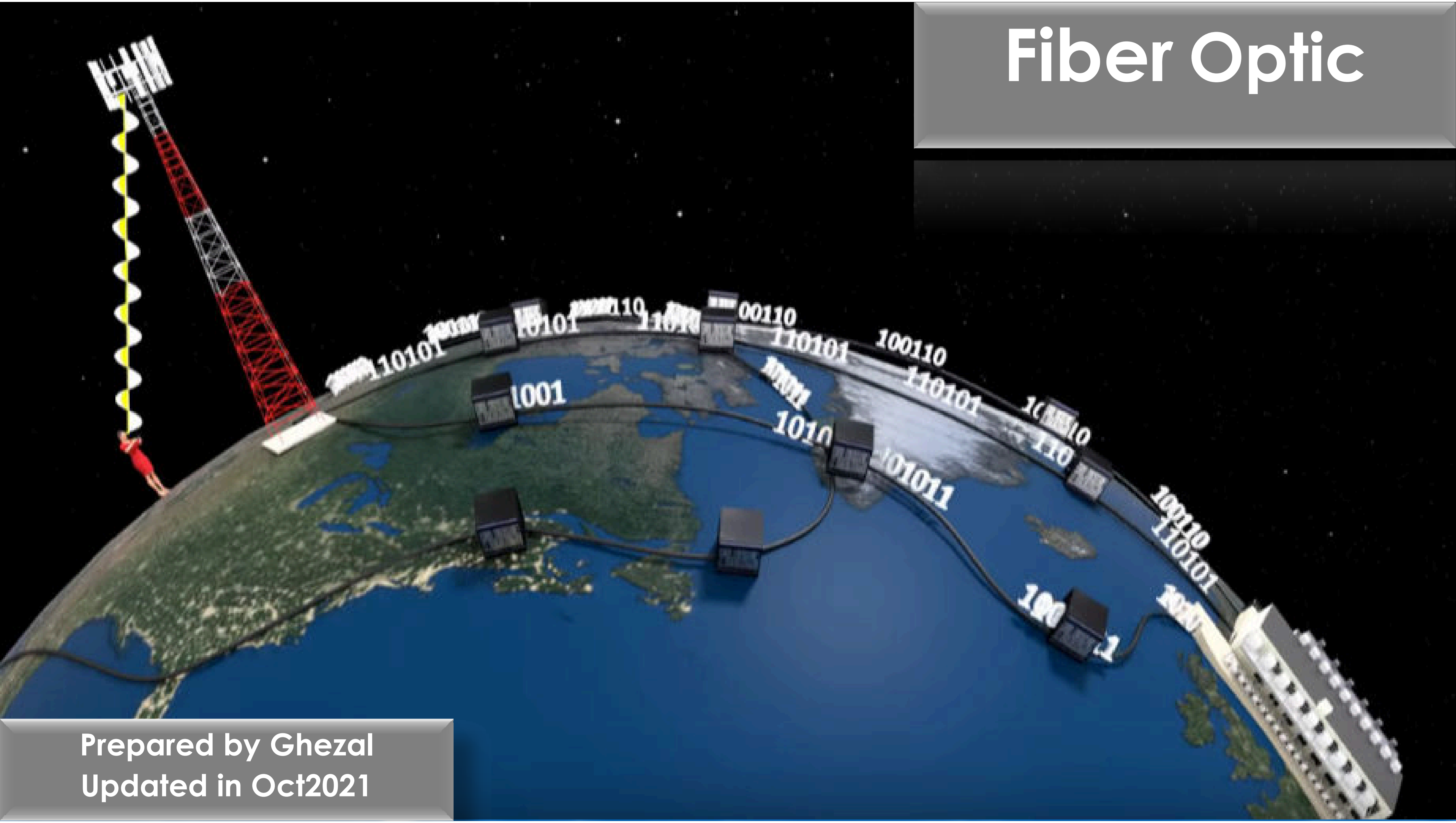
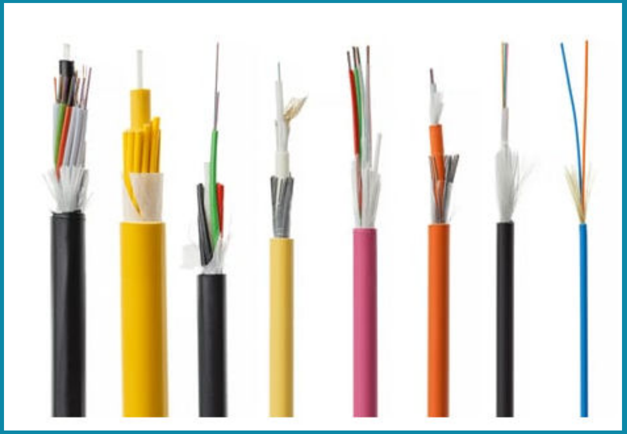
Fiber Optic



Prepared by Ghezal
Updated in Oct2021

History of fiber optic:-



- 1854-John Tyndall -think that (Sunlight was refracted through the stream of water).
- 1880- William Wheeling (Used mirrored pipes to carry Light from one source to many rooms.
- 1880-Alexander Graham Bell (Invented the photophone , A device to carry voice signals through the air instead of wire.

History of fiber optic:-

- 1920 -{First attempt with optical transmissions} by John Logie

Baird From (England and Clarence W. Hansell (U.S)

- 1954-Invention of modern optical fiber by Abraham Van Heel,

Which can covered a bare glass fiber with a transparent coating..

- 1960- Invention of the laser.
- 1970-Corning Glass invents Optical Fiber.
- 1977- Phone Companies use Optical Fiber.
- 1980- Bell Labs Proposes First Fiber Transatlantic Cable and used single mode fiber. .
- 1992- 1550 nm system appeared and TAT-10 activated

- **Question:-** What is fiber optic?
- **Answer:-** Is a communication technology that has thin strands of very

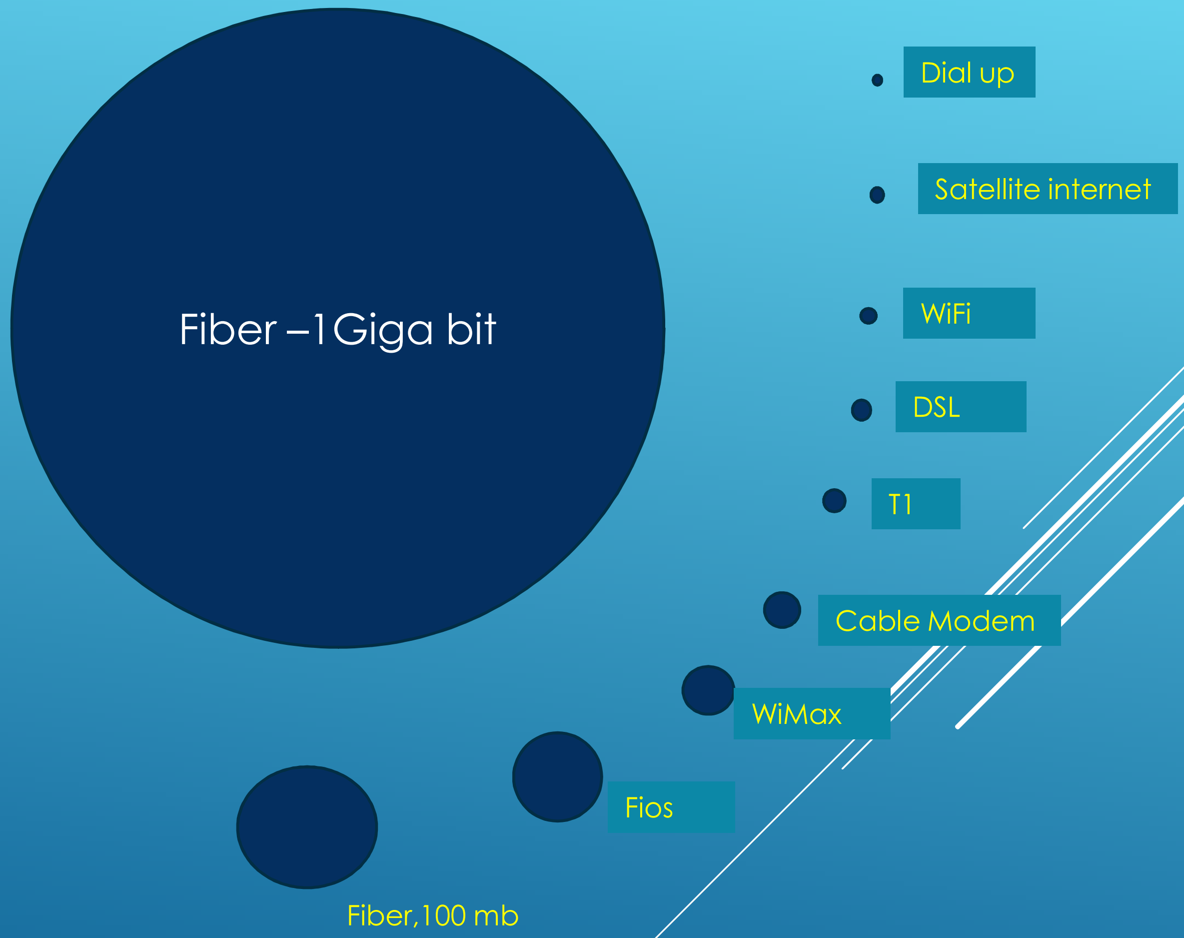
pure glass about the diameter of a human hair. fiber optics means sending light beams down thin strands of plastic or glass by making them bounce repeatedly off the walls.

- **Question:-** What is fiber optics made of?
- **Answer:-** Made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair.

- **Question: How Do Fiber Optics Work?**
- **Answer:** Light travels down a fiber optic cable via bouncing off the partitions of the cable repeatedly. Each light particle (photon) bounces down the pipe with endured internal mirror-like reflection.
- The light beam travels down the core of the cable. The core is the middle of the cable and the glass structure.
  The cladding is another layer of glass wrapped round the core.
  Cladding is there to keep the mild signals internal the core.

Fiber optic Band width-comparison with the other connectivity

- **Question:** Why fiber optic is the better?
- **Answer:** To allows tremendously larger bandwidth and relatively economical long-distance communications, can transfer from minimum 10 Gbps up to unlimited amounts.



Advantages of optical fiber:

- Higher bandwidth. it can transfer more data.
- Reduce signal attenuation.
- High carrying capacity.
- lighter in weight.
- Flexible .
- There is no stray interference pickup that suffers from fibre optics which happens because of coaxial cabling
- Optical fiber cables take up less space.

Advantages of optical fiber:

- Loss of signal less than that in copper wire.
- Longer life cycle for over 100 years.
- Smaller diameter.
- Light signals
- Resistance to corrosive materials.
- Immunity to electromagnetic interference and tapping
- It can be made cheaper than equivalent lengths of copper wire

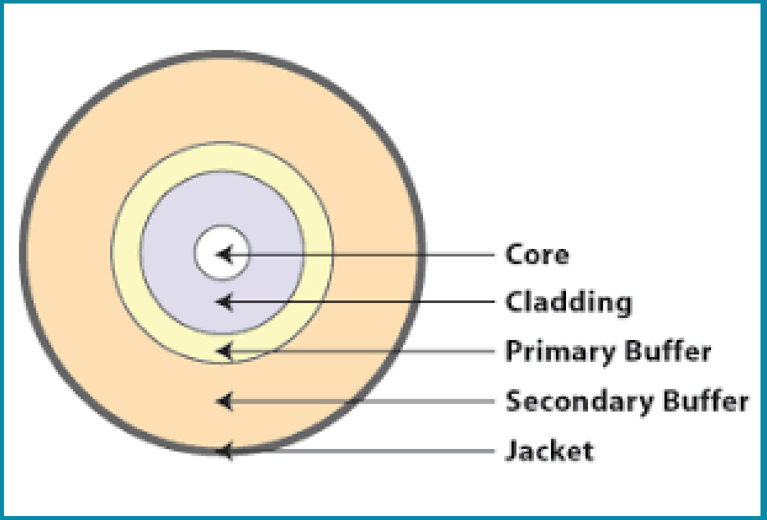
Disadvantages of Optical Fiber:

- Can not transmit electricity.
- Not easy to installation and maintenance (need more experience).
- Limited application.
- Low Power, need extra cost.
- Moderate to form any sort of Network.

