

OPTICAL FIBER COMMUNICATION

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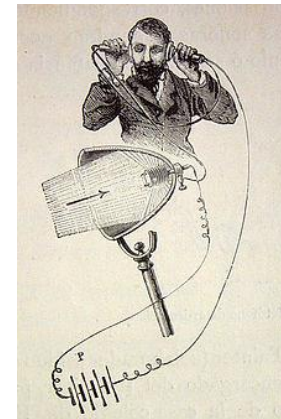
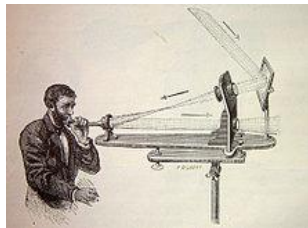
Multinet, Pakistan.

HISTORICAL PERSPECTIVE

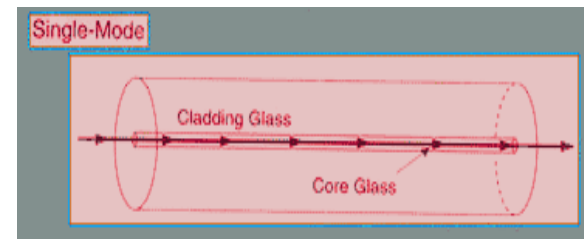
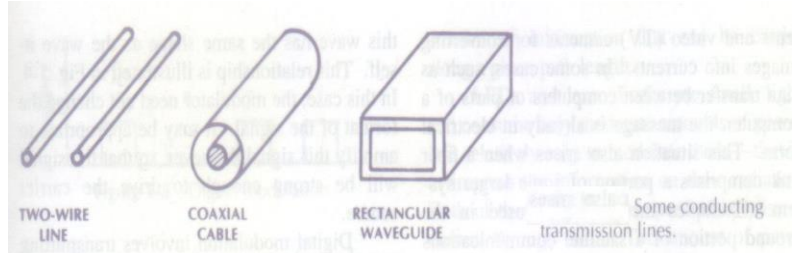
- **Hand signals** from torch



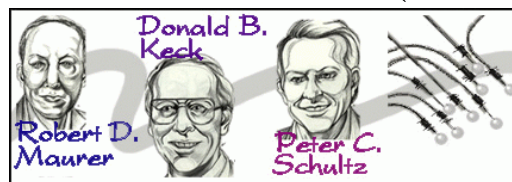
- In 1880, Alexander Graham invented, a light Communication system, the **photophone** to carry conversation.



- A major breakthrough that led to optic communications when **Elias Snitzer** published a theoretical description of single mode fibers the in **1961**. (American Optical)
- Glass produced were too lossy for modern long distance communications.



- Optical Waveguide Fibers were invented by **Robert Maurer**, **Donald Keck** and **Peter Schultz** in **1970**(Corning Glass)



ADVANTAGES OF FIBER-WAVEGUIDES AND OTHER GUIDED CHANNELS

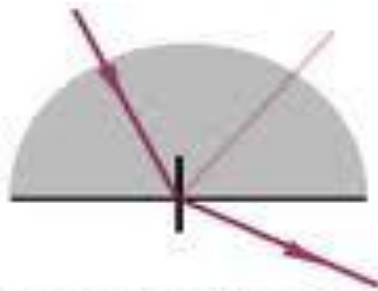
- Privacy (no spoofing)
- No weather dependence (corrosion)
- Thinner (<diameter than fiber wire)
- Higher Carrying Capacity(40G)
- Less Signal Degradation & Low power (no int. with other fiber)
- Non-Flammable (no elec, heat issues)
- Light Weight
- Repeaters can be spaced 75 miles apart

DISADVANTAGES

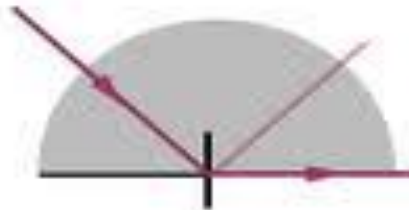
- The cost of interfacing equipment necessary to convert electrical signals to optical signals. (optical transmitters, receivers)
- Splicing fiber optic cable is also more difficult.
- Expensive over short distance

PRINCIPLE OF PROPAGATION

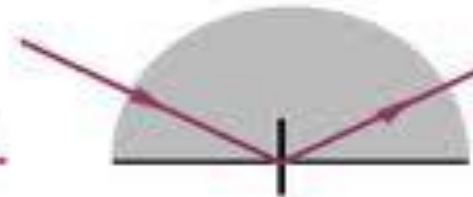
- When we transfer light from high R.I to lower R.I region with angle equal or less than the critical angle reflection/reflection take place
- It is also called Limiting angle of material



The angle of incidence is **less** than the critical angle.
Ray is **refracted** with a very small reflection.

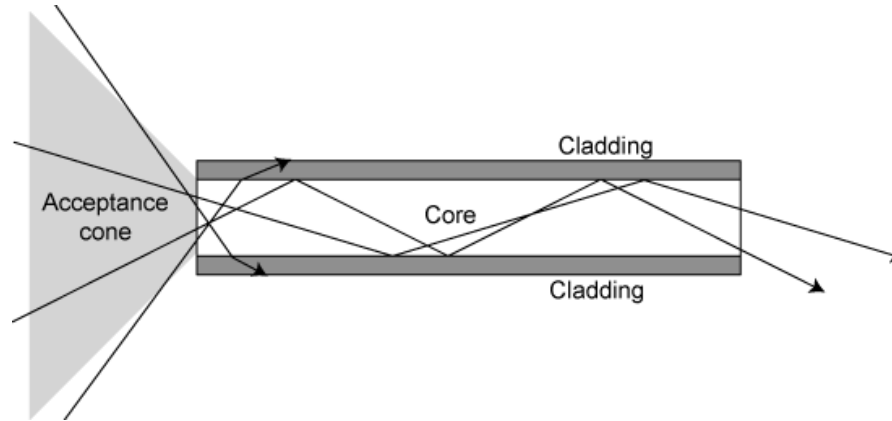


The angle of incidence is **equal** to the critical angle.
Ray **emerges** along the edge of the block.



