Fundamentals of Optical Communications

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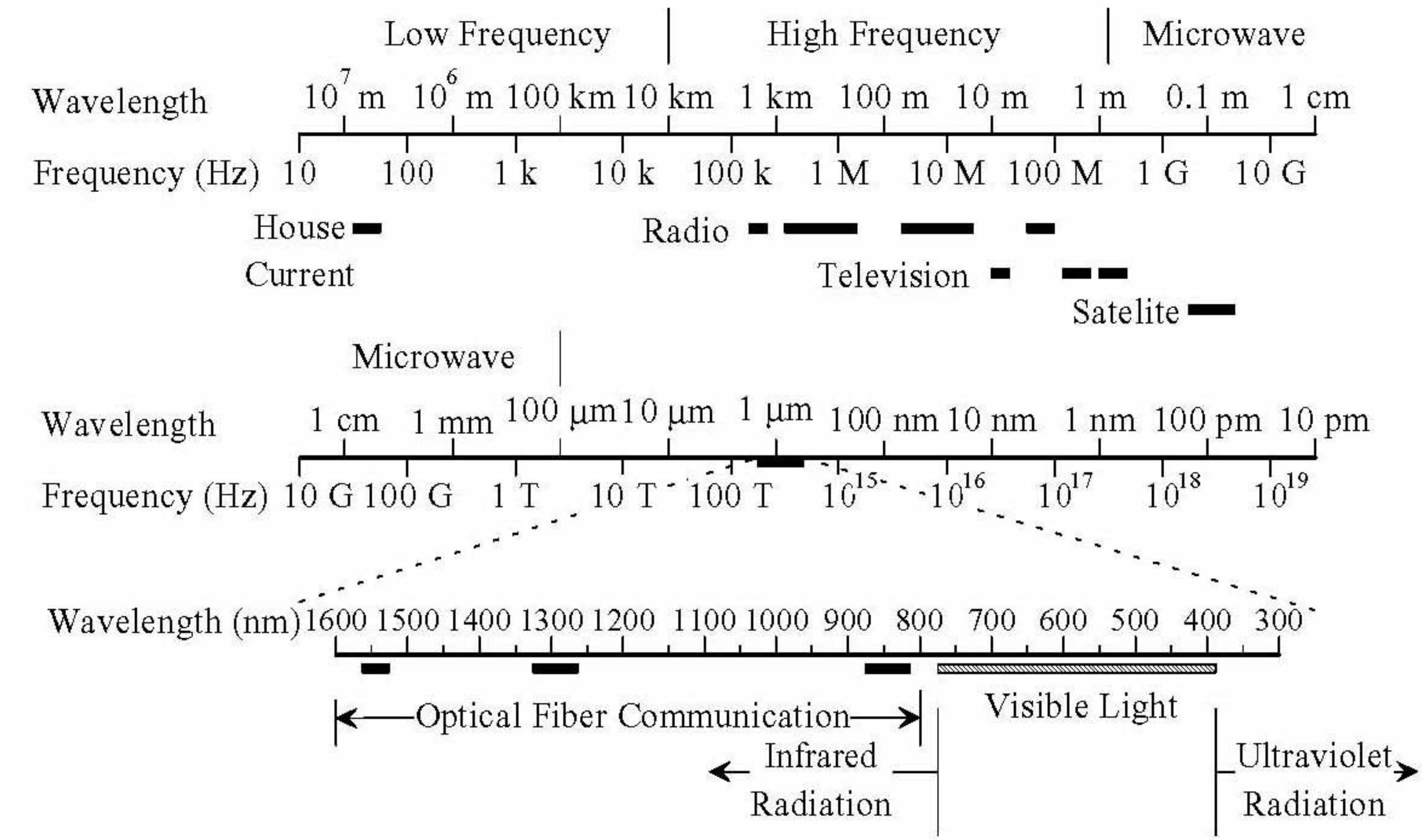
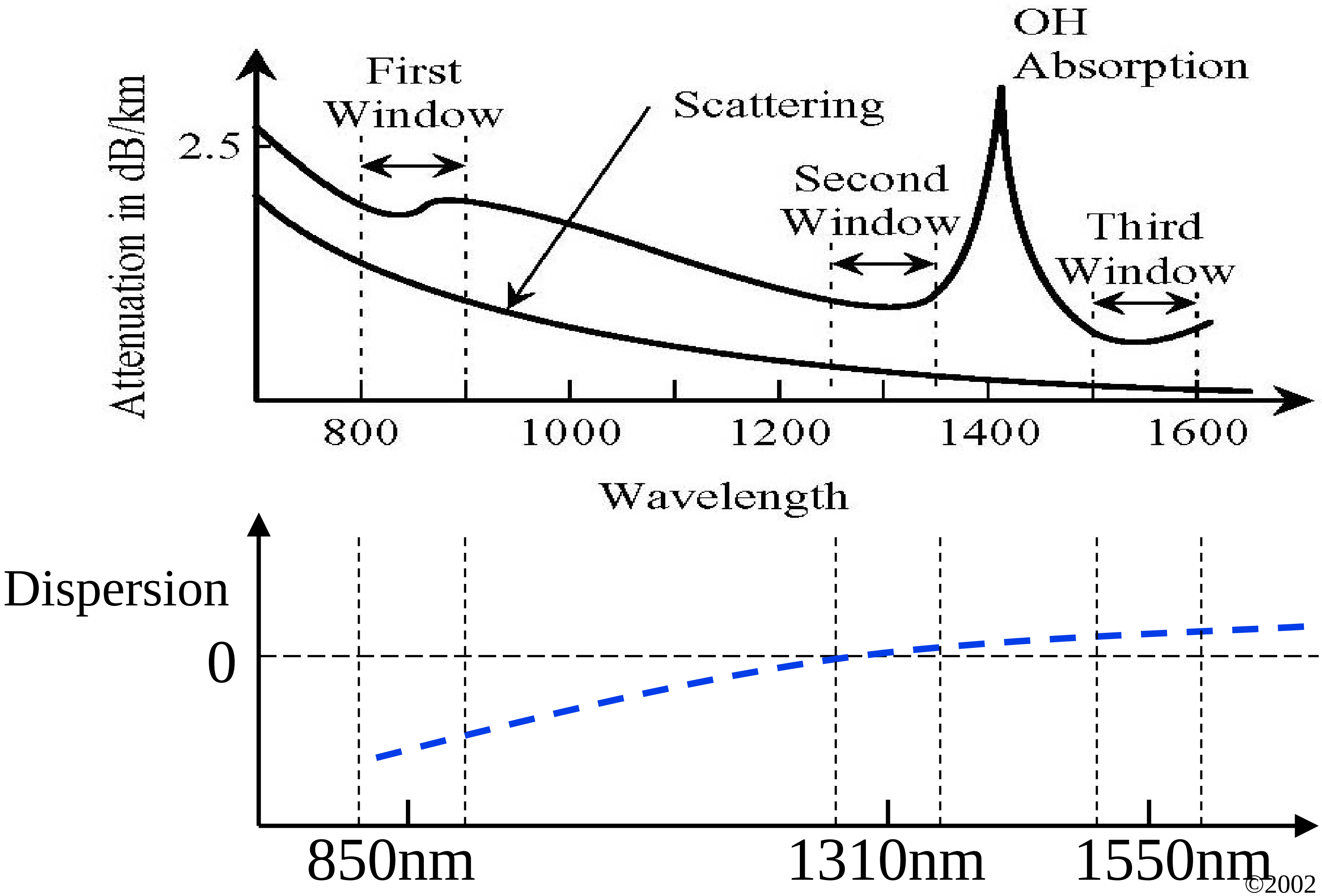
- Characteristics of Light
- Optical components
- Fibers
- Sources
- Receivers,
- Switches