Disadvantages of Optical Fiber

- Highly cost.
- Unidirectional light propagation.
- Optical fiber is rather fragile
  and extra prone to harm compared to copper wires.
- Needs for more expensive optical transistors and receivers.
- Sensitive structure.
- Distance problem—Transmitter and receiver should keep short ,other wise need repeater

- **Question:** How many part of fiber optic ?
- **Answer:** There are three part of fiber optic:

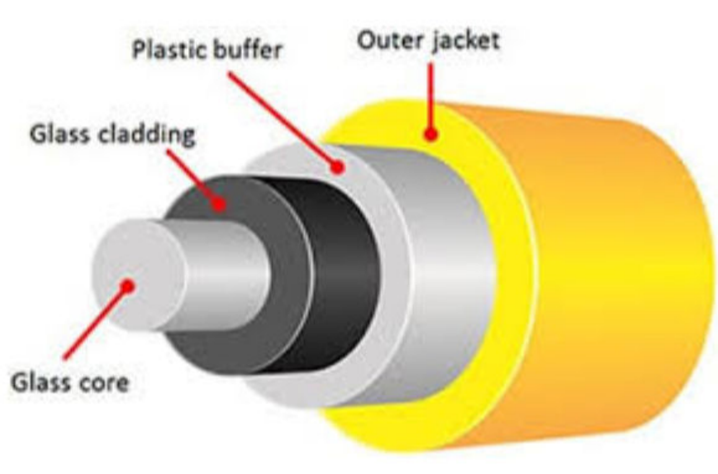


1- Core - Core acts as denser medium, core is the thin glass center of the fiber where the light travels.

2- Cladding - Cladding acts as rarer medium, Outer optical material surrounding the core that reflects the light back into the core.

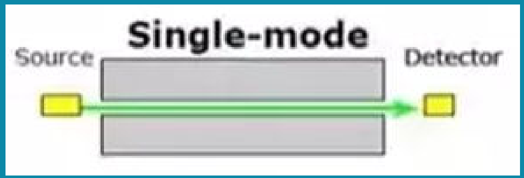
Light passes through the core after total internal reflection, also clad can provide mechanical strength to the core.

- **Buffer coating** - It is the outermost part Of an optical fiber, or it is plastic coating that protects the fiber from external impurities , damage and moisture.



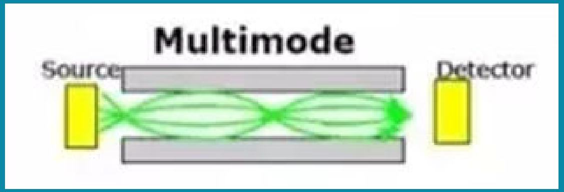
- **Question:-** How many Type of fiber optic mode?
- **Answer :-** There are two type of fiber optic mode:

<u>1-Single mode fiber (SMF) :</u>



It has very small light carrying core of 8 to 10 microns in diameter. Core diameter is very less for single made optical fiber It is normally used for long distance transmissions with laser diode based fiber optic transmission equipment.

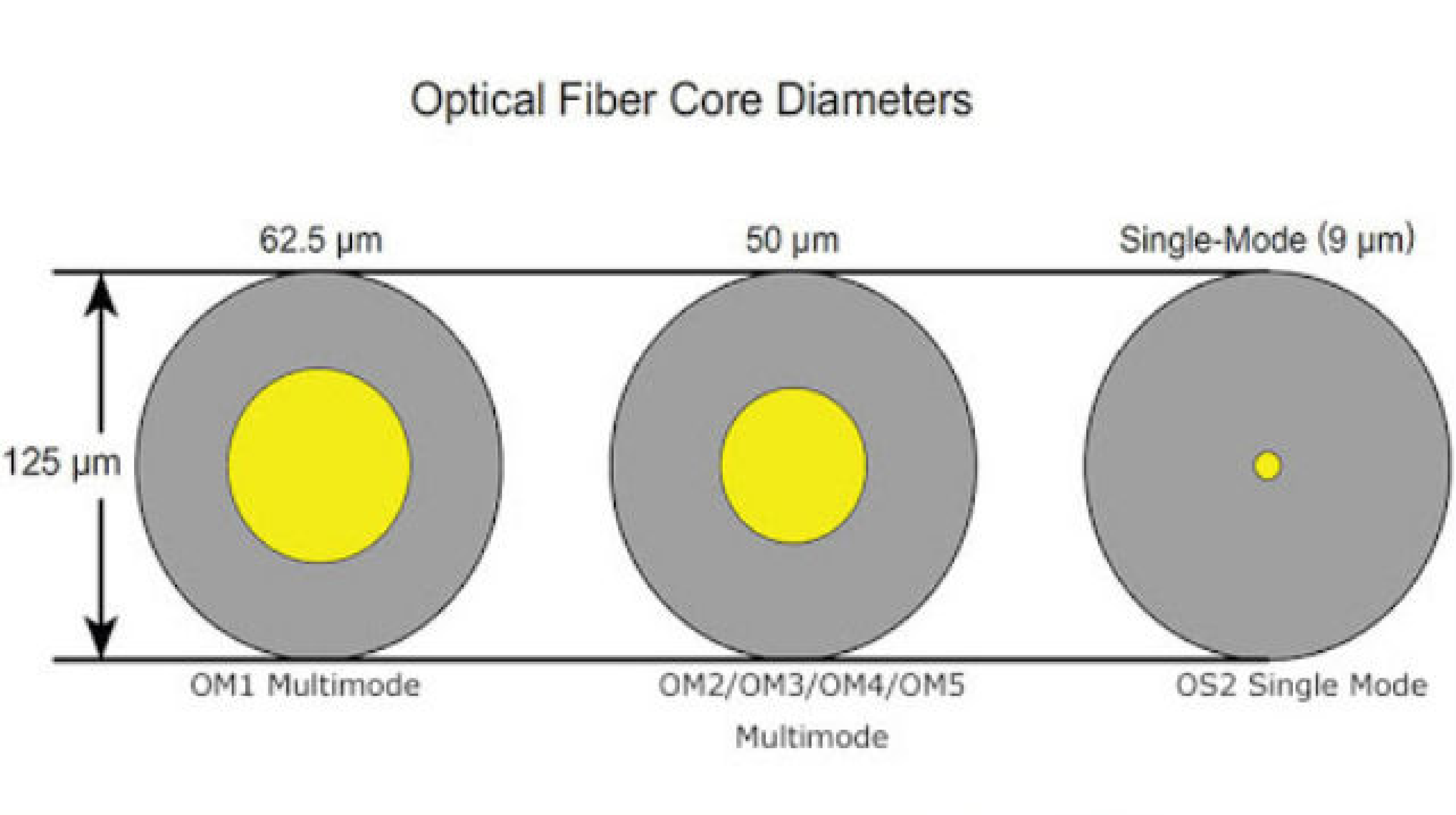
2-Multi mode fiber (MMF):



It transmitters more than one mode through fiber,

the light can pass through more than one path, mostly used for communication over short distances, has a large core diameter ,usually 62.5 microns or larger in diameter, multi-mode optical fiber is less expensive than that for single-mode optical fiber.

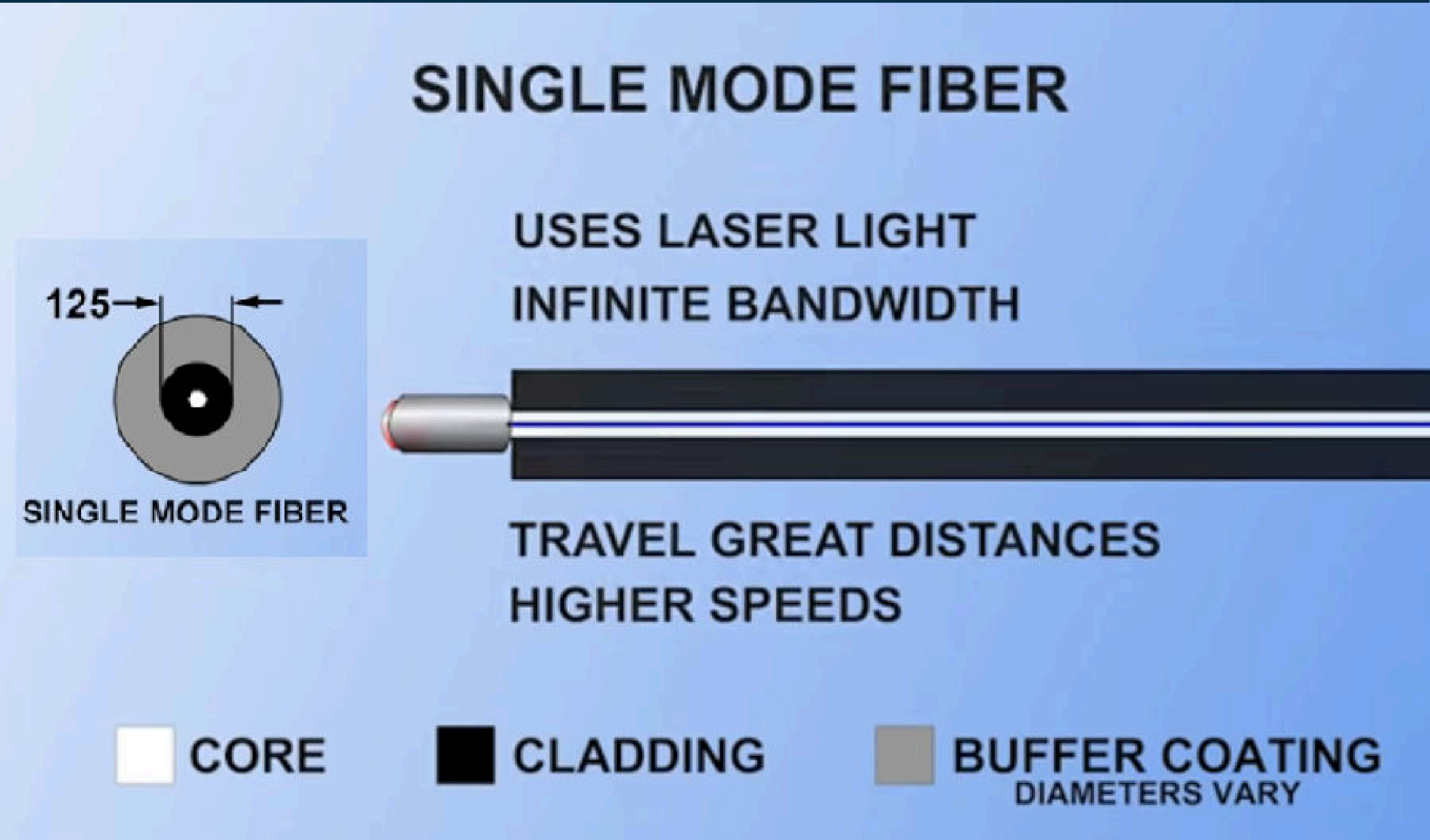
Single mode core and Multi mode core :