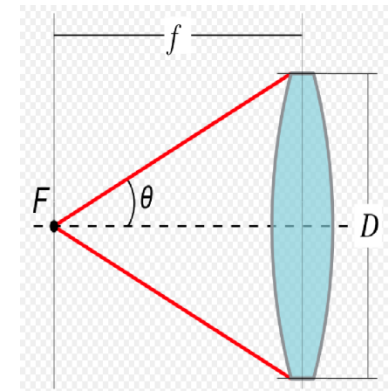
The angle of incidence is **greater** than the critical angle.
The ray is **totally internally reflected**.

ACCEPTANCE ANGLE /CONE HALF-ANGLE



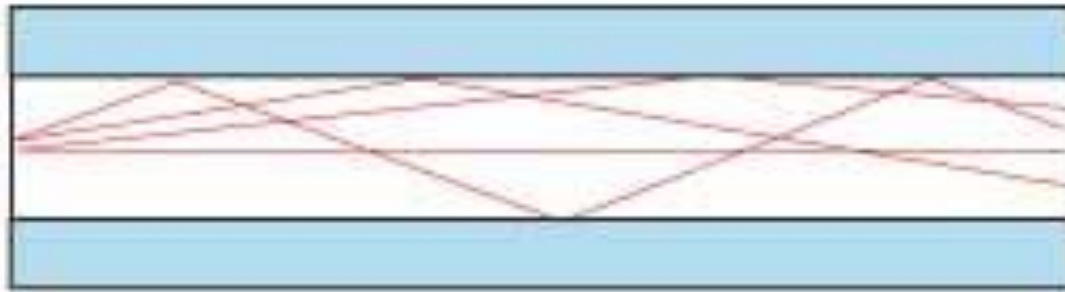
The maximum angle in which external light rays may strike the air/glass interface and still propagate down the fiber.

Numerical Aperture (NA) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light

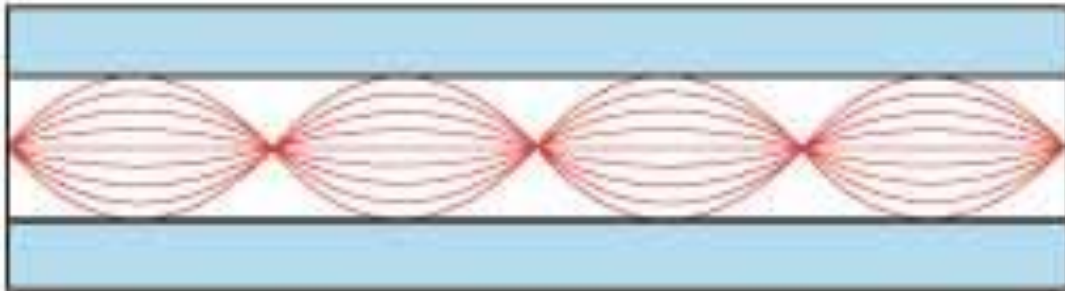


TYPES OF FIBER

- In terms of Light propagation
 - **Single Mode** (transmit one signal per fiber, core < 10 micrometers, Long distance, Laser transmission, interfacing equip. expensive)
 - **Multi Mode**(transmit many signals per fiber, core ≥ 50 micrometres, short dist communication, led, equip less exp)
- In terms of Refractive index
 - **Step Index**(Uniform core index of core & cladding)
 - **Graded Index**(the index of refraction in the core decreases continuously between the axis and the cladding)



