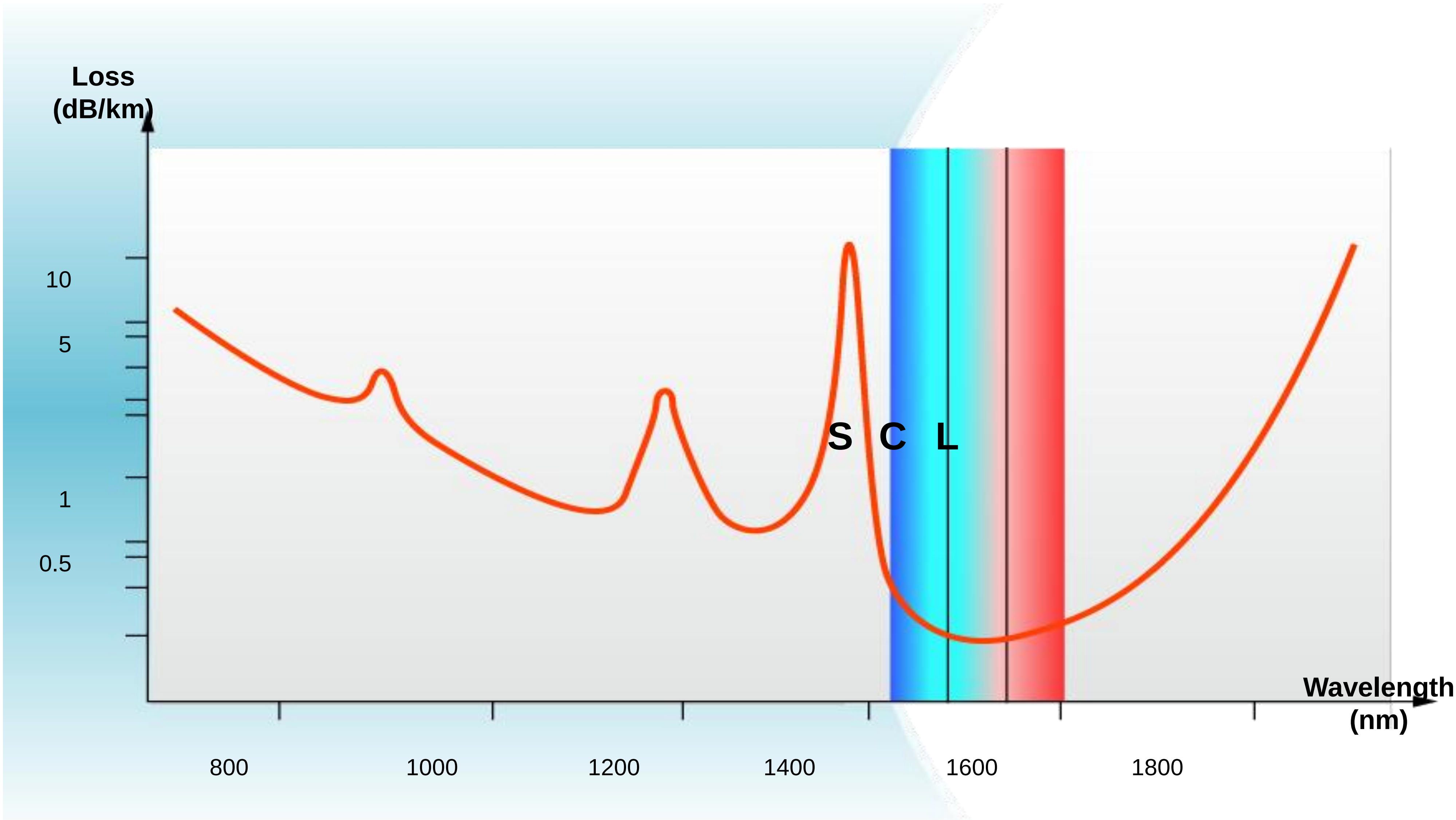

**Wavelength Regions**

# C Band

C Band



# Absorption Spectrum of the Optical Fiber



**WDM Operating wavelength**: *C waveband & L waveband*

C waveband coverage: 1528-1561nm（192.1~196.0THz）

C+ 192.15~196.05THz

L waveband coverage: 1571-1603nm（187.0~190.9THz）

L+ 187.05~190.95THz

As G.692 required, the channel distance is an integral multiple of 100GHZ (about 0.8nm).