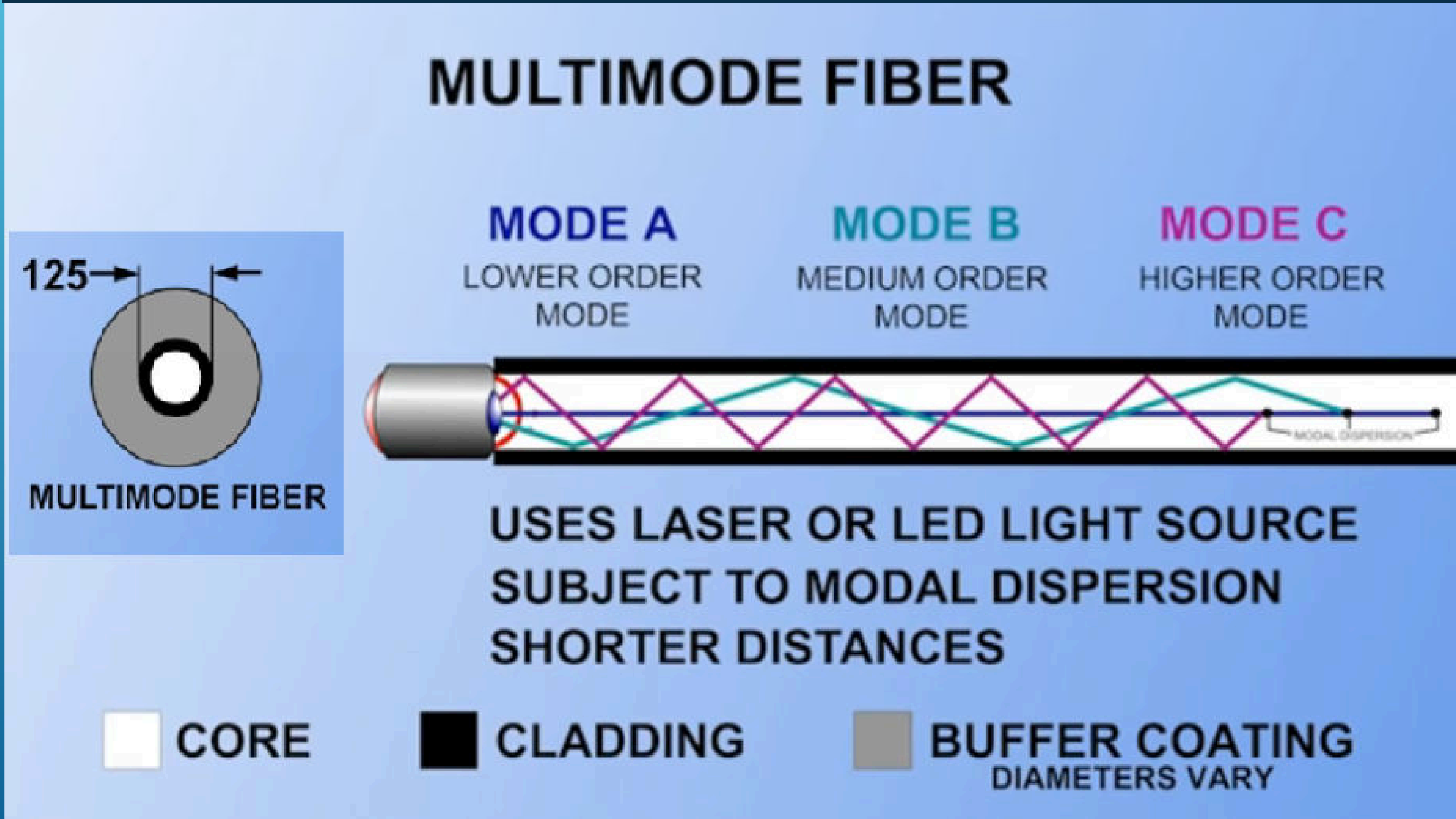
Different between Single mode fiber and Multi mode fiber

Single mode	Multi-mode
1. LED cannot be used as light source.	1. It uses LED source that generates differtes angles along cable.
2. High cost for connector and installation.	2. Low cost for both connectors and installation.
3. High system cost.	3. Low system cost.
4. Use for long distance communication.	4. Use for Short distance communication.
5. Low fiber cost.	5. Higher fiber cost.
6. V number is less than 1.15.	6. V number is greater than 1.15.
7. High bandwidth.	7. Low bandwidth.
8. Lower loss.	8. High loss.
9. Used for access, Campus, WAN, MAN...	9. Used for SAN , Data Center ,LAN,CO...
10. High cost source 1310+ nm lasers 1 and 10 Gb/s.	10. Low cost source (+850 nm and 1310 nm LEDs)
11. Small Core.	11. Larger core than single mode cable.
12. Less dispersion.	12. Allows greater dispersion and therefore, loss of signal.
13. Employ for long distances of several through meters.	13. Used for shorter distance application, but shorter than single, Often uses in LAN or small distances such as campus network.
14. Propagation of only one mode take place.	14. Many modes propagate at the same.

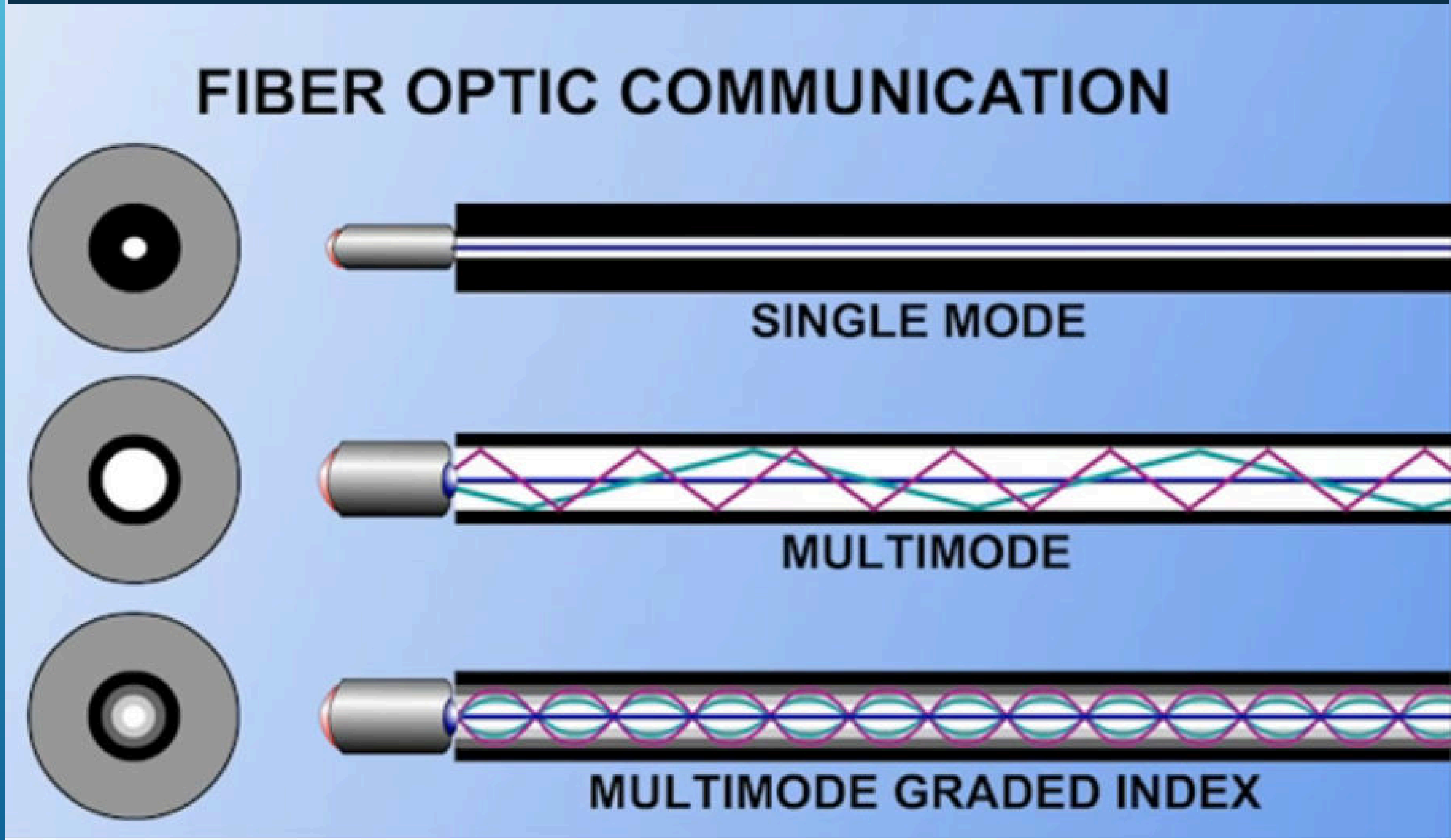
Single mode core and Multi mode core :



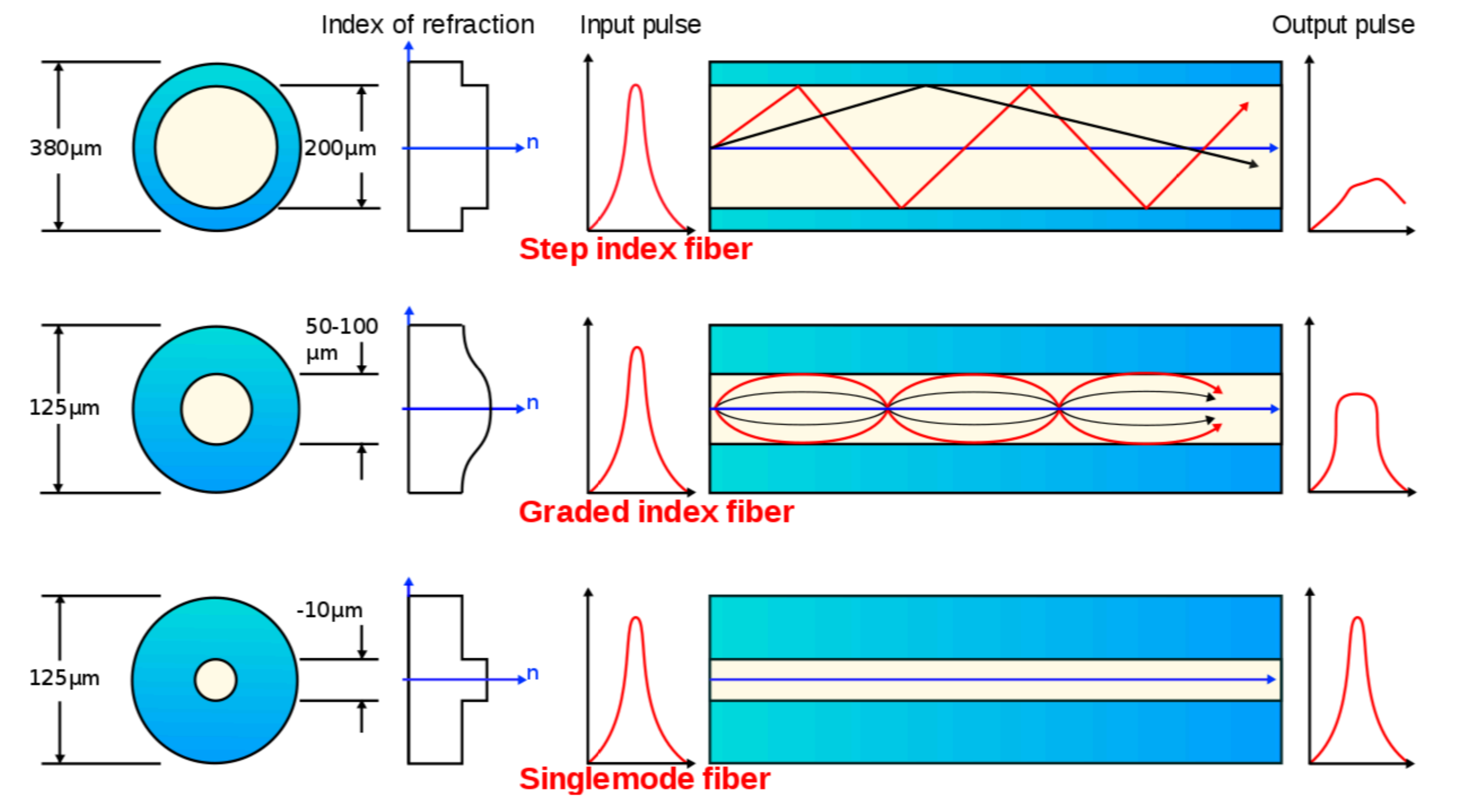
Single mode core and Multi mode core :



Single mode core and Multi mode core :



Single mode core and Multi mode core :



Definition of Chromatic Dispersion

CD is the property of a medium (optical fiber) that makes different light wavelengths propagate at different speeds as they travel in it. In an optical fiber, both the wavelength dependence of the material itself (glass) and the properties of the structure of the index of refraction (IOR) create the guide in which the light is confined and propagating.

In optical telecommunications transmission, a pulse of light made up of multiple wavelengths
(colors) that are each traveling at different speeds (group velocities), because of CD. The
pulse spreads as wavelengths arrive at differing intervals. The wavelength dependence of
the group velocity is formally known as group velocity dispersion. However, the terms group
velocity dispersion and CD are typically used interchangeably in describing the propagation of
wavelengths at different speeds.