Multimode, Step-index



Multimode, Graded Index



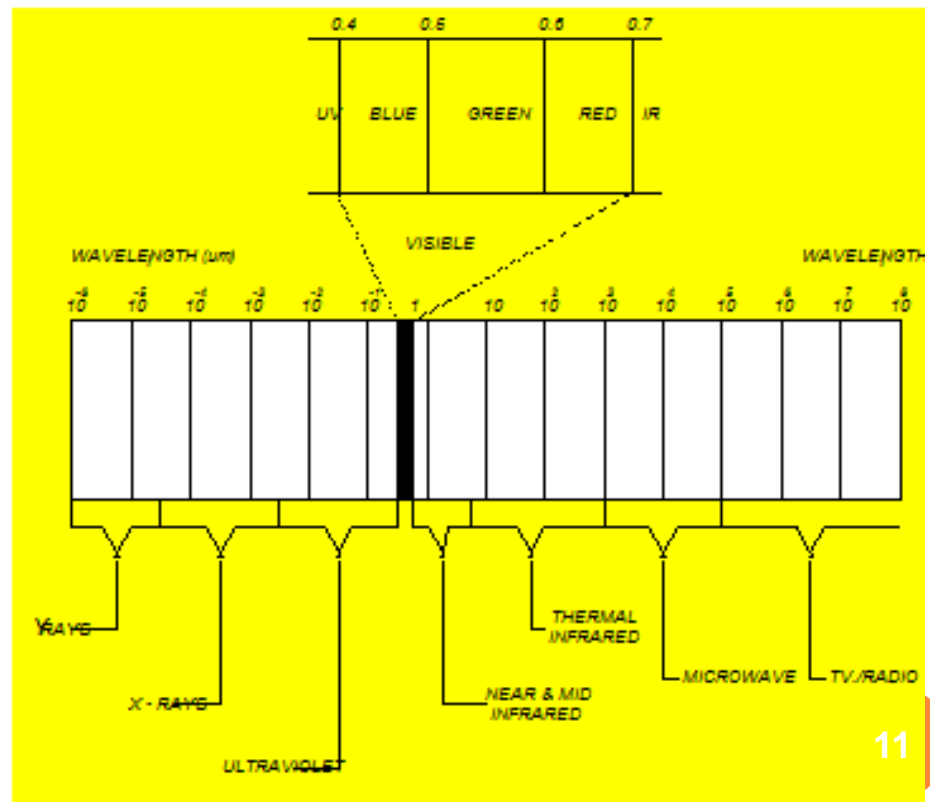
Singlemode

NATURE OF LIGHT

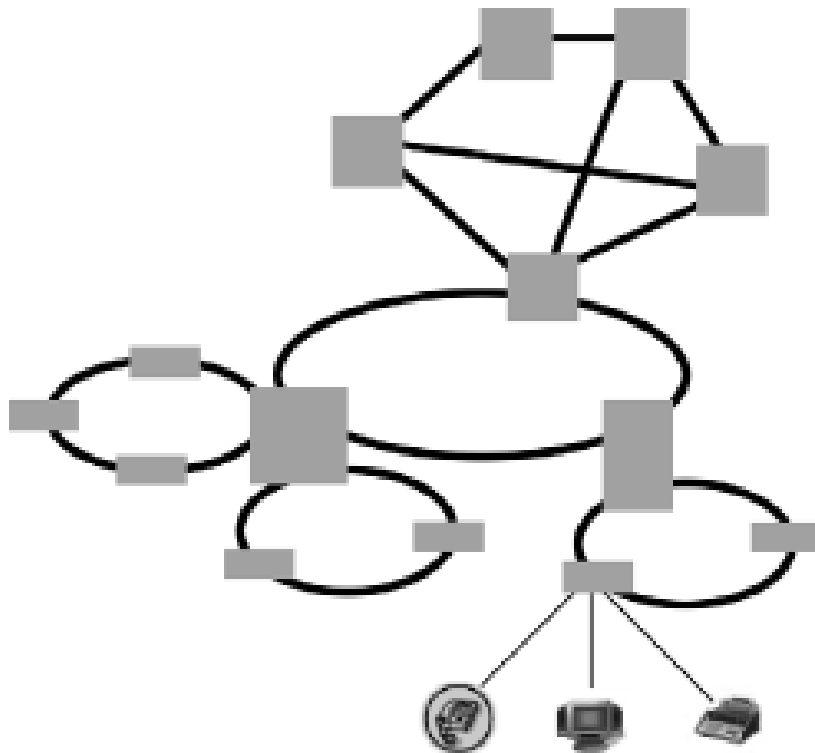
- Sometimes light behaves as a wave.
- Sometimes light behaves as a particle.
- **Wave nature of light:**
- Light is an electromagnetic wave having a very high oscillation frequency and a very short wavelength.

Frequencies in the **Infrared**, **visible** and **ultraviolet** portions of the spectrum are referred to as **optic** (as well as *light*) because of same analysis, techniques and devices applicable to these ranges.

- **Visible** wave lengths extend from **0.4 μm (distinguished as blue) to 0.7 μm** (which appear as red).
- **Silica glass fibers** are **not** very good transmitters of light in the **visible** region. They attenuate the waves to such an extent that only short transmission links are practical.
- **Losses** in the **ultraviolet** are even **greater**.
- In the **Infrared**, however, there are **three regions** in which glass is relatively efficient.
- These three regions occur at wavelengths close to **0.85, 1.3 and 1.55 μm** and are often referred to as the **three fiber “transmission windows”**.



TOPOLOGY



Long Haul

- 100s–1000s km
- Mesh

Metro (Interoffice)

- 10s of km
- Rings

Access

- A Few km
- Hubbed Rings, PONs

Users

OXC (LONG HAUL); ADM(METRO); PON/CRUB SW(ACCESS)

ITU-T STANDARDS

- Categorizes fiber on the basis of Dispersion Windows, Capacity & Distance
- Zero dispersion-Shifted Fiber **ITU-T(G.652)**
- Dispersion-Shifter Fiber **ITU-T G.653**
- Zero Dispersion Shifted Fiber (cut-off wavelength shifted) **ITU-TG.654**
- Non-zero dispersion-shifted single-mode **ITU-T G.655**

NON-DISPERSION SHIFTED FIBER G.652

- Transmission at zero-dispersion wavelength
- Created in 1984
- Standard SMF deployed for short distances(60km)
- Zero Dispersion wavelength lies between 1301-1322nm
- DWDM use in the 1550-nm region (with dispersion compensators).

- **ITU G.652** Covers *single-mode* NDSF (non-dispersion-shifted fiber). This fiber is in most of the cable that was installed in the 1980s. Optimized in the 1,310-nm range. Low water peak fiber has been specifically processed to reduce the water peak at 1400 nm to allow use in that range. There are 4 subcategories:

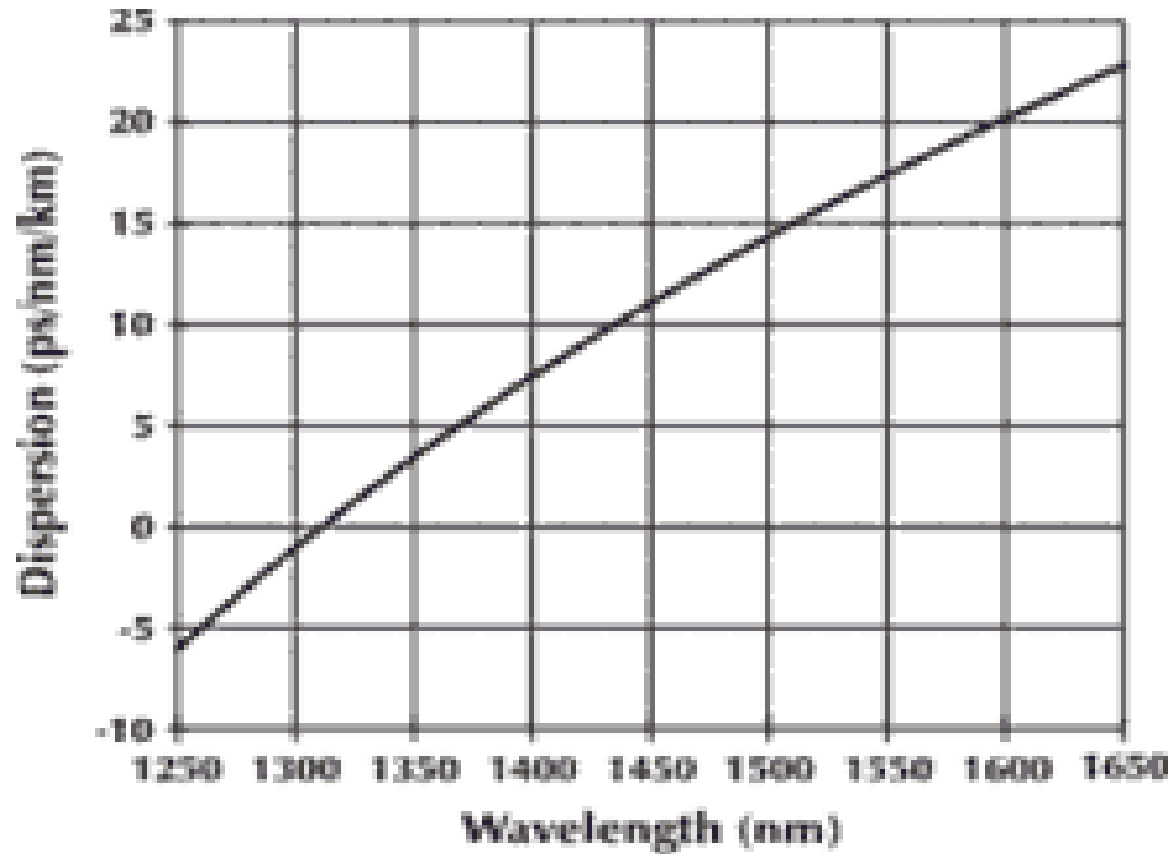
- G.652A :
Atten $\leq 0.5 / 0.4$ at 1310 / 1550nm
Macrobend ≤ 0.5 dB at 1550nm
PMD ≤ 0.5 ps/sqrt(km)