WDM systems are divided in different wavelength patterns :

1.Conventional / Coarse-DWM**(CWDM)**

1.Dense- WDM**(DWDM)**

- Conventional WDM systems provide up to 16 channels in the 3rd transmission window (C-band, around 1550 nm) of silica fibers.

- Dense WDM (DWDM) uses the same 3rd transmission window (C-band) ***but with denser channel spacing***.

As channel plans vary, but a typical system would use 40 channels at **100 GHz** spacing or 80 channels with **50 GHz** spacing.

Some technologies are capable of **25 GHz** spacing (sometimes called ultra dense WDM). Where new amplification options (Raman amplification) enable the *extension* of the usable wavelengths to the L-band, more or less doubling these numbers.

Coarse WDM (CWDM) in contrast to conventional WDM and DWDM uses increased channel spacing to allow less sophisticated and thus cheaper transceiver designs .

Avoiding this region, the channels 31, 49, 51, 53, 55, 57, 59, 61 remain and these are the most commonly used.

Note - By providing 16 channels on a single fiber CWDM uses the entire frequency band between 2nd and 3rd transmission window (1310/1550 nm respectively) including both windows (**minimum dispersion window** and **minimum attenuation window**) but also the critical area where OH scattering may occur, recommending the use of OH free silica fibers .

In case the wavelengths between 2nd and 3rd transmission window shall also be used.

So, avoiding this region, the channels 31, 49, 51, 53, 55, 57, 59, 61 remain and these are the most commonly used.

Hence, WDM, DWDM and CWDM are based on the **same concept** of using multiple wavelengths of light on a single fiber, but differ in the -

- Spacing of the wavelengths
- Number of channels
- The ability to amplify the multiplexed signals in the optical space.

EDFA provide an efficient wideband amplification for the C-band, and

Raman amplification adds a mechanism for amplification in the L-band.

Note - For CWDM wideband optical amplification is not available as it limits the optical spans to several tens of kilometres.

Conclusion-

Hence,

All conventional **WDM systems** operate in the third communication band with a channel grid having exactly a 100 GHz (0.8 nm) spacing and a reference frequency fixed at 193.10 THz (1552.52 nm).

This grid is placed inside the optical fiber amplifier bandwidth and can be extended to denser channel spacings.

In DWDM systems the channels grid varies and a typical system would use –

1. 40 channels at 100 GHz (0.8 nm) spacing
2. 80 channels with a 50 GHz (0.4 nm) spacing
3. 160 channels with a 25 (GHz) (0.2 nm) spacing.

Some variants, sometimes called ultra dense WDM, are capable of 12.5 GHz (0.1 nm) spacing for up to 320 channels operations.

| CWDM | DWDM |
| --- | --- |
| Defined by wavelengths | Defined by frequencies |
| Short-range communications | Long-haul transmissions |
| Uses wide-range frequencies | Narrow frequencies |
| Wavelengths spread far apart | Tightly packed wavelengths |
| Wavelength drift is possible | Precision lasers required to keep channels on target |
| Breaks the spectrum into big chunks | Dices the spectrum into small pieces |
| Light signal isn't amplified | Signal amplification maybe used |

# DWDM Components and Architecture

Multichannel Receivers:- Multi-channel receivers can be manufactured using similar process and technology as multichannel transmitters particularly Waveguide grating routers.

Receivers detect the optical signals & converts into electrical form for further transmission.

The receiver usually consists of

1. A Semiconductor(Semi-conductor based
2. Photo detector
3. Hybrid amplifiers,

This improves gain flatness & noise performance.

In General- As the signal becomes weak then -

1. Amplifier: increases the strength of the optical signal.
It is an analog device, so what you put is what you get; with some noise, of course.