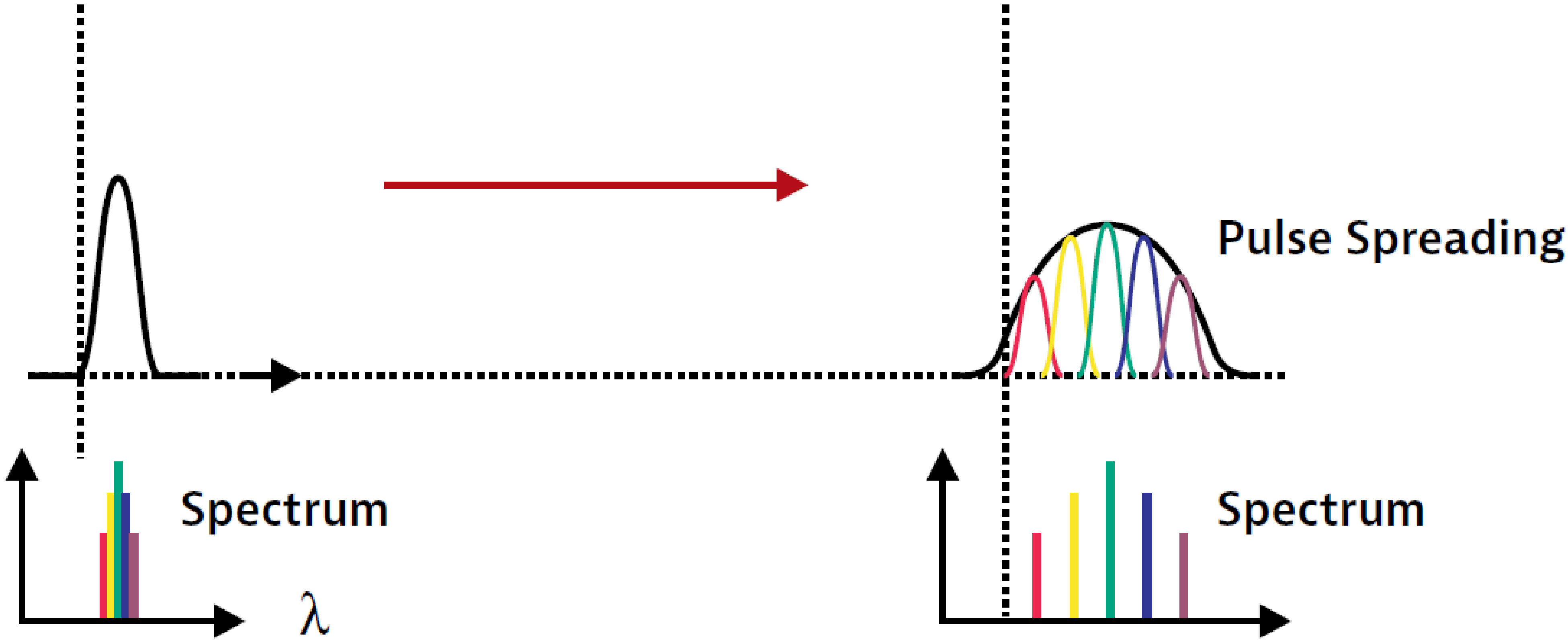


Figure 1. Pulse spreading caused by wavelengths traveling at different group velocities

Fiber Types—The CD History:-

Fiber manufacturers continue to manipulate CD to produce different types of fibers for different applications and requirements. The International Telecommunication Union (ITU) has classified these various single-mode fibers into four main categories according to their CD properties: Non-Dispersion-Shifted Fiber (NDSF), Dispersion-Shifted Fiber (DSF), Non-Zero Dispersion-Shifted Fiber (NZ-DSF), and Wideband NZ-DSF.

Note: CD is not limited to single-mode fibers but also impacts multimode fibers. Multimode fibers are not considered in

this document

Non-Dispersion-Shifted Fiber

ITU-T G.652 fiber, often referred to as standard single-mode fiber (SSMF), was the first type of single-mode fiber manufactured. It was originally developed for optimized transmission around 1310 nm, with an abrupt index profile change between the core and the cladding (see figure below). Today, the SSMF is well suited for DWDM transmission in the C and L bands.

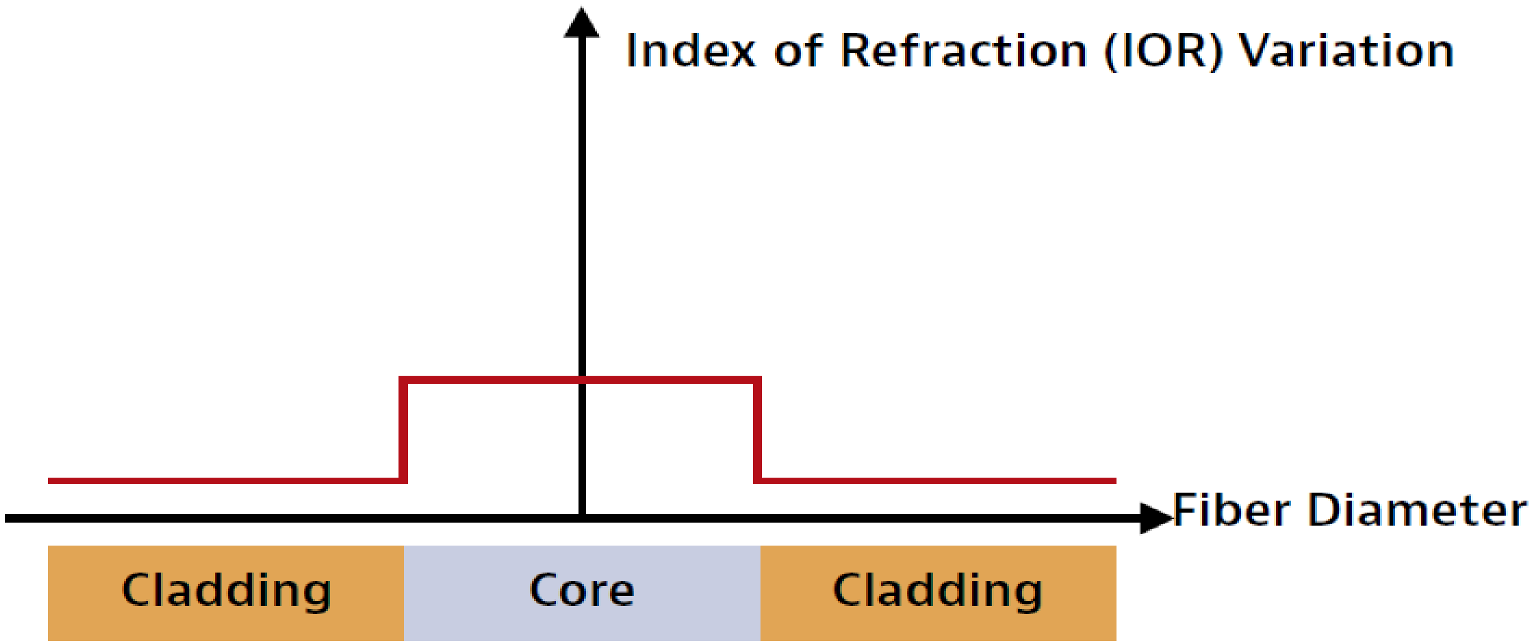


Figure 9. Schematic of index of refraction variation for an SSMF

Dispersion-Shifted Fiber

Dispersion-shifted fibers were designed with the zero dispersion wavelength moved within the 1550 nm region to increase the reach of long-distance transmission systems as well as to take advantage of the lower fiber attenuation. Classified as ITU-T G.653 fiber, it is ideal for single wavelength transmission in very long haul networks.

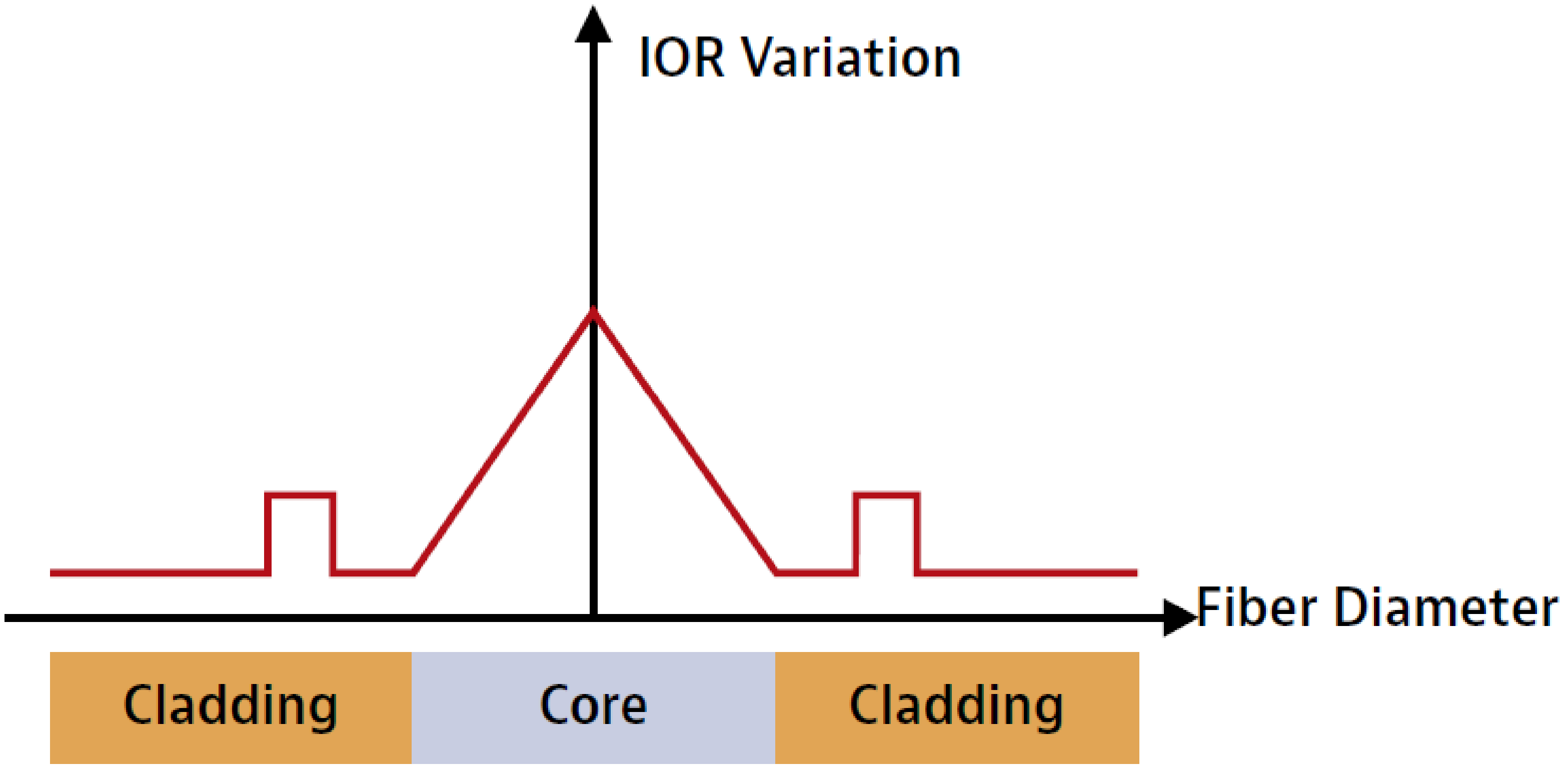


Figure 10. Schematic of index of refraction variation for a DSF

Non-Zero Dispersion-Shifted Fiber

With the advent of DWDM applications, a slightly positive or negative CD is desirable for wavelengths around 1550 nm as it eliminates nonlinear interactions between multiple DWDM channels, known as four-wave mixing. Typically, fiber classified as ITU-T G.655 has a CD magnitude one-third that of NDSF of positive or negative dispersion.