G.652B :
Atten $\leq 0.4 / 0.35 / 0.4$ at 1310 / 1550 / 1625nm
Macrobend ≤ 0.5 dB at **1625**nm
PMD ≤ 0.2 ps/sqrt(km)

G.652C :
Atten ≤ 0.4 from 1310 to 1625nm, ≤ 0.3 at 1550nm, and at 1383nm, it must be \leq that specified at 1310nm, after hydrogen aging.
Macrobend ≤ 0.5 dB at **1625**nm
PMD ≤ 0.5 ps/sqrt(km)

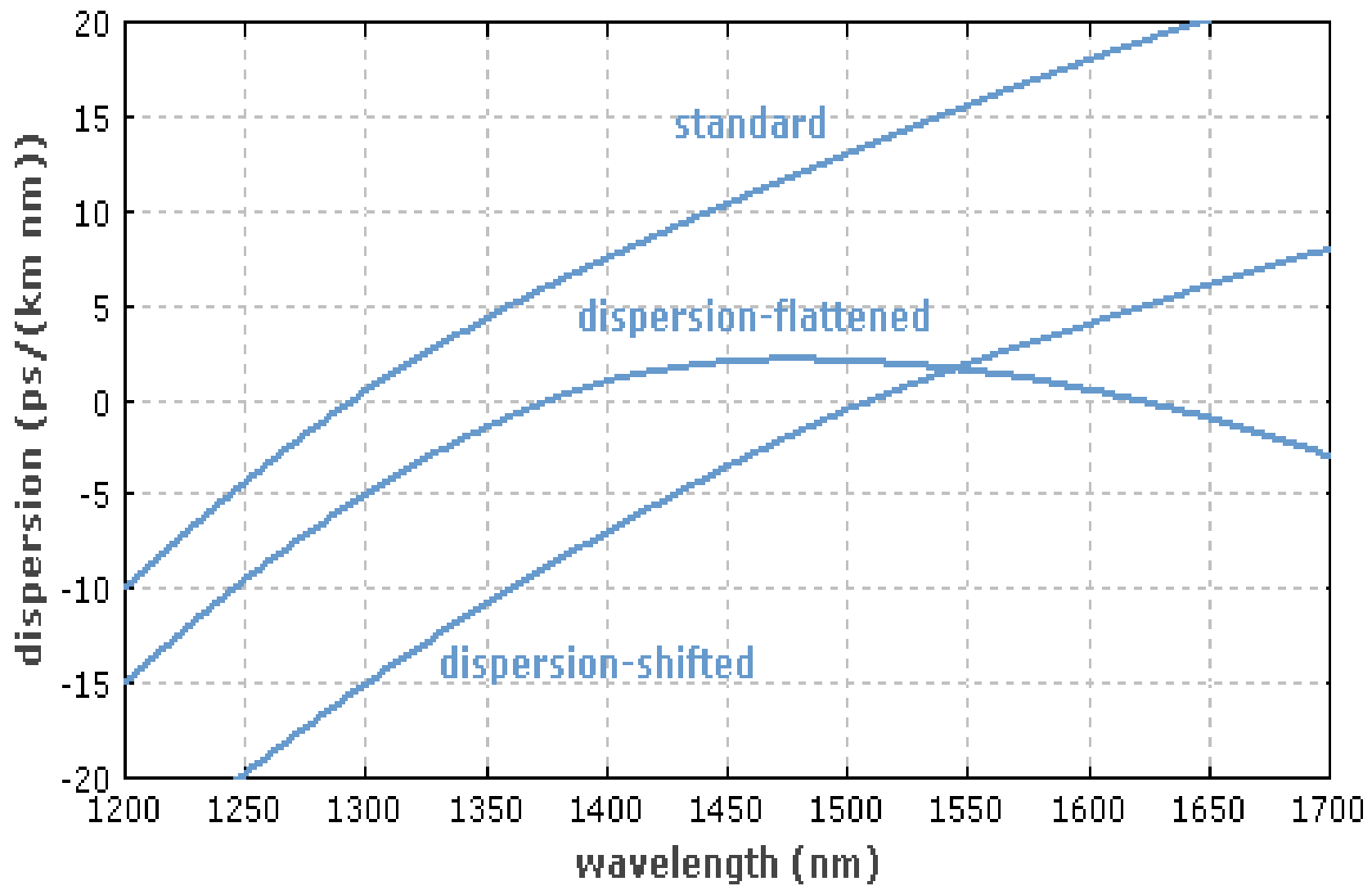
G.652D (covers all above):
Atten ≤ 0.4 from 1310 to 1625nm, ≤ 0.3 at 1550nm, and at 1383nm, it must be \leq that specified at 1310nm, after hydrogen aging.
Macrobend ≤ 0.5 dB at **1625**nm
PMD ≤ 0.2 ps/sqrt(km)

SMF DISPERSION



DISPERSION-SHIFTER FIBER G.653

- Shifting from 1310 to 1550 & 1600nm (to increase data rates)
- Core-Clad index profile tailored to shift the zero-dispersion wavelength from the natural 1300nm to the minimum-loss window at 1550 nm
- Fiber losses are lower in 1550nm, and erbium-doped fiber amplifiers (EDFAs) are available for this region (whereas 1.3- μ m amplifiers do not reach comparable performance)
- In WDM systems, dispersion-shifted fibers can suffer from four-wave mixing
- Optimized for Max wavelengths up to 1625 nm and Min wavelengths down to 1460 nm
- Support (CWDM)



ZERO DISPERSION SHIFTED FIBER (CUT-OFF WAVELENGTH SHIFTED) ITU-T G.654

- G.652(**Zero Dispersion Shifted Fiber**) cut-off shifted and loss minimized at a wavelength around 1550 nm and which is optimized for use in the 1500-1600 nm region.