Electromagnetic Spectrum

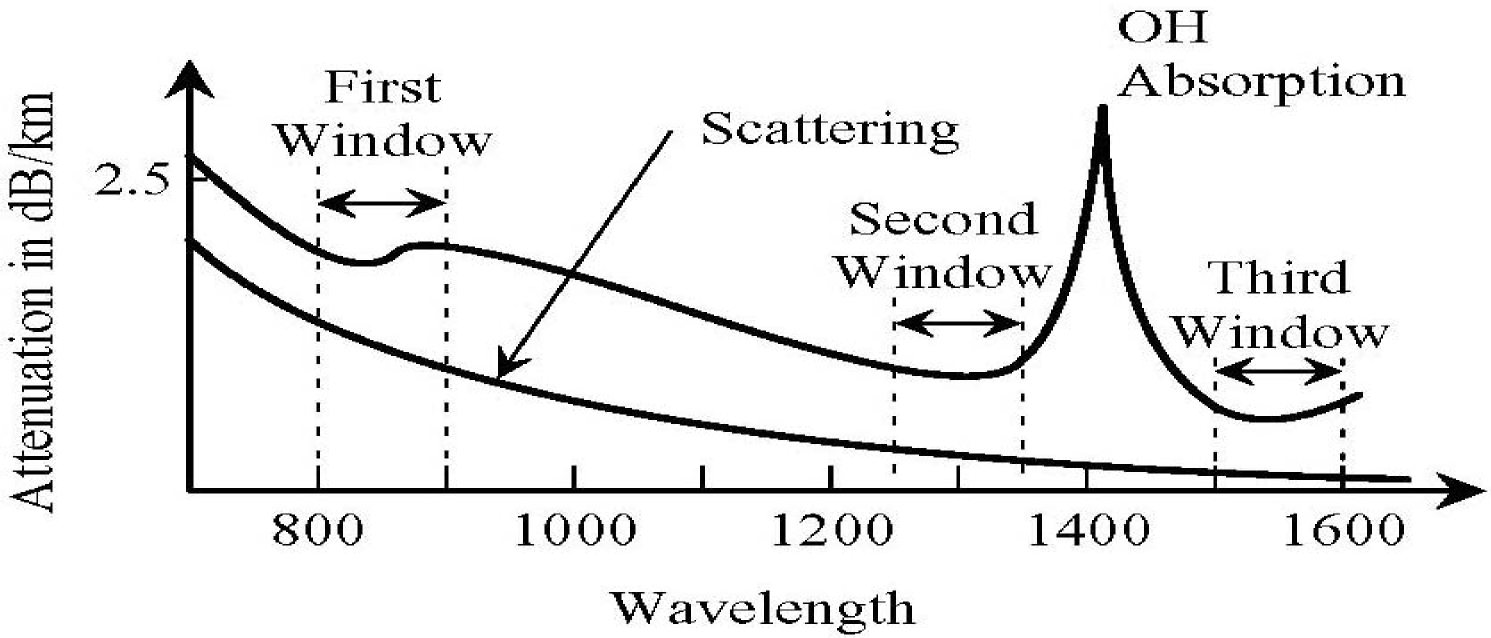


- Infrared light is used for optical communication

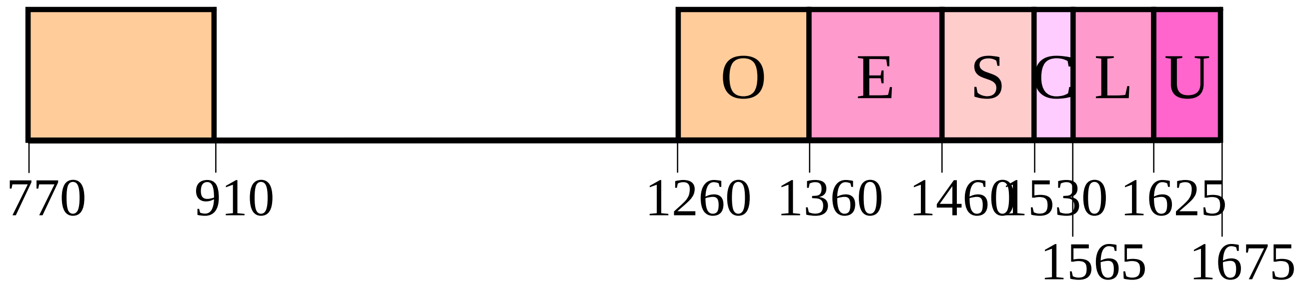
Attenuation and Dispersion



Wavebands

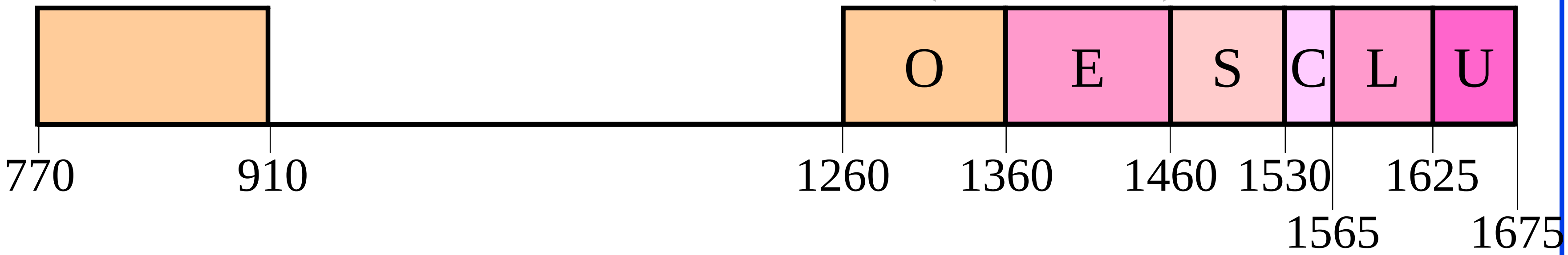