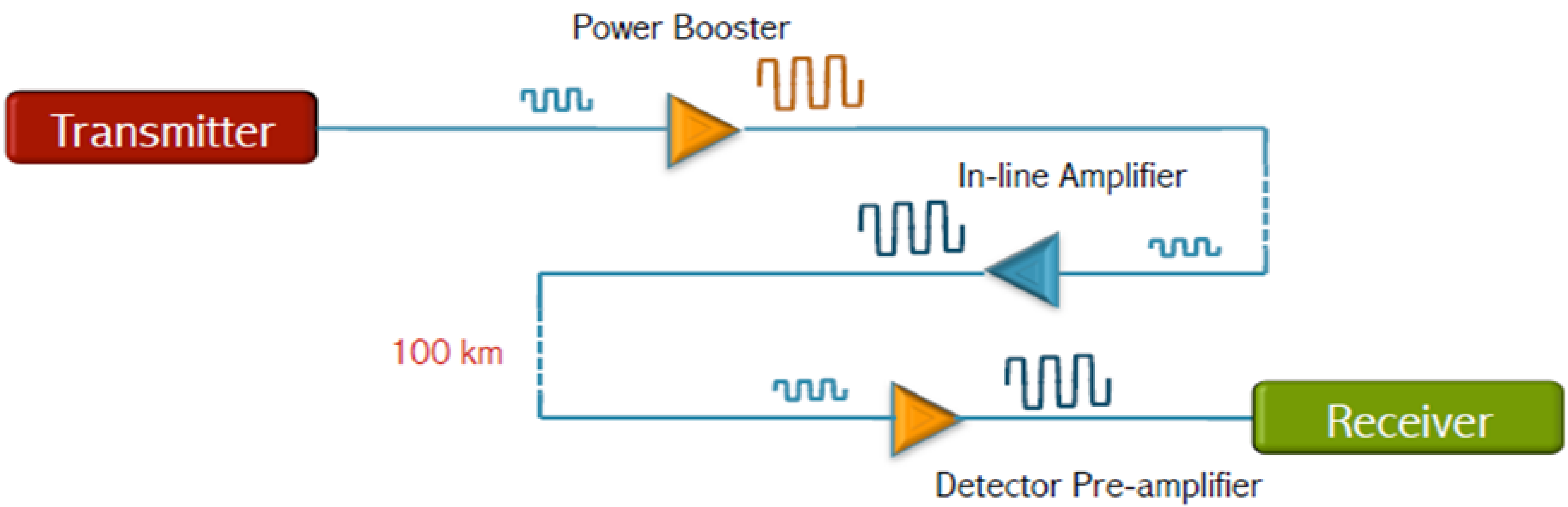
2. Repeater: Converts weak optical signal into electronic form, uses electronic signal to drive a transmitter that recreates the signal.

A receiver – transmitter placed back to back

3. Regenerator: cleans up digital signal by removing noise and distortion and regenerating a fresh signal.

They have discrimination circuits that examine the time-varying signal, identifies signal and noise; clean the signal

- Typical fiber loss around 1.5 μm is ~0.2 dB/km.
- After travelling ~100 km, signals are attenuated by ~20 dB,
- They need to be amplified or signal-to-noise ratio (SNR) of detected signals is too low and bit error rate (BER) becomes too high (typically want BER < 10-9).
- Can be done by detecting the weakened signals, then modulating a new laser with modulation read off the detected signals.
- This {Optical to Electrical to Optical} conversions requires costly high-speed electronics (>10 GHz).
- Best way to amplify is optically, and best optical method is fiber amplifier (lowest loss, most efficient, most stable).


Power Booster
Transmitter
In-line Amplifier
100 km
Receiver
Detector Pre-amplifier

Power booster : Placed immediately after transmitter. Help increase the power of the signal, noise may not be the major issue.

- SOA

In-line amplifier : Compensate for the signal attenuation as it propagates.

Needed in long-haul networks. Noise plays a considerable role as the signal weakens.

- Combination of EDFA, Filters and Raman Amplifiers.

Preamplifier : A weak op,cal signal is usually amplified before it enters the receiver. Noise is a crucial factor.

An Optical Amplifier is characterized by :

- Gain : ratio of output power to input power (in dB).
- Gain efficiency : gain as a function of input power (dB/mW).
- Gain bandwidth : range of wavelengths over which the amplifier is effective.
- Gain saturation : maximum output power, beyond which no amplification is reached
- Noise : undesired signal due to physical processing in amplifier