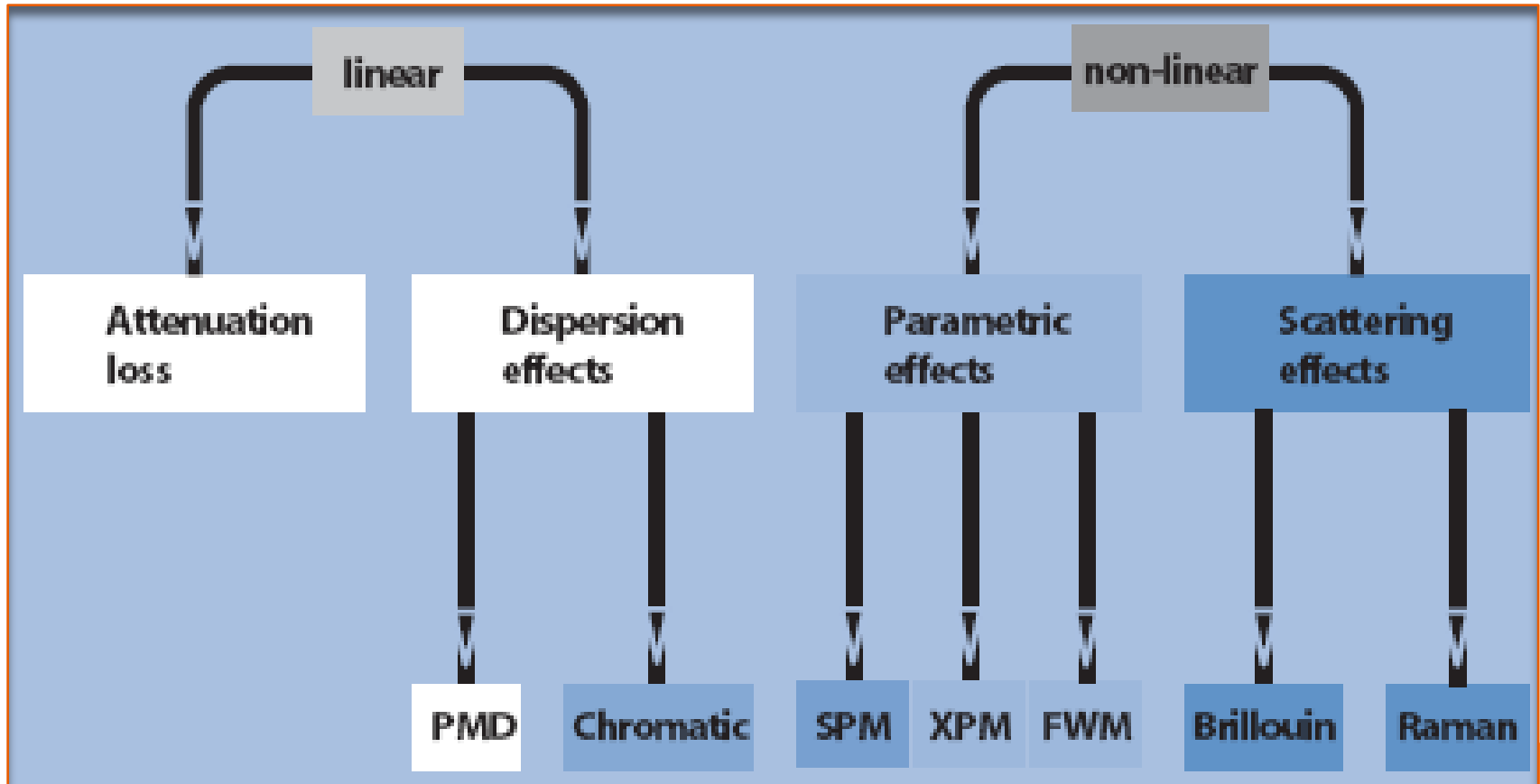
Main features

- Its longer cut-off wavelength and
- lower attenuation coefficient at 1550 nm compared to other single-mode optical fiber
- Low loss **Cut-off Shifted Fiber (CSF)** can be used for long distance digital transmission applications
- In 1988 standardized for the purpose of **submarine** cable system

NONZERO DISPERSION SHIFTED FIBER (ITU-T G.655)

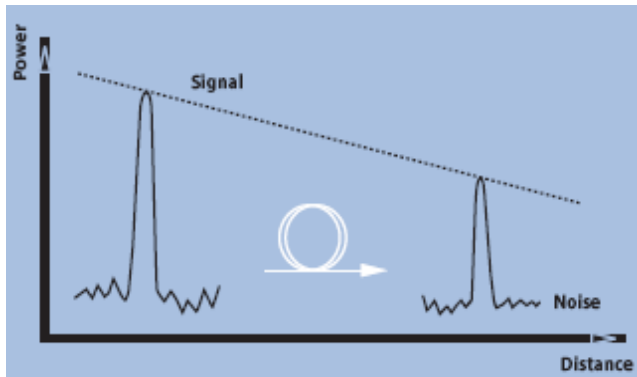
- For long Distance Communication
- Chromatic dispersion coefficient greater than some non-zero value throughout the wavelength range from 1530 nm to 1565 nm
- It Reduces the growth of non-linear effects at high data rates (DWDM)
- Non-Linear issues when operating in zero dispersion window for DWDM