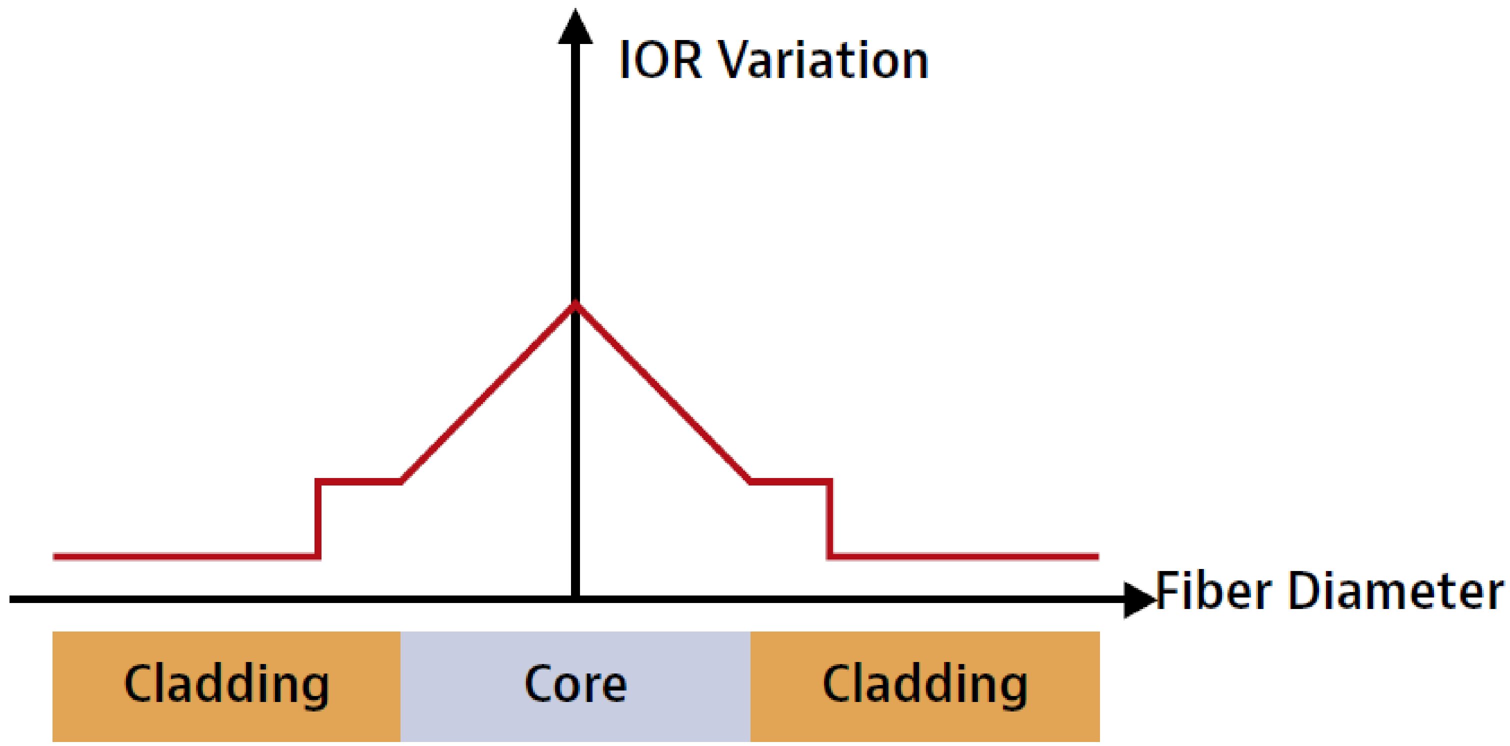


Figure 11. Schematic of index of refraction variation for an NZ-DSF

Wideband NZ-DSF

A newly standardized fiber type known as ITU-T G.656 offers a wider WDM transmission capability that extends beyond the conventionally defined C- and L-bands (nominally 1530 to 1565 nm and 1570 to 1610 nm, respectively). It offers a moderate dispersion (2 to 14 ps/[nm x km]) between 1460 and 1625 nm wavelengths.

Waveguide Dispersion

Waveguide dispersion is the variation in group velocity of different wavelength components

of light caused primarily by the mode field diameter (MFD), or the diameter of the light beam

within the wavelength of a single-mode fiber.

Engineering differences in the IOR between the fiber core and cladding regions cause light to

propagate faster in the cladding than in the core. The propagation velocity difference is largely

independent of wavelength. Therefore, as the MFD increases, a greater percentage of the light

propagates within the cladding region resulting in a faster propagation.

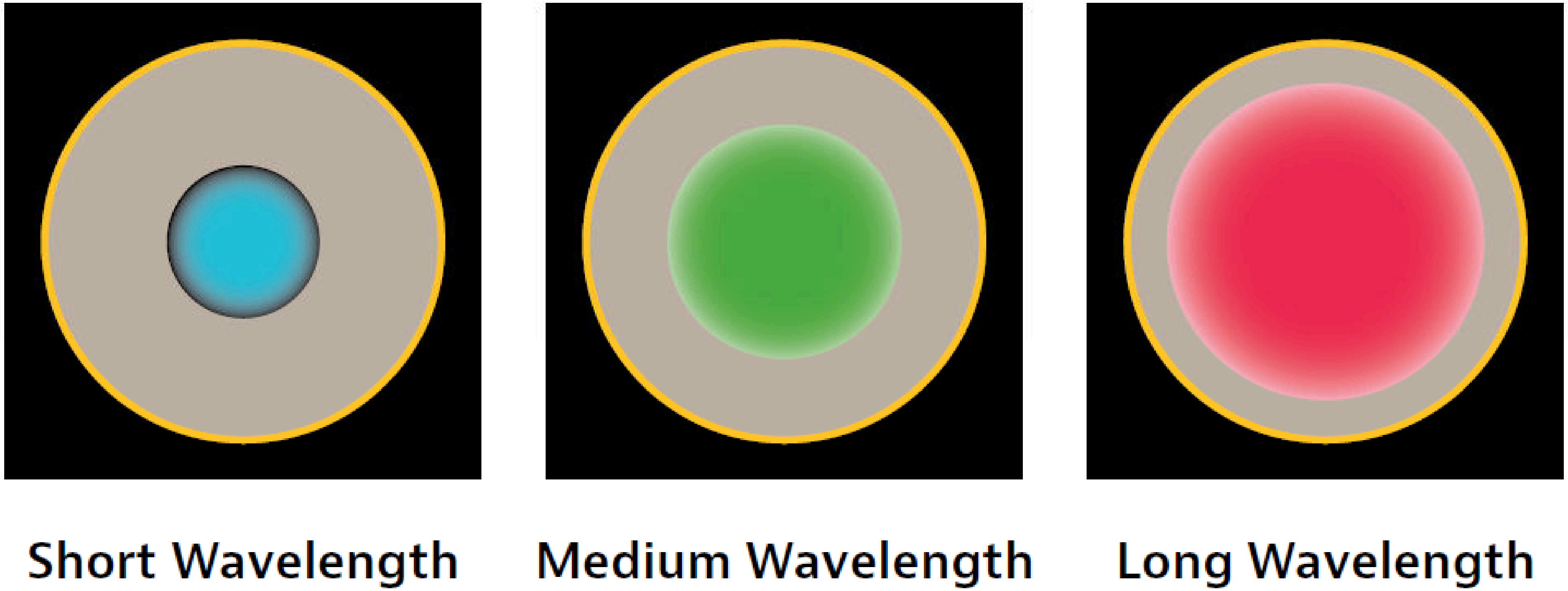


Figure 6. Variation of the MFD according to the wavelength

Limiting Transmission Parameter

Signal Bandwidth and Modulation Format:

The modulation format used to encode the digital information onto the optical signal can significantly impact the tolerance of the signal to CD experienced during transmission. With the conventional encoding of digital information onto the amplitude of the optical signal (example of non-return-to-zero [NRZ]), both the optical bandwidth of the signal and the width of the optical pulses are directly related to the data rate of the signal. For higher data rates, the pulses are shorter and spaced closer together with a wider optical spectrum.

The impact of CD-induced pulse spreading becomes increasingly significant at higher data rates, as the shorter, closer-spaced pulses have less room to spread before overlapping into an adjacent bit period. Furthermore, given the wider spectrum, these pulses comprise a greater range of wavelength components, which travel at different speeds and, therefore, experience greater spreading.

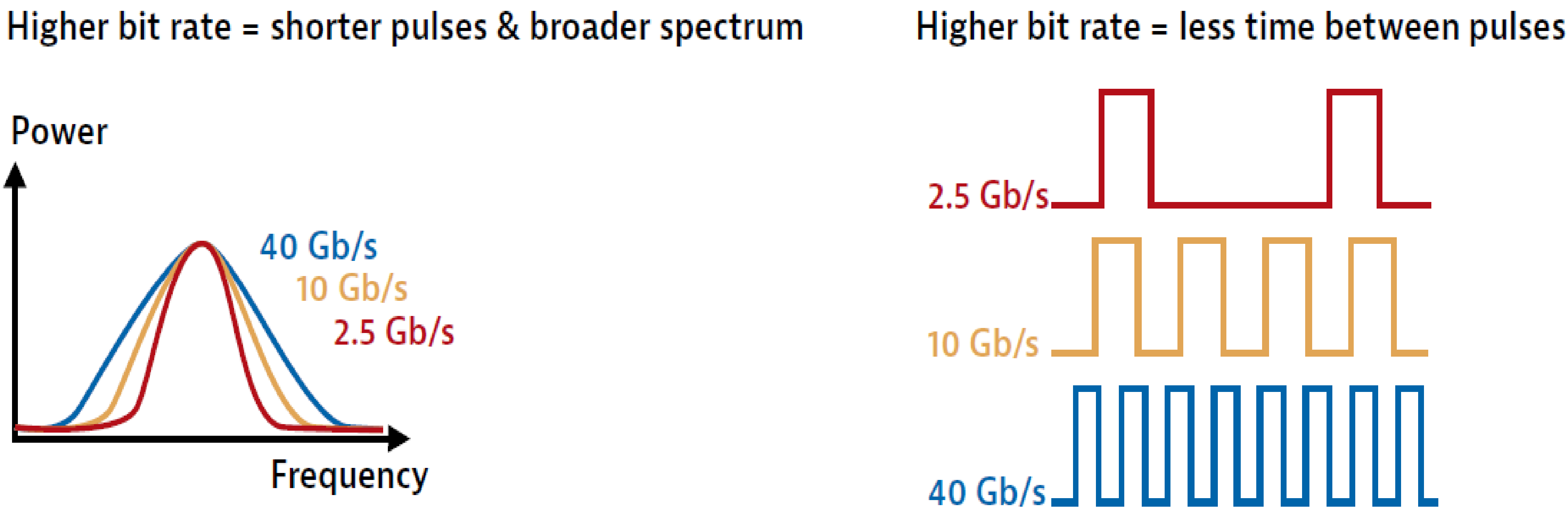


Figure 15. Effect of bit rate increase on pulse width and intervals

Fiber Length Limitations Due to Chromatic Dispersion

CD is a linear effect that accumulates on a link linearly with distance. Consequently, the total CD on a longer fiber increases proportionally with the distance. The table below provides the maximum tolerance for total CD for each respective standardized interface.

Table 9: Maximum theoretical distance reach for G.652 and G.655 fiber types

Bit Rate/Channel (Gbps)	CD Tolerance at 1550 nm (ps/nm)	Max. Distance (km) for ITU-T G.652 Fiber Type	Max. Distance (km) for ITU-T G.655 Fiber Type
2.5	18817	>1100	>4700
10	1176	~70	~290
40	73.5	~5	~20

Similarly, proprietary transmission interfaces each have a total CD tolerance. Adequate link performance requires that the total chromatic dispersion for the entire fiber link be less than the maximum tolerable value.

Measurement Principle Using an OTDR

The OTDR sends pulses of four or more wavelengths into one end of the fiber. The relative

arrival time is then measured for each backscattered wavelength signal. The first wavelength is

used as a reference and compared with arrival times of the other wavelengths.

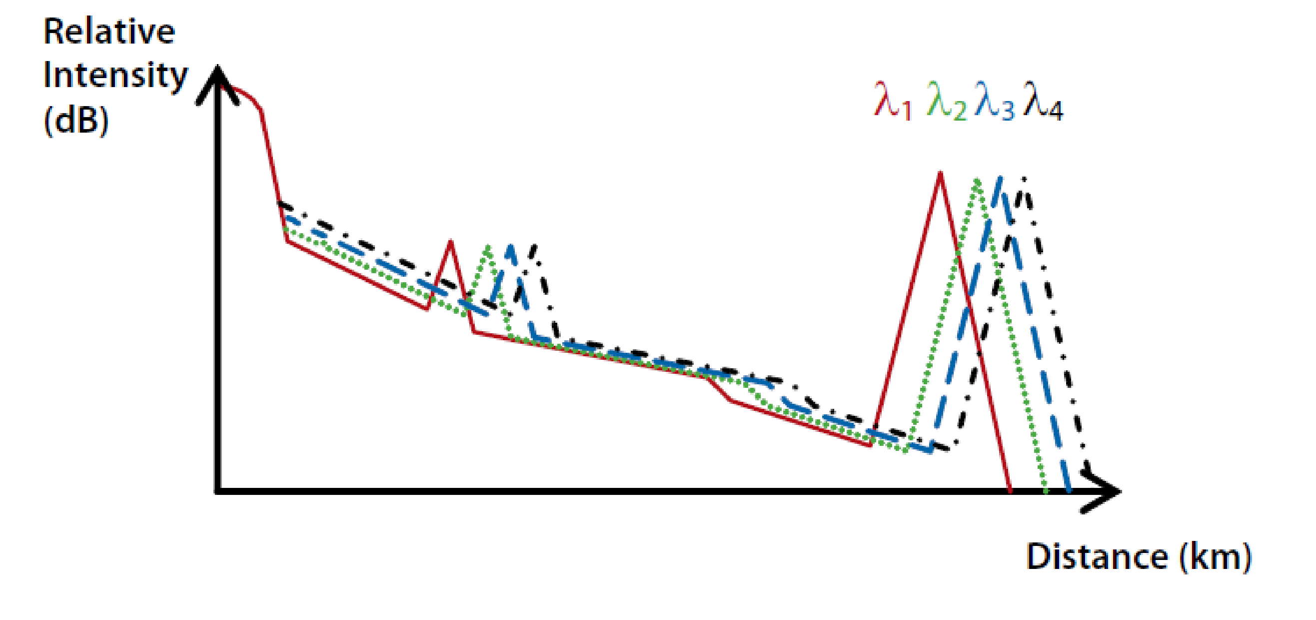


Figure 28: Multi-wavelength OTDR traces of a Pulse Delay method

Measurement Applications

Because of the performance differences between each measurement method, when choosing a CD analyzer it is important to match its capabilities to the specific application. The suitability of methods to specific applications is compared in Table 16.