Attenuation in dB/km
2.5
First Window
Scattering
Second Window
OH Absorption
Third Window
800
1000
1200
1400
1600
Wavelength



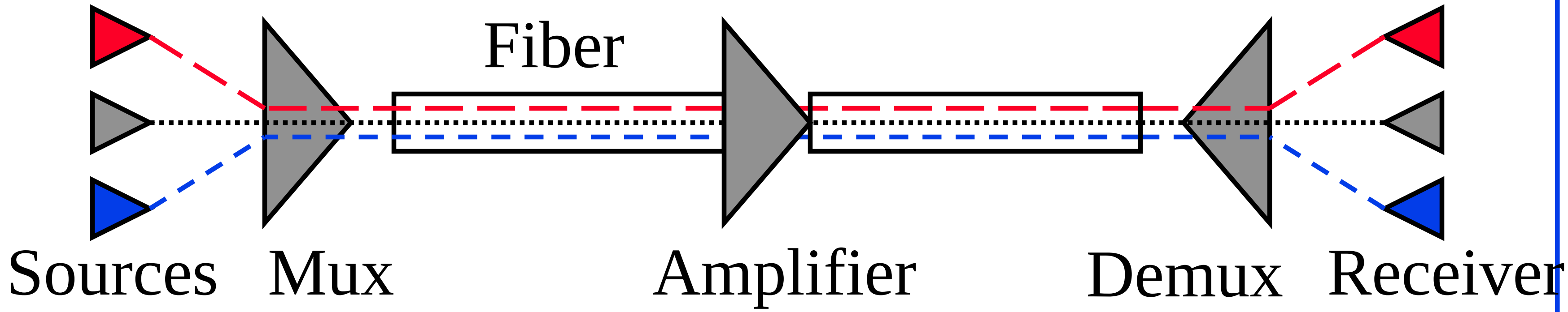
O
E
S
C
L
U
770
910
1260
1360
1460
1530
1625
1565
1675

Wavebands (Cont)