LIMITING FACTORS

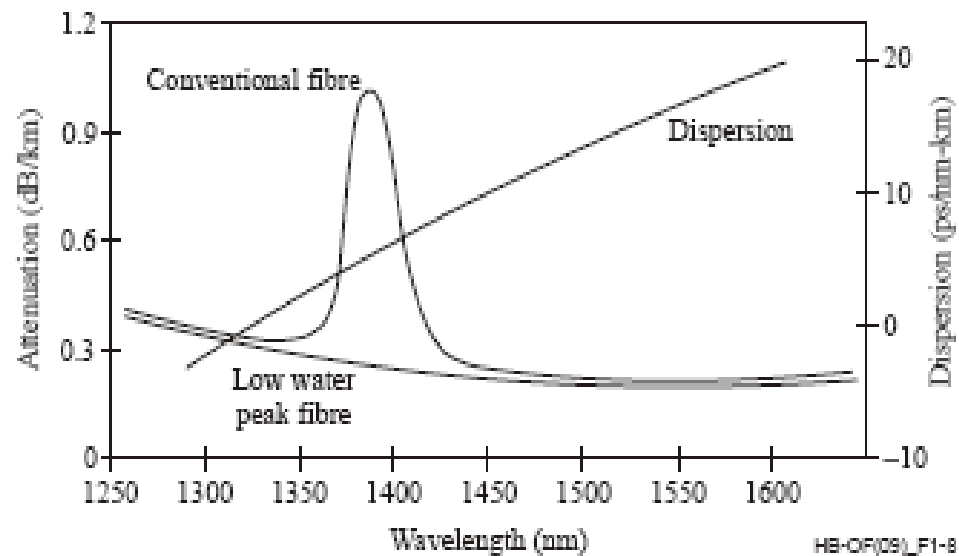


LINEAR FACTORS

- **Attenuation:** Loss of signal power due to material absorption (due to natural impurities in glass), later converted into vibrational energy and results in power loss



- Micro bending (pressure)
- Macro bending (bend on fiber)
- Residual Water Vapor (OH) in silica



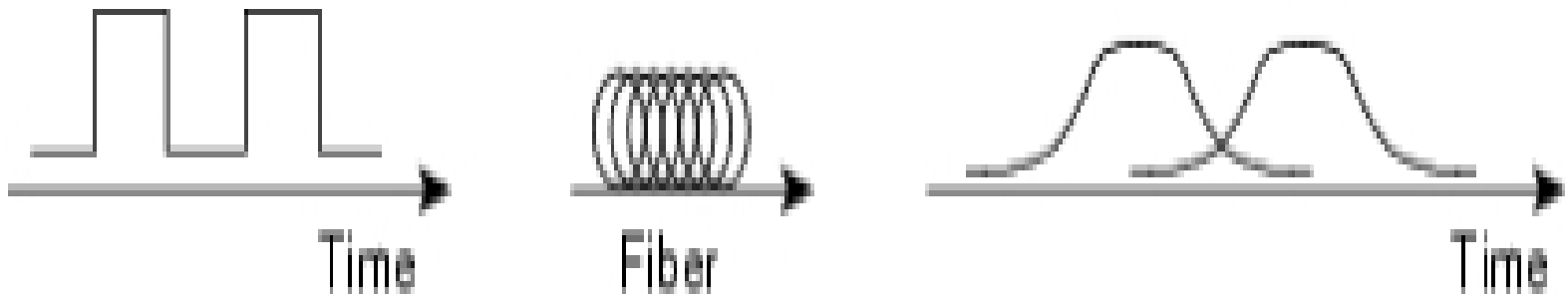
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G.652.B v/s G.652.D

LINEAR FACTORS CONT..

○ Dispersion:

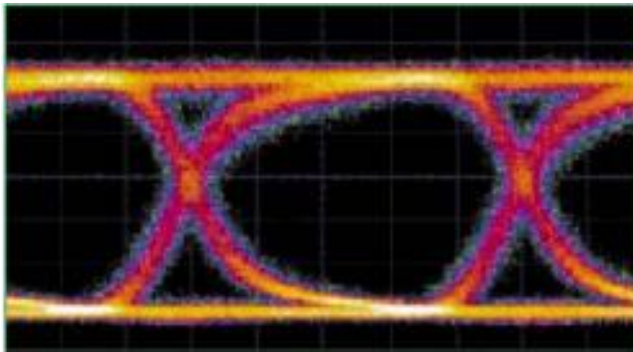
- Dispersion is the spreading of light pulses as they travel down optical fiber.
- Dispersion results in distortion of the signal which limits the bandwidth of the fiber.



LINEAR FACTORS CONT..

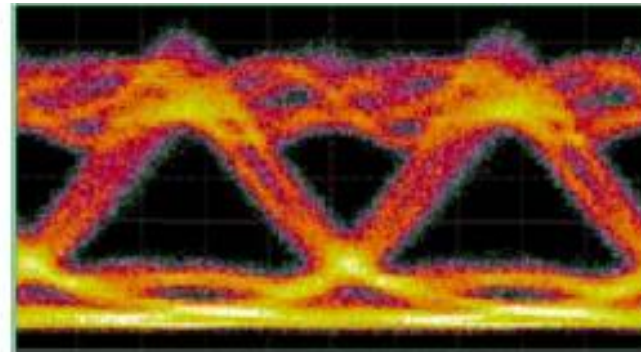
○ Chromatic dispersion:

- Occurs because different wavelengths propagate at different speeds.
- The effect of chromatic dispersion increases as the **square** of the **bit rate**
- The consequence of the chromatic dispersion is a **broadening** of the transmitted impulses