Table 16: Test method suitability according to the application

Application	Phase Shift	Diff. Phase Shift	Pulse Delay
Standard fiber G652	✓	✓	✓
Dispersion shifted fiber G653	✓	✓	✓
NZDSF G655	✓	✓	✓
Mix of fiber types	✓	✓	✗
Medium distance and metro networks (<80 km)	✓	✓	✓
Long-distance network (>120 km)	✓	✓	✗
CD compensators qualification	✓	✓	✓
Amplified links testing	✓	✓	✗
Short distances (<10 km)	✓	✓	✗

- Attention should be paid to portability, autonomy (battery powered), ease of use, set up time,

warm up time, and degree of operator intervention, among other factors.

Polarization Mode Dispersion (PMD)

Polarization mode dispersion, or PMD, is defined as the temporal spreading of the transmission signal pulses due to birefringence. PMD is generally conceptualized and mathematically modeled as the resulting differential time delay between signal components that is transmitted in two well-defined orthogonal polarization states, or principal states of polarization (PSPs) of the fiber. The two PSPs propagate at different speeds through the fiber. This creates two time delayed copies of the launched signal that may cause severe distortion in the optical receiver at the end of the fiber. Furthermore, PMD may vary with time and with optical frequency due to higher-order PMD effects. Therefore, signals transmitted over different wavelength channels of a given fiber usually experience different amounts of distortion.

Differential Group Delay

The difference in arrival time between the two principal modes of polarization (known as Eigen modes of the fiber) is known as birefringence. Fibers always exhibit two orthogonally polarized modes that traverse the fiber at largely different speeds. They introduce a differential time delay between optical signal components that are transmitted in these two modes. The magnitude of PMD in a fiber is usually expressed as this difference that is known as the DGD and is usually denoted as $\Delta\tau$ (delta tau).

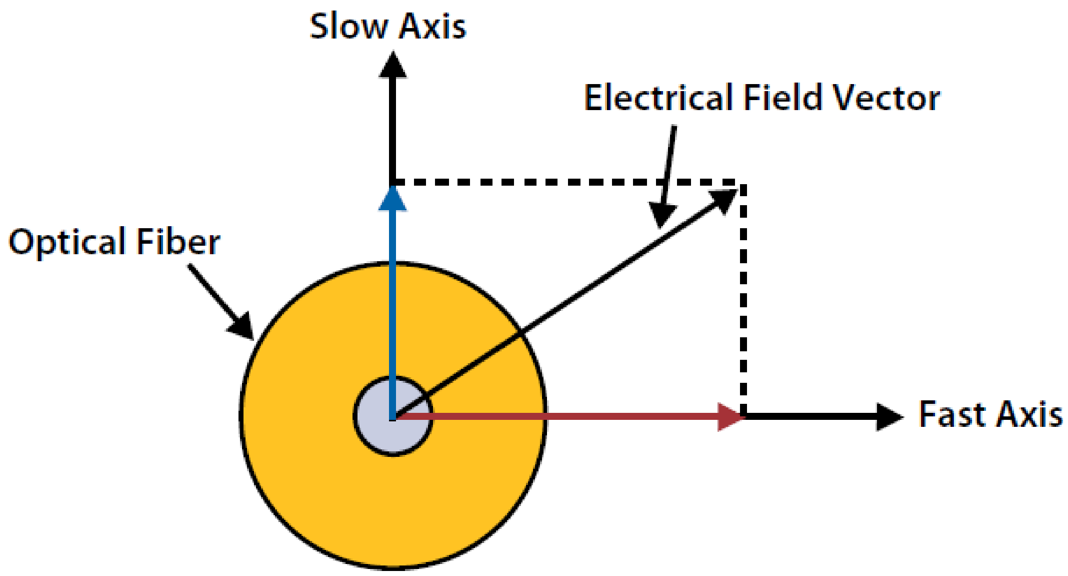


Figure 36: Signals transmitted through a birefringent fiber experience a slow and fast polarization mode

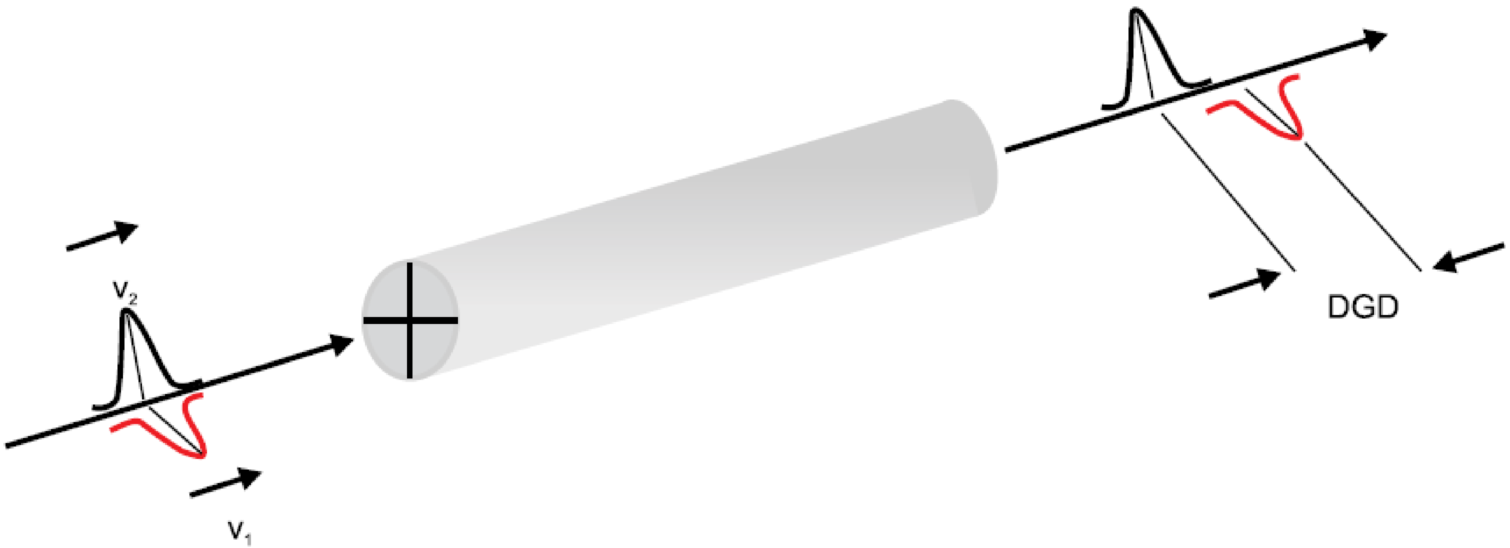


Figure 37: Differential group delay in a highly birefringent fiber

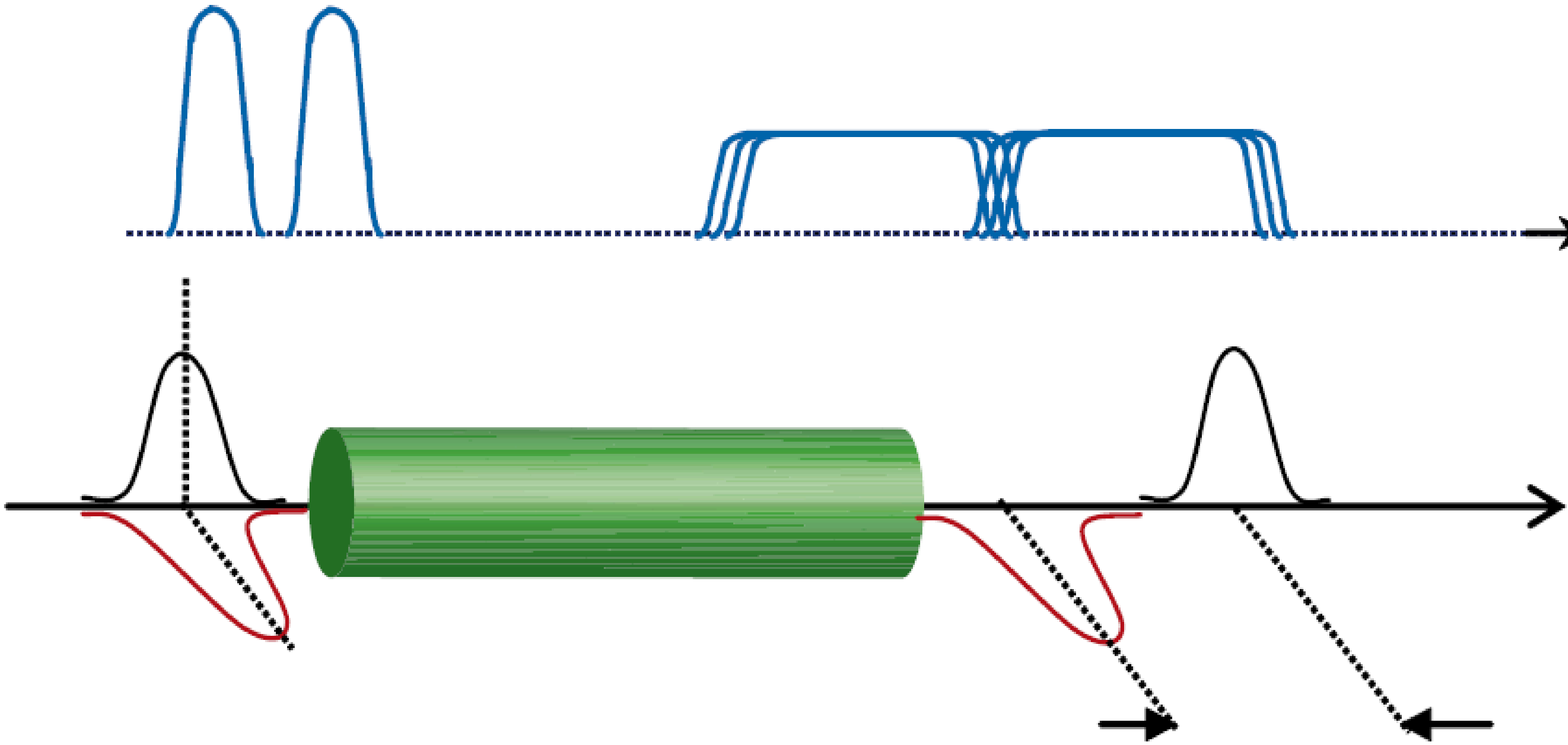


Figure 42. Typical signal distortions caused by excessive PMD in a fiber transmission line

Mean DGD and PMD Coefficient

The fastest and most common method for measuring the mean DGD ($\Delta\tau$) of a fiber is to measure the DGD variations as a function of frequency over a wide range of different wavelengths, as explained in more detail below. For long optical fibers with strong polarization mode coupling, the mean DGD scales with the square root of the total fiber length. This means that if a fiber is shortened to only 25 percent of its original length, the mean DGD decreases to only 50 percent of its original value. According to this scaling law, the mean DGD of a fiber is usually characterized by a normalized PMD coefficient, given by

$$(\Delta\tau c) = (\Delta\tau c)/\sqrt{L}$$

This is typically expressed in units of ps/√km where L is the fiber length

PMD-Induced System Outages

Excessive PMD in a fiber optic link generally causes pulse broadening or jitter in the received electrical signal, as shown schematically in Figure 42. As a result, errors may occur in the decoding of the signals. These transmission impairments increase with the magnitude of the instantaneous DGD $\Delta\tau$.