Band	Descriptor	Range (nm)
		770-910
O	Original	1260-1360
E	Extended	1360-1460
S	Short Wavelength	1460-1530
C	Conventional	1530-1565
L	Long	1565-1625
U	Ultralong	1625-1675

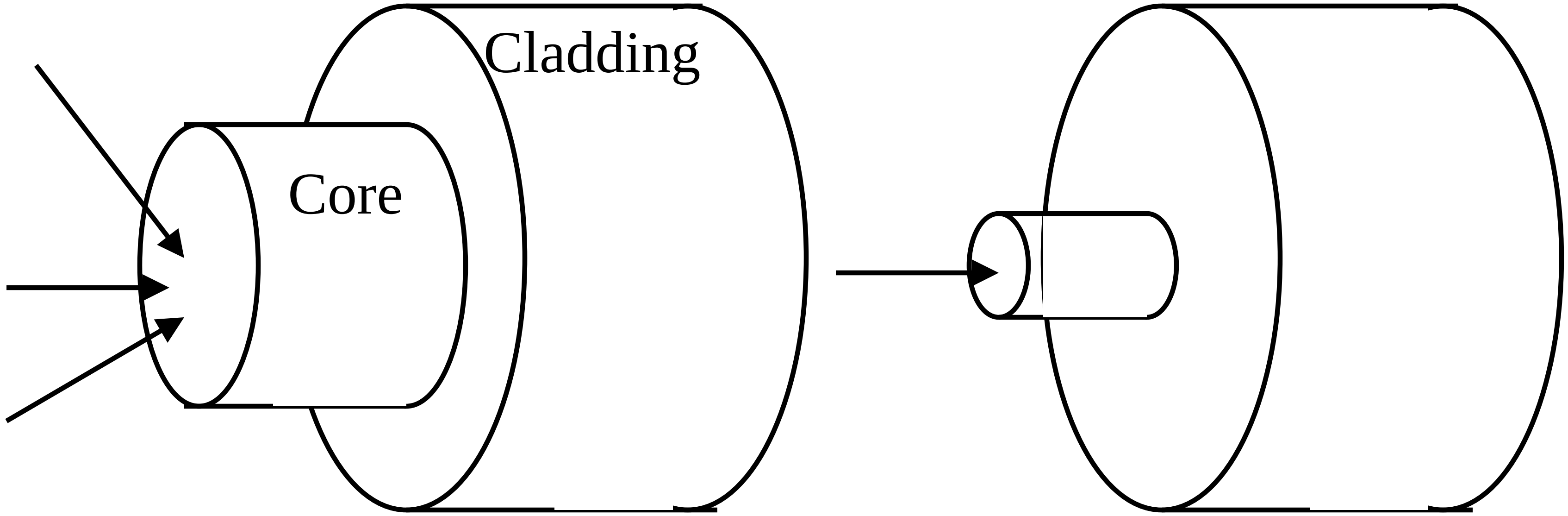
Optical Components



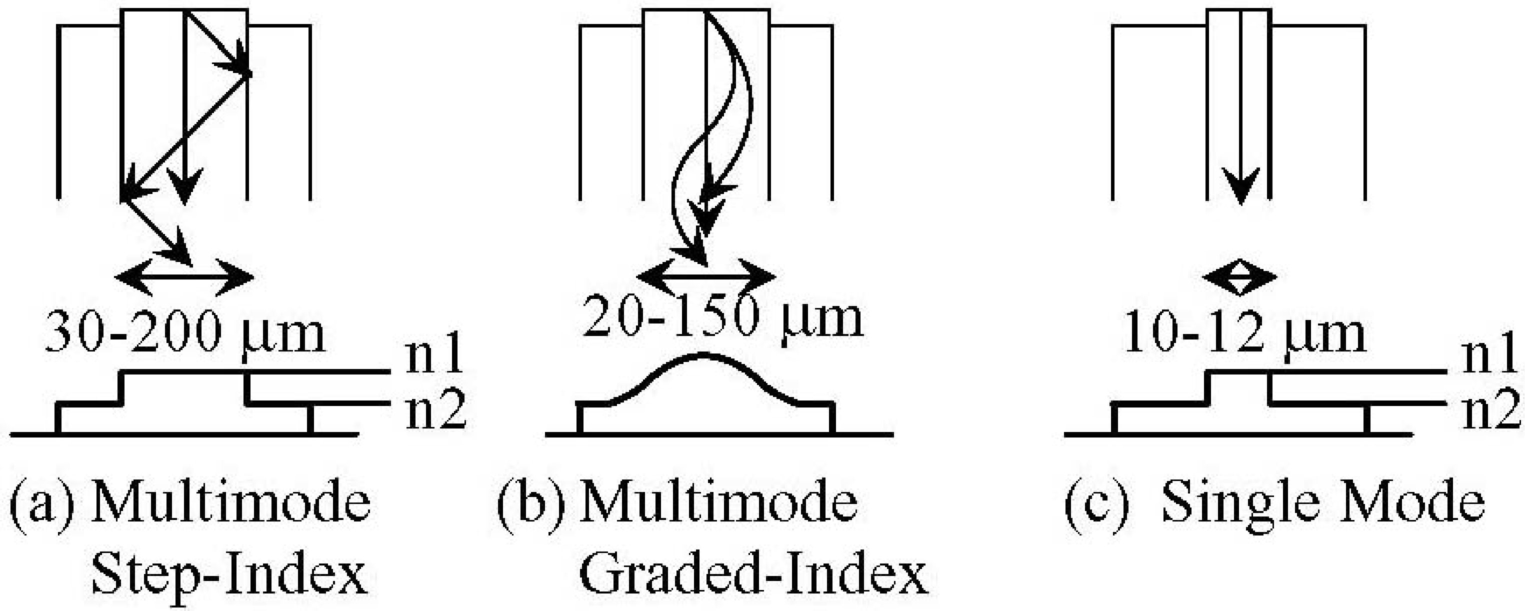
- Fibers
- Sources/Transmitters
- Receivers/Detectors
- Amplifiers
- Optical Switches