Pulse stream without chromatic dispersion

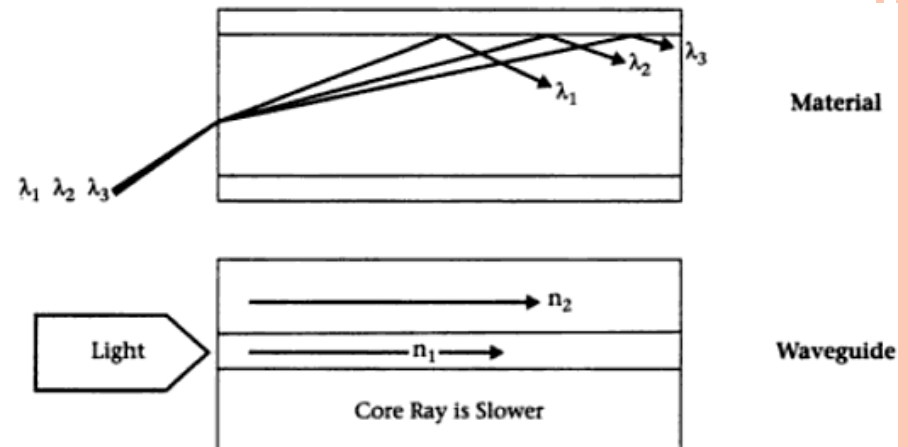
HB-OFDB_LF1-5



Pulse stream with chromatic dispersion

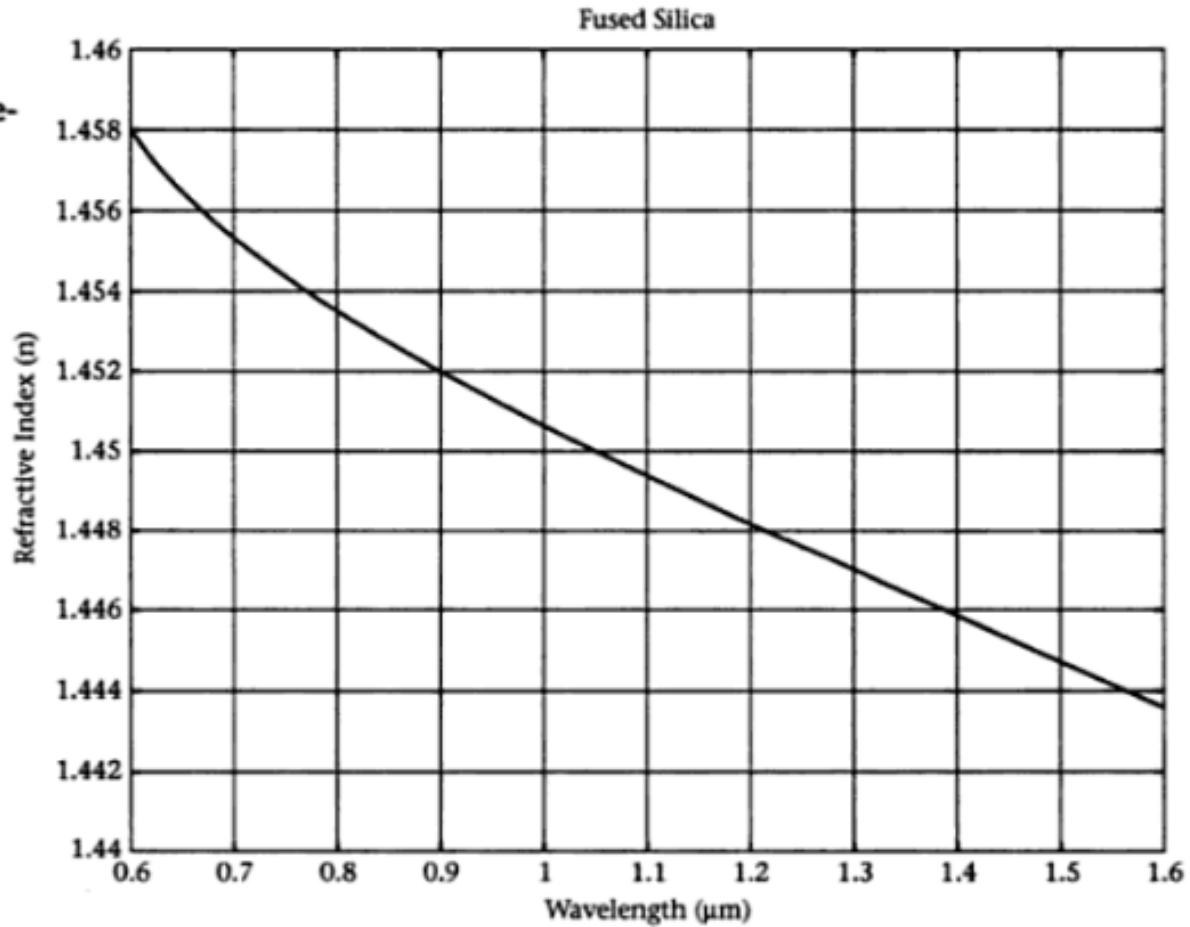
LINEAR FACTORS CONT..

- Material dispersion occurs when wavelengths travel at different speeds through the material & arriving at different time at receiver
- Waveguide dispersion, occurs because of the different refractive indices of the core and the cladding of fiber. The effective refractive index varies with wavelength



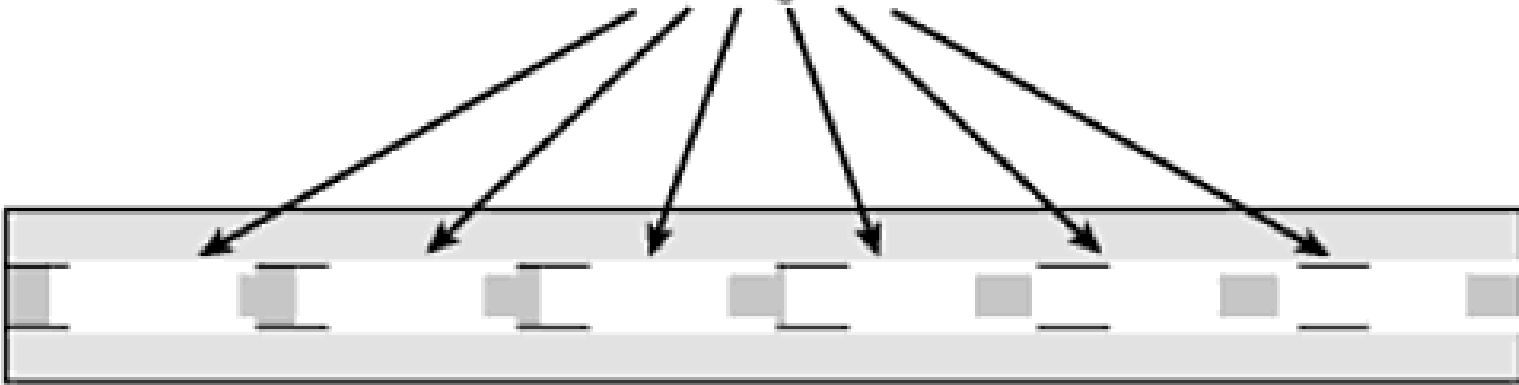
MATERIAL DISPERSION

Refractive index versus wavelength for typical silica glass.