If the mean DGD exceeds certain known limits by a small amount, sometimes it is sufficient for additional margins to be allocated in the system design to cope with signal distortions caused by PMD. Typically, an extra margin of 1 to 3 dB may be added to the optical signal-to-noise ratio (OSNR) at which the system operates reliably. However, no matter how large this margin is, there always exists a finite probability that the randomly fluctuating DGD in the fiber becomes larger than the maximal value at which the system operates error free, in which case the system has to be taken out of service.

The likelihood of such an outage to occur is called the outage probability that may be calculated for any given transmission system based on the mean DGD in the fiber, the allocated OSNR margin, and the sensitivity of the signal to instantaneous DGD. Conversely, given a maximal tolerable outage probability (typically in the range between 10–5 and 10–7), one may calculate the maximal tolerable average DGD in the transmission link, as shown schematically in the Figure 43.

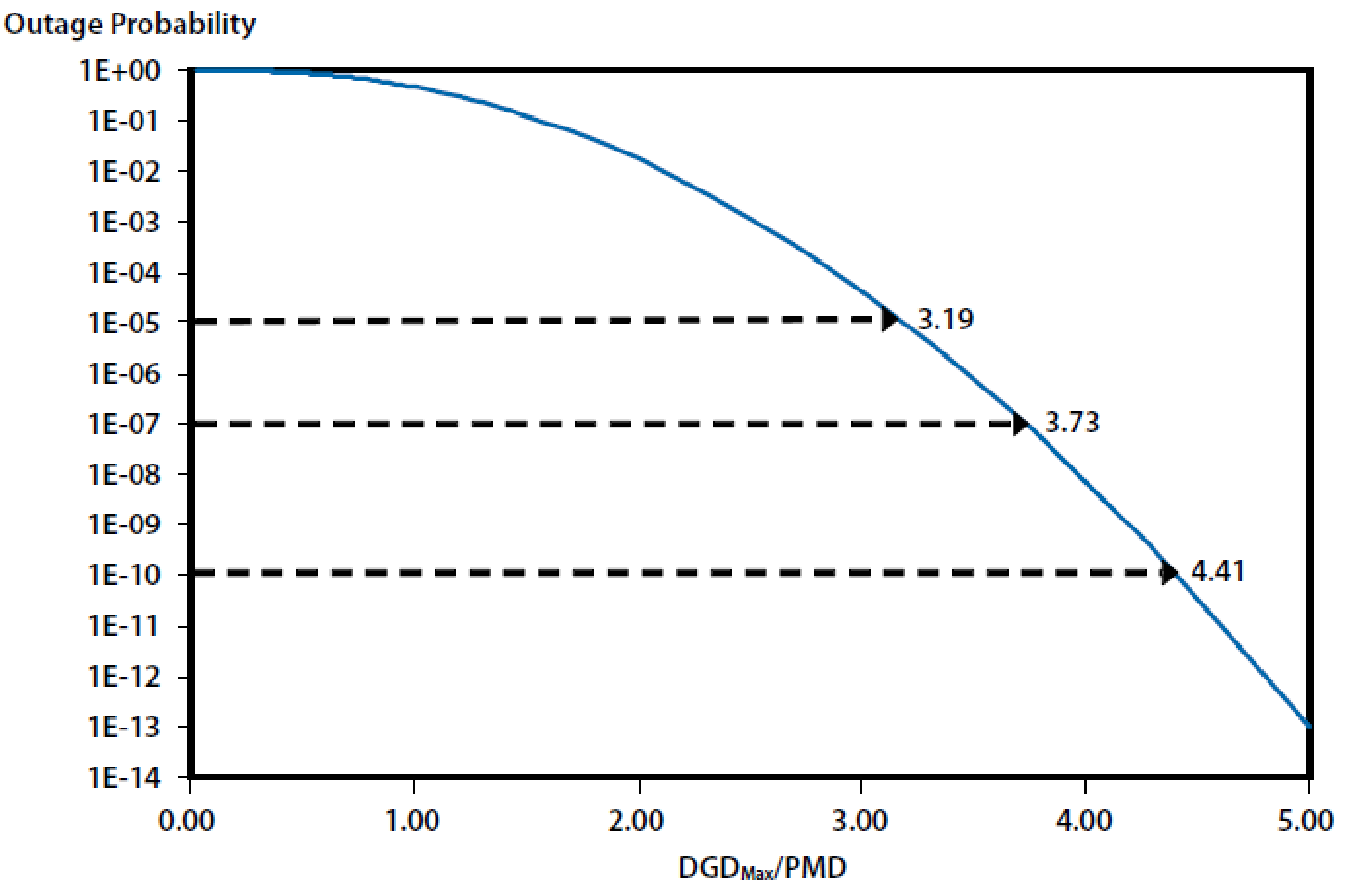


Figure 43. Outrage probability vs DGD_{Max}/PMD

Distance Limitations

Once $(\Delta\tau)$Max is known for a specific modulation format and transmission system,
one may then calculate the maximal allowable PMD coefficient as a function of the
transmission distance *L*.

$$(\Delta\tau_c)_{Max} = (\Delta\tau)_{Max}\sqrt{L}$$

As an example, Table 17 lists the maximal PMD coefficient for NRZ-formatted SONET and SDH
signals that are transmitted over a distance of 400 km for three different bit rates.

Table 17: Maximal mean DGD as a function of bit rate-

Bit Rate (Gb/s)	SDH Format	SONET Format	Bit Period (ps)	Max. Mean DGD (ps)	PMD Coefficient for L = 400 km (ps/$\sqrt{km}$)
2.5	STM-16	OC-48	400	40	<2
10	STM-64	OC-192	100	10	<0.5
40	STM-256	OC-768	25	2.5	<0.125

The maximal allowable PMD coefficient decreases linearly with increasing bit rate. This can be clearly seen in Figure 44, which displays the maximal PMD coefficient as a function of transmission distance for the three different bit rates.

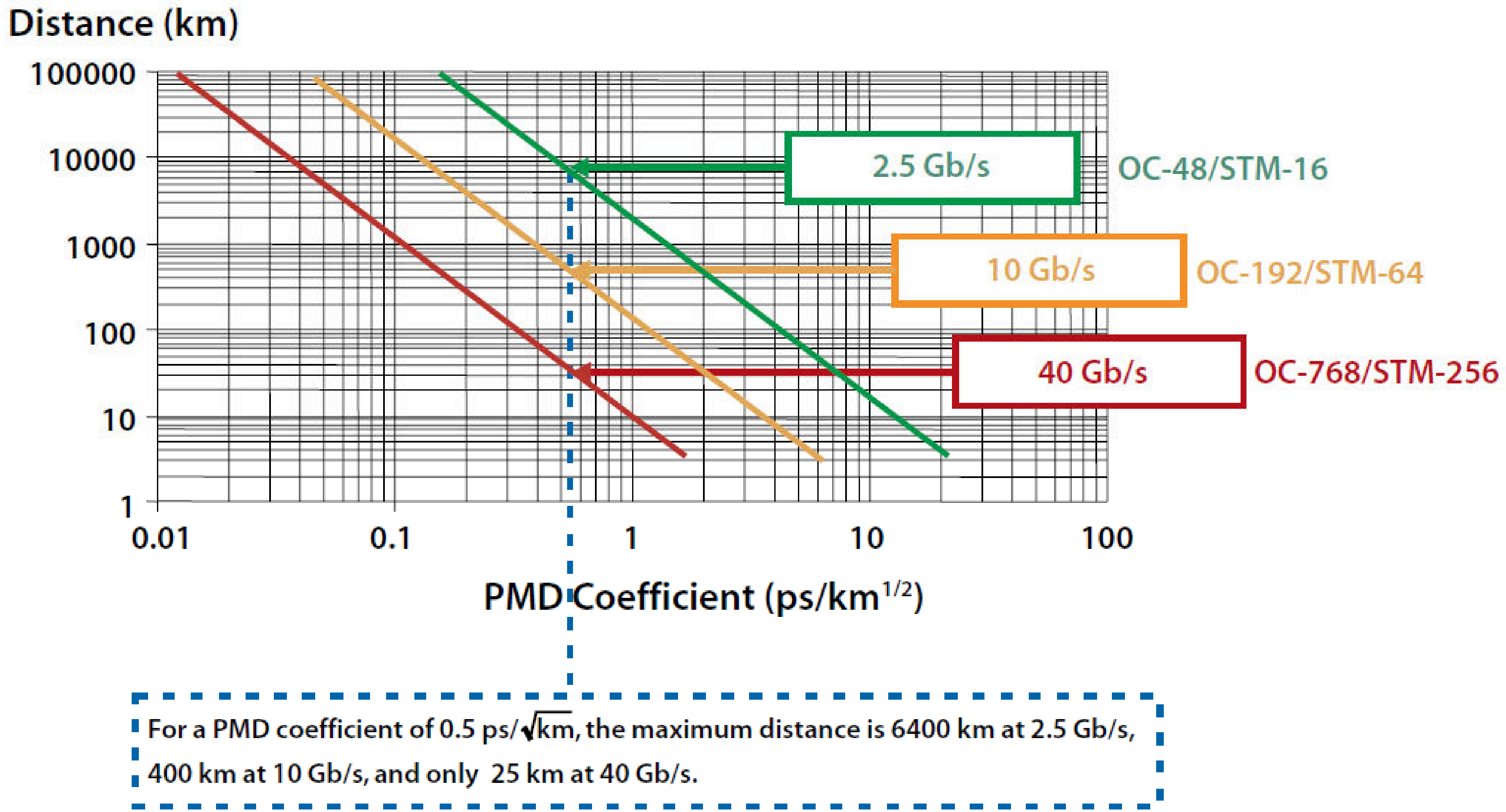


Figure 44. Maximum distant as a function of PMD coefficient and bit rate

Attenuation:-

In fiber optic transmission, several wavelength regions, called windows, are utilized with different windows typically used in different applications. These windows are generally centered about 850, 1310, and 1550 nm. Each of these windows was historically selected due to a technological or performance advantage such as available lasers (850 nm), low chromatic dispersion (1310 nm), or low attenuation (1550 nm). Initially, only a single wavelength channel was used per wavelength window; however, the dense wavelength division multiplexing (DWDM) transmission technology introduced the concept of packing multiple independent wavelength channels into the 1550 nm window. This window (approximately 1530 – 1565 nm) is commonly referred to as the "C-band." To further increase capacity, a second DWDM window from 1565 – 1625 nm has been employed commonly referred to as the L-band.
Table 25 shows the allocation of spectral bands for single-mode fiber systems.

Table 25: DWDM Wavelength Bands

Wavelength Band	Wavelength Range
O-band	1260 – 1360 nm
E-band	1360 – 1460 nm
S-band	1460 – 1530 nm
C-band	1530 – 1565 nm
L-band	1565 – 1625 nm
U-band	1625 – 1675 nm

To enable lower-cost transceivers, coarse wave division multiplexing (CWDM) technology utilizes uncooled semiconductor technology requiring adjacent channels to be spaced by 20 nm. CWDM channels cover the entire single-mode transmission band from 1261 to 1621 nm (defined by ITU-T G.695). Within this wavelength band, some types of fibers possess regions of high optical loss centered about 1383 nm (commonly referred to as the “water-peak”), which limits the suitability of these types of fibers to the use of a subset of CWDM channels.

In long-distance transmission, as well as at a very high bit rate (10, 40, and 100G systems), some systems employ Raman amplification to compensate for the loss in the fiber. In addition, distal pumping of Erbium amplifiers using 1480 nm is currently deployed. These applications require characterization of the fiber loss at the pump wavelengths (such as 1420, 1450, and 1480 nm) to ensure the proper amount of amplification will occur.

As all of these applications make such a broad and varied use of the spectrum of the optical fiber, characterization of the optical loss over the full useful wavelength region is required and characterizing the loss at only a single discrete wavelength is not always sufficient.

Fiber Attenuation vs. Wavelength

The attenuation of optical fiber changes with wavelength and with the general fiber design or fiber type. The main contribution and ultimate limitation to fiber losses is due to Rayleigh scattering, with the loss being inversely proportional to the fourth power of the wavelength. By plotting the attenuation of a fiber versus wavelength, some characteristics of the fiber can be identified. The graph of Figure 59 illustrates an example of the loss versus the wavelength of a typical fiber.