Types of Fibers I

- Multimode Fiber: Core Diameter 50 or 62.5 μm
  Wide core ⇒ Several rays (mode) enter the fiber
  Each mode travels a different distance
- Single Mode Fiber: 10-μm core. Lower dispersion.



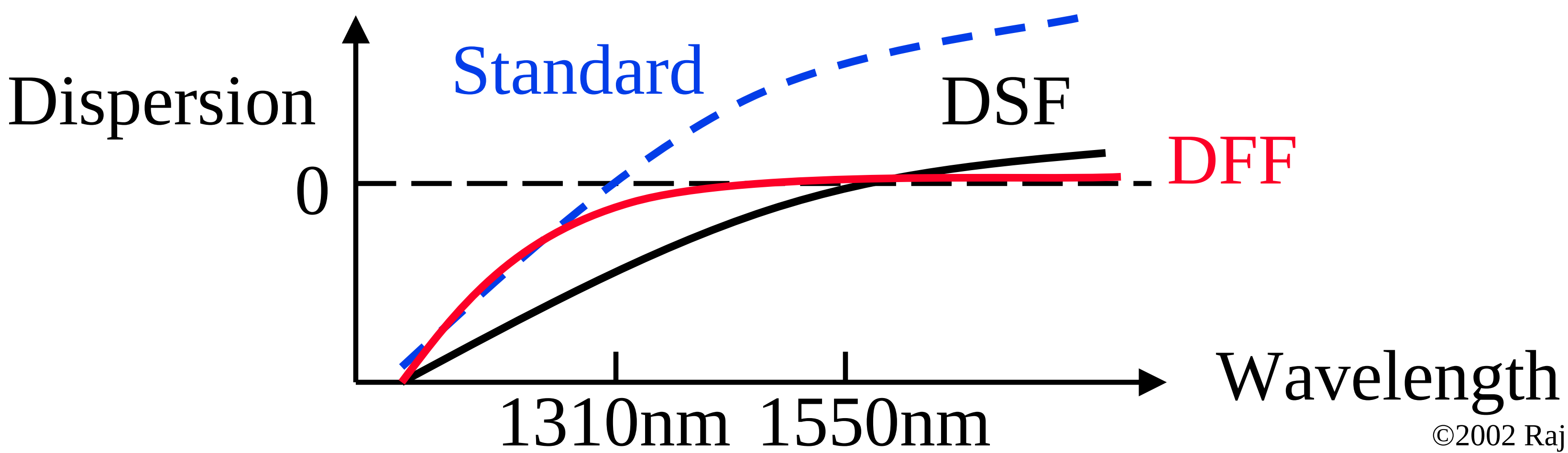
Reducing Modal Dispersion



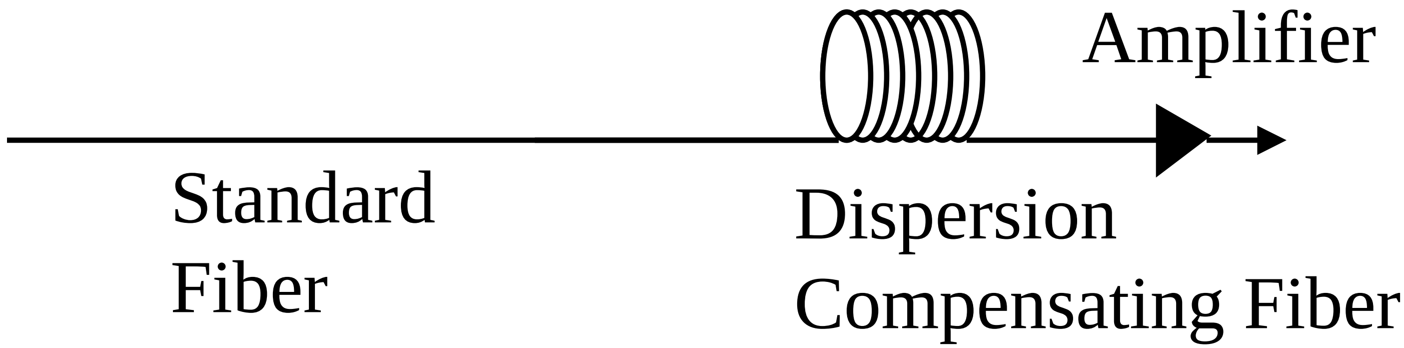
- Step Index: Index takes a step jump
- Graded Index: Core index decreases parabolically