WAVEGUIDE DISPERSION

Light in cladding moves faster than light in core.

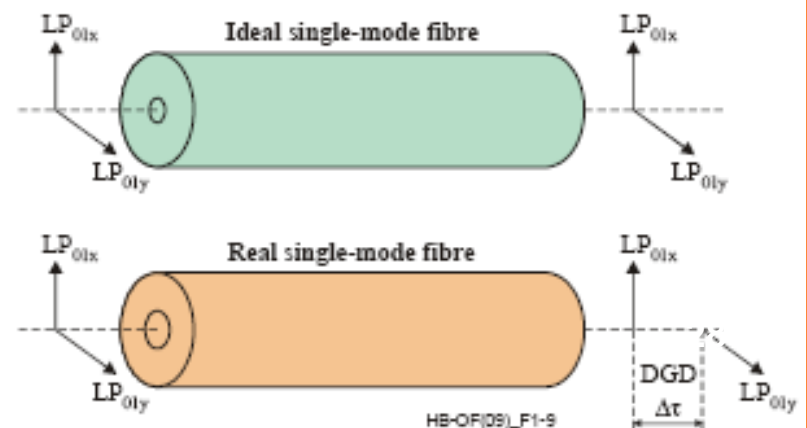


LINEAR FACTORS CONT..

- **Polarization Mode Dispersion**

- SMF support two perpendicular polarizations of the original transmitted signal
- If symmetry is perfectly round and free from all stresses, both polarization modes would propagate at exactly the same speed, resulting in zero PMD. called (DGD)

- Pulses spreading
- Leads to bit errors

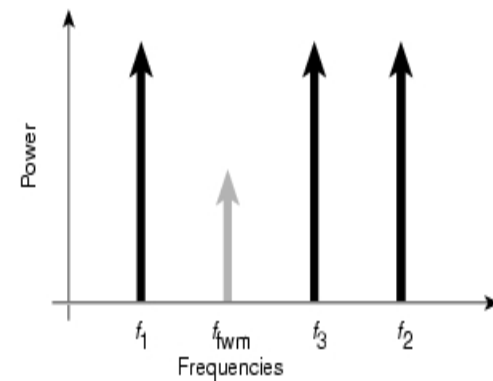


NON-LINEAR FACTORS

- Demand for capacity and high data rates increases which require high power & increasing no. of channels resulting in Non-linear effects
- **Categories**
- Refractive Index/Parametric (Phase Modulation)
- Scattering (Power Loss)

NON-LINEAR CONT.. (FWM)

- Four-wave mixing is caused by the nonlinear nature of the refractive index
- Nonlinear interactions among DWDM channels creates sidebands(Ghost Channels) that can cause interchannel interference
- Increases with the length of the fiber
- Small amount of chromatic dispersion can be used to mitigate four-wave mixing.(NZ-DSF) **(1550nm)**
- CD leads to different group velocities and reduction of FWM due to dissimilar channel spacing.

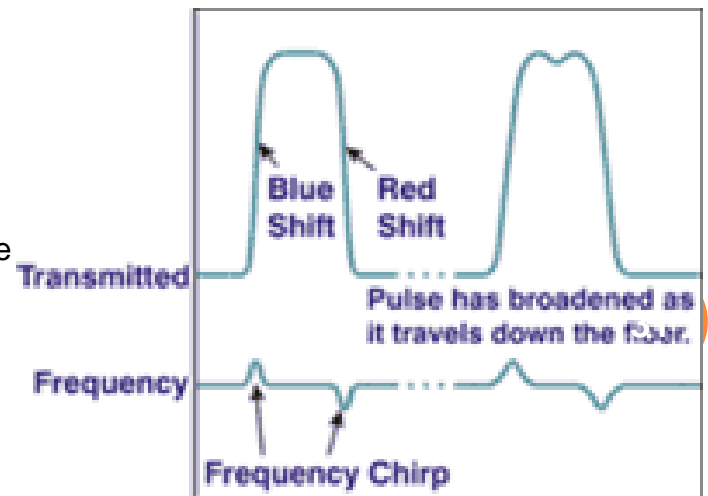


NON-LINEAR CONT.. (SPM)

- At high signal intensities the signal modulate itself and experience a phase change, this results in pulse spreading
- At high intensities it interacts with CD to change the rate at which the pulse broadens
- Opposite to +ve CD (inc. freq. w.r.t time)
- The leading edge causes the R.I of the fiber to rise, resulting in a blue shift.
- The falling edge causes the R.I of the fiber fall causing a red shift

Reduction By,

- Lowering the optical power at the expense of increased noise
- Dispersion management, because dispersion can partly mitigate the



NON-LINEAR CONT.. (XPM)

- Cross-phase modulation (XPM) is very similar to SPM except that it involves two pulses of light
- In XPM, two pulses travel down the fiber, each changing the refractive index as the optical power varies.
- If these two pulses happen to overlap, they will introduce distortion into the other pulses through XPM
- This distortion leads to inter modulation(mixing) of two pulses
- Increasing the fiber effective area will reduce XPM and all other fiber nonlinearities(more lambda separation between channels)

NON-LINEAR CONT.. SCATTERING

- Scattering of light in all directions by minute vibrations in atomic structure(material density, in homogeneity, manufacture fault)
- Stimulated Brillouin Scattering (SBS)
- Stimulated Rayman Scattering (SRS)

(SBS)

- (SBS) sets an upper limit on the amount of optical power that can be usefully launched into an optical fiber.
- When the SBS threshold for optical power is exceeded, a significant amount of the transmitted light is redirected back to the transmitters.
- In addition to causing a saturation of optical power in the receiver, problems also arise with back reflection in the optical signal, and noise that degrades the BER performance.

(SRS)

- Threshold is close to 1 Watt, nearly a thousand times higher than SBS
- Transfer of power from short wavelength to longer wavelength
- This effect is maximum for a wavelength difference between the 2 signals of about 100nm(13.2tz)