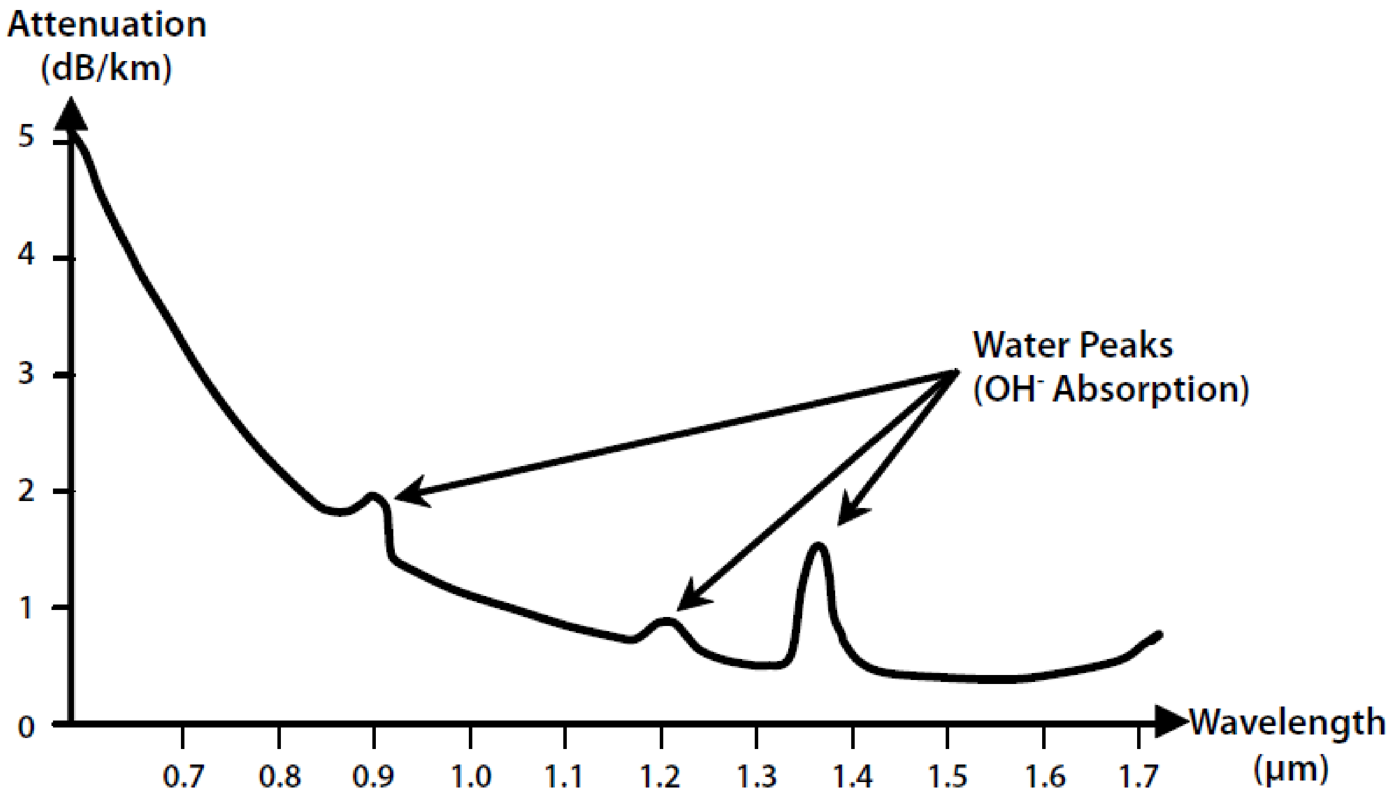
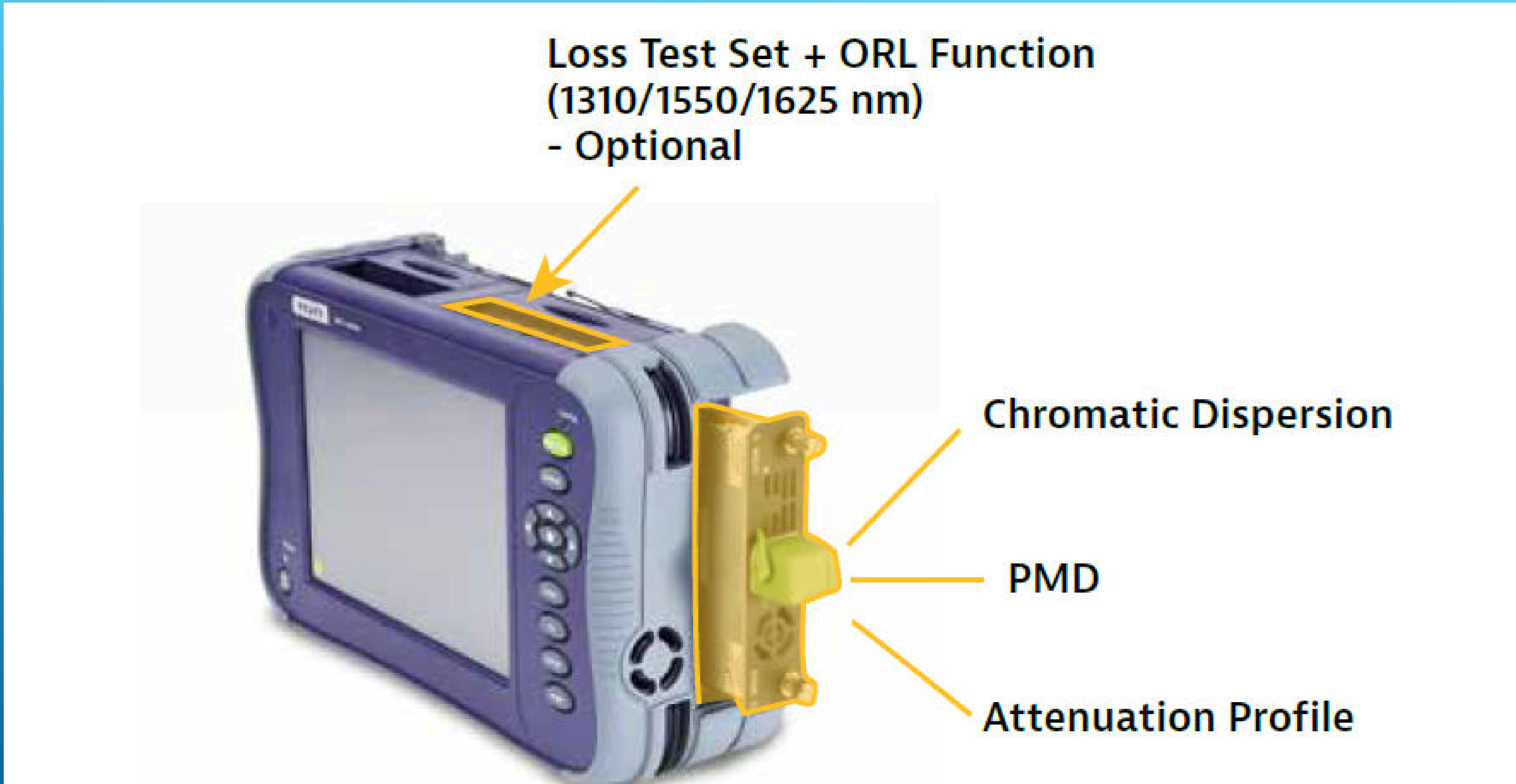
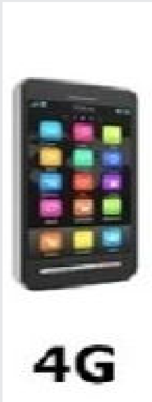


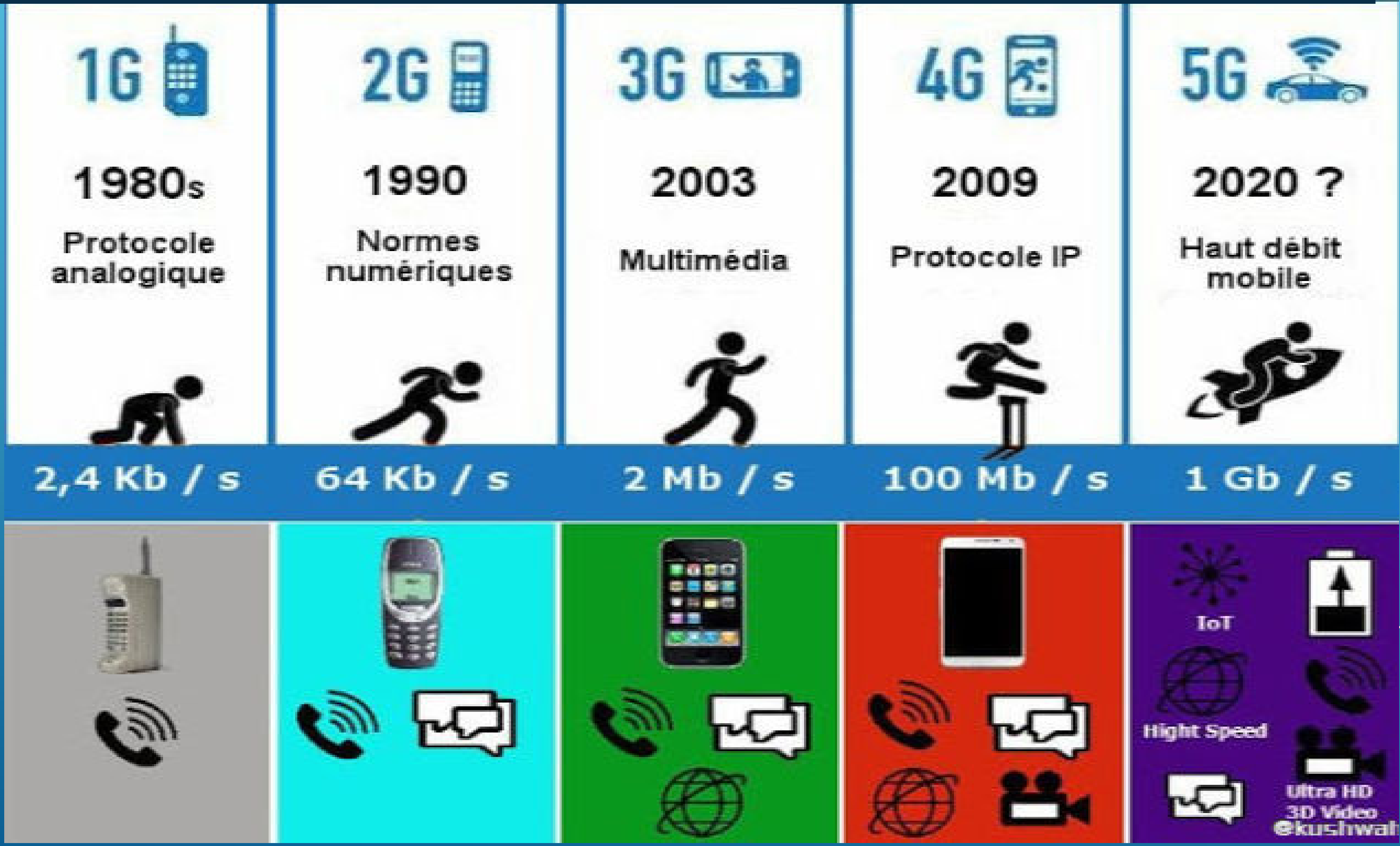
Figure 59. Fiber attenuation as a function of wavelength


Loss Test Set + ORL Function
(1310/1550/1625 nm)
- Optional
Chromatic Dispersion
PMD
Attenuation Profile

Development of optical fiber communication(1G,2G,3G,4G and 5G)generation system:

First Generation 1G	Second Generation 2G	Third Generation 3G	Forth Generation 4G	Fifth Generation 5G
Bit rate=45 mbps	Bit rate=100 mbps	Bit rate=10 Gbps	Bit rate=10 Tbps	Bit rate=40-160 Tbsp
Repeater Spacing= 10 km	Repeater Spacing= 50 km	Repeater Spacing= 100 km	Repeater Spacing= 10,000 km	Repeater Spacing= 35000 km
Wave length= 1.3 nm	Wave length= 1.3 nm	Wave length= 155 nm	Wave length= 1.62 nm	Wave length= 1.5 nm
				

Development and History of optical fiber communication(1G,2G,3G,4G and 5G)generation system:



Source:-

1-History of Fiber Optics Timbercon.
2-Https://www.
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Thanks