Types of Fibers II

- **Dispersion-Shifted Fiber:** Zero dispersion at 1310nm
  EDFAs/DWDM systems operate at 1550 nm
  Special core profile ⇒ zero dispersion at 1550 nm
- **Dispersion Flattened Fiber:** 3 ps/nm/km 1300-1700nm
  Use 1300 nm now and 1550 in future
  Low dispersion causes four-wave mixing
  ⇒ DSF/DFF not used in DWDM systems



Types of Fibers III



- **Non-zero dispersion shifted fiber (NZ-DSF):**
  ⇒ 4 ps/nm/km near 1530-1570nm band
  - Avoids four-way mixing
- **Dispersion Compensating Fiber:**
  - Standard fiber has 17 ps/nm/km. DCF -100 ps/nm/km
  - 100 km of standard fiber followed by 17 km of DCF
    ⇒ zero dispersion

LOMMF

- Laser Optimized Multimode Fiber
- Supports 10 Gbps up to 300m with 850nm VCSEL
- Designed for central offices and storage area networks
- Easy upgrade from 10Mbps to 10Gbps
- 50 μm core diameter
- Limits Differential Mode Delay (DMD)
- Made by Lucent, Corning, Alcatel, New Focus, …
- Ref: NFOEC 2001, pp. 351-361

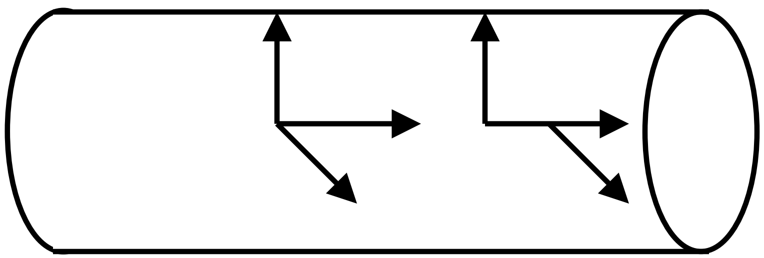
Plastic Fiber

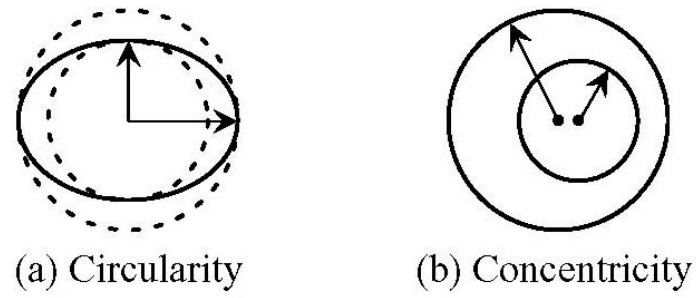
- Original fiber (1955) was plastic (organic polymer core rather than glass)
- 980μ core of PolyMethylMethyelAcrylate (PMMA)
- Large Dia ⇒ Easy to connectorize, cheap installation
- Higher attenuation and Lower bandwidth than multimode fiber
- Can use 570-650 nm (visible light) LEDs and lasers (Laser pointers produce 650 nm)
- OK for short distance applications and home use
- Cheaper Devices: Plastic amplifiers, Plastic lasers

Hard Polymer Clad Silica Fiber

- 200 micron glass core $\Rightarrow$ Easy to join
- Uses same wavelength (650nm) as plastic fiber
- Lower attenuation and lower dispersion than plastic fiber
- 155 Mbps ATM Forum PHY spec for plastic and HPCF up to 100m.

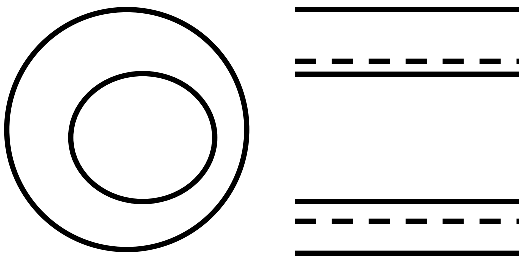
Polarization Mode Dispersion





- Two polarization modes may travel at different speeds
- Non-circular core may increase PMD
- High winds may induce time-varying PMD on above-ground cables
- Polarization Mode Dispersion (PMD) limits distances to square of the bit rate
  $\Rightarrow$ 6400 km at 2.5 Gbps, 400 km at 10 Gbps, 25 km at 40 Gbps

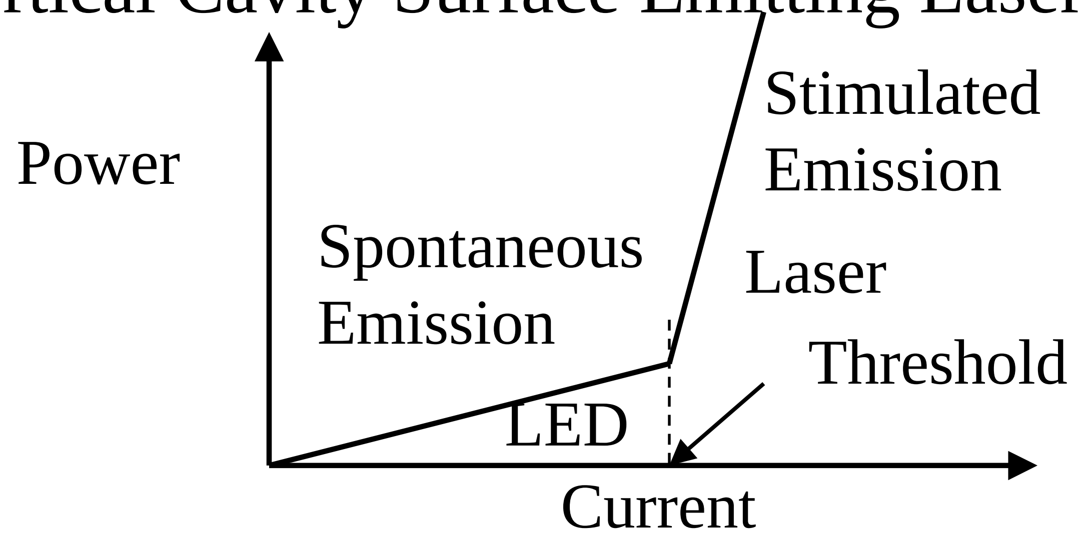
Fiber Specifications



- Mode Field Diameter: 9.2 μm @1550nm
- Core Eccentricity: < 0.6μm
- Fiber Non-Circularity: <1%
- Attenuation at different wavelengths: 0.25 dB/km @1550, 1.5 dB/km @1383
- Dispersion at different wavelengths: 5.5 ps/nm-km @1530, 13.8 ps/nm-km @1620
- Attenuation uniformity: No discontinuity > 0.1 dB
- Cutoff Wavelength: < 1300 nm. Multimode below this.
- Zero Dispersion Wavelength: <1440 nm
- PMD < 0.1 ps/√km
- Effective Area: 65 μm^2
- Zero Dispersion Slope: 0.058 ps/nm2km

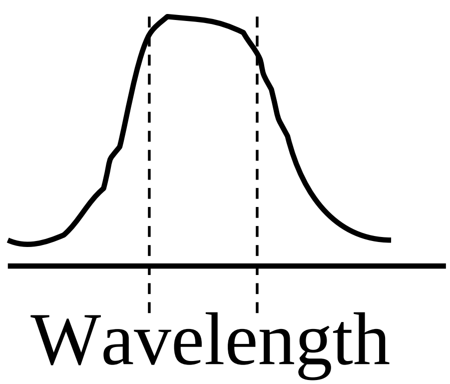
Optical Sources

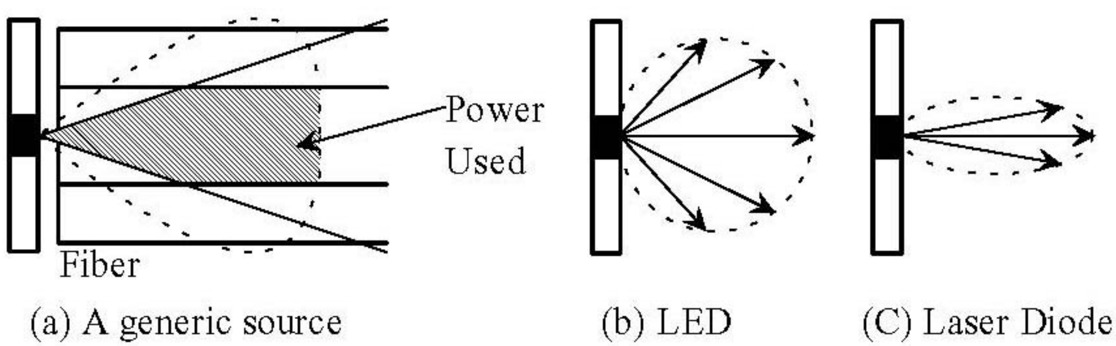
- Light Emitting Diodes (LEDs)
- Lasers (Light amplifier using stimulated emission of radiation):
  - Fabry-Perot Lasers
  - Distributed Feedback Lasers (DFBs): long distance
  - Vertical Cavity Surface Emitting Laser (VCSEL)



Light Emitting Diodes (LEDs)

- Wide spectral width = 60 nm ⇒ Low bit rates
- Low Power: 1 mW ⇒ Short distances
- Wide beam ⇒ Used with multimode fibers
- Rates up to 622 Mbps

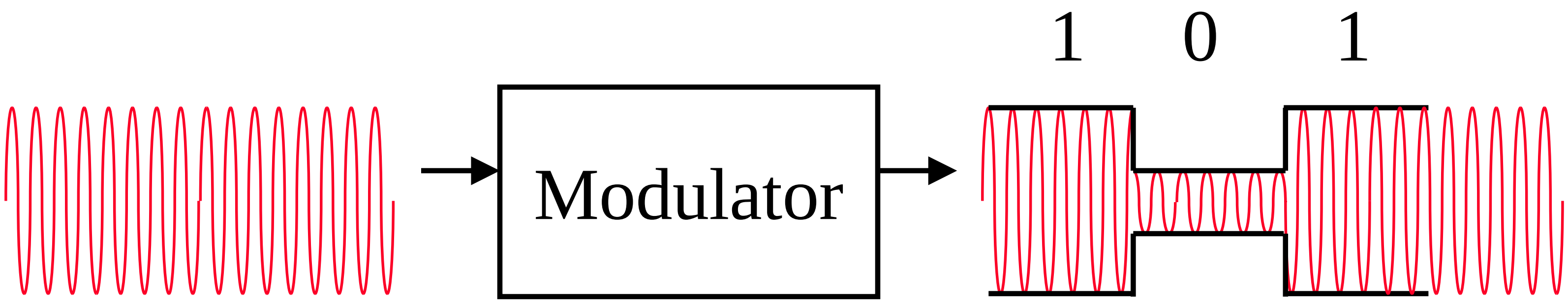




LEDs vs Laser Diodes

Issue	LED	Laser Diode
Bias current	50-150 mA	100-500 mA
Power output	Low	High
Spectral Width	25-40 nm	2-5 nm
Rise/Fall Time	3-20 ns	0.5-2 ns
Bit Rate	Lower	Higher
Coupling Efficiency	Medium	High
Fiber Type	Multimode	Single-Mode (Generally)
Failure Rate	Lower	Higher
Safety	Safe	Unsafe if high power
Cost	Low	High

Modulators



- External Mach-Zehnder (MZ) Modulators:
  - Electro-optic material: Index changes with voltage
  - Light split into two paths and then combined
  - Index controlled ⇒ Phase at output is same or opposite ⇒ High or low amplitude
- Integrated Electro-absorption:
  - Absorption (loss) depends upon the voltage
  - Integrated: The center frequency changes with level ⇒ "Chirp" ⇒ Wider line width ⇒ Cheaper

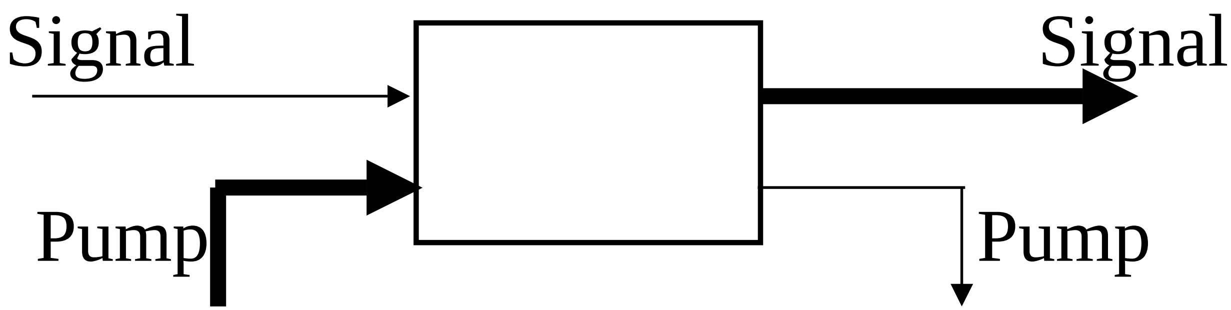
Optical Detectors

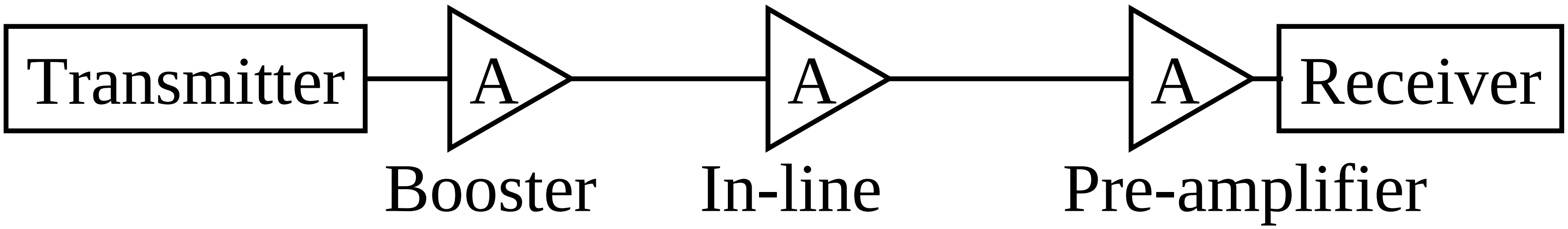
- Avalanche Photodetector (APD):
  - Electronic amplifier built in
  - Better sensitivity than PIN detector
  - Temperature sensitive
  - Data rates to 2.5 Gbps
- P-I-N Photodiode: Wideband 800 - 1600 nm
  - High data rate up to 100 Gbps

PIN vs Avalanche Photodiodes

Characteristics	PIN	APD
Responsivity	0.5-0.7 μA/μW	30-80 μA/μW
Bias Voltage	10 V	100+ V
Temperature Sensitivity	Less	More
Availability	Easy	Mostly 850 nm
Cost	Less	More

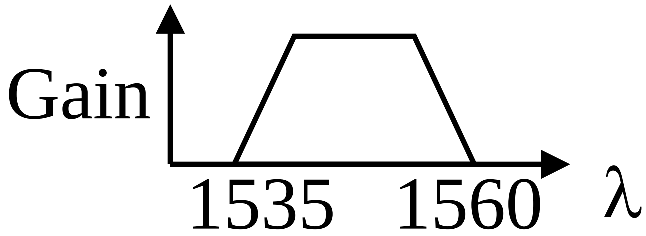
Optical Amplifiers