- Rare-earth doped Fiber Amplifiers

  - Erbium Doped (EDFA) – 1,500 – 1,600 nm band

  - Praseodymium Doped (PDFA) – 1,300 nm band

- Raman (and Brillouin) Amplifiers

- Semiconductor Optical Amplifiers (SOAs) – 400 – 2,000 nm band

| Property | EDFA | Raman | SOA |
|---|---|---|---|
| Gain (dB) | > 40 | > 25 | >30 |
| Wavelength (nm) | 1530-1560 | 1280-1650 | 1280-1650 |
| Bandwidth (3dB) | 30-60 | Pump dependent | 60 |
| Max. Saturation (dBm) | 22 | 0.75 × pump | 18 |
| Polarization Sensitivity | No | No | Yes |
| Noise Figure (dB) | 5 | 5 | 8 |
| Pump Power | 25 dBm | >30 dBm | < 400 mA |
| Time Constant | $10^{-2}$ s | $10^{-15}$ s | 2 x $10^{-9}$ |
| Size | Rack mounted | Bulk module | Compact |
| Switchable | No | No | Yes |
| Cost Factor | Medium | High | Low |

| Band Name | Meaning | Wavelength (nm) | Technology |
| --- | --- | --- | --- |
| O | Original | 1260-1360 | Praseodymium |
| E | Extended | 1360-1460 | - |
| S | Short | 1460-1530 | Thulium fiber |
| C | Conventional | 1530-1565 | Erbium fiber |
| L | Long | 1565-1625 | Erbium fiber |
| U | Ultra-long | 1625-1675 | - |

Amplifier definition – An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal.

An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed.

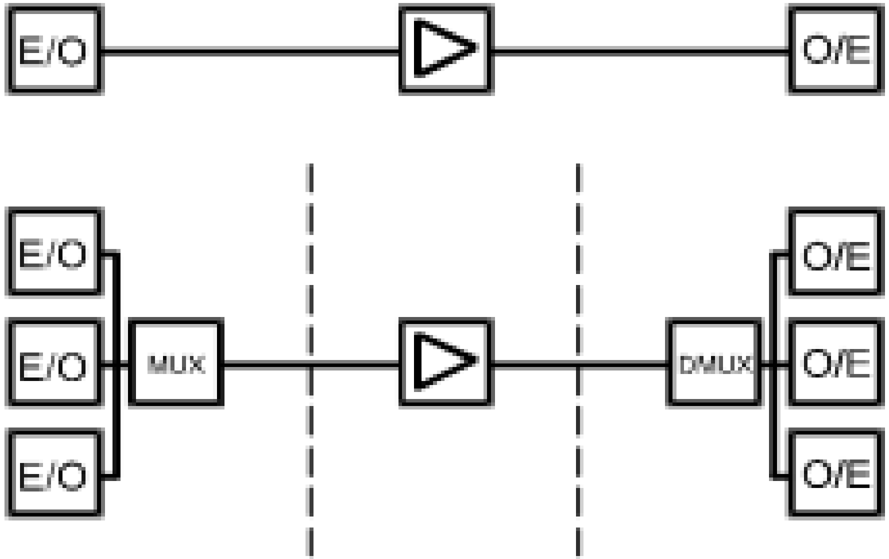
Optical amplifiers are important in optical communication and laser physics .

A Typical Optical Amplifier works on the same principle as that of a laser, where incident light is amplified by sustained stimulated emission .

The amplification is achieved by a pumping process whereby either electrical or optical pumping boosts the incident signal power in a gain medium or just in a fiber.

A **Pump** is a local power source that couples its power to an incident optical signal, thereby amplifying the incident signal by transferring its power either directly or through doped impurities to the optical signal.

It is **disadvantageous** that with a given repeater only a given protocol at a fixed data rate can be transmitted, therefore it is more reasonable to use optical amplifiers in DWDM systems.




transmission system with
optical signal amplification

Fig. shows a 1-channel system above and a DWDM system below with optical amplification.

In comparing the two multi-channel DWDM systems the superiority of using an optical amplifier becomes obvious.

The optical amplification is Independent of the bit rate as well as of the transmission capacity and it is independent of the data protocol.

It operates without converting the signal into the electrical range.

Until now, Optical Amplifiers with appropriate features have been available for the 3. optical window only and suitable optical amplifiers for the 4. optical window are *being Developed now.*

Hence, DWDM systems can soon be realized in the 3. and the 4. optical window up to 1610nm (*L-band, long wavelength*).

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 and the spontaneous emissions in the EDFA also add noise to the signal, which determines the noise figure of an EDFA.

The key performance parameters of optical amplifiers are :

1. Gain
2. Gain flatness
3. Noise level and
4. Output power.

EDFAs are typically capable of gains of 30 dB or more and output power of +17 dB or more and the target parameters when selecting an EDFA, however, are low noise and flat gain.

Thank You

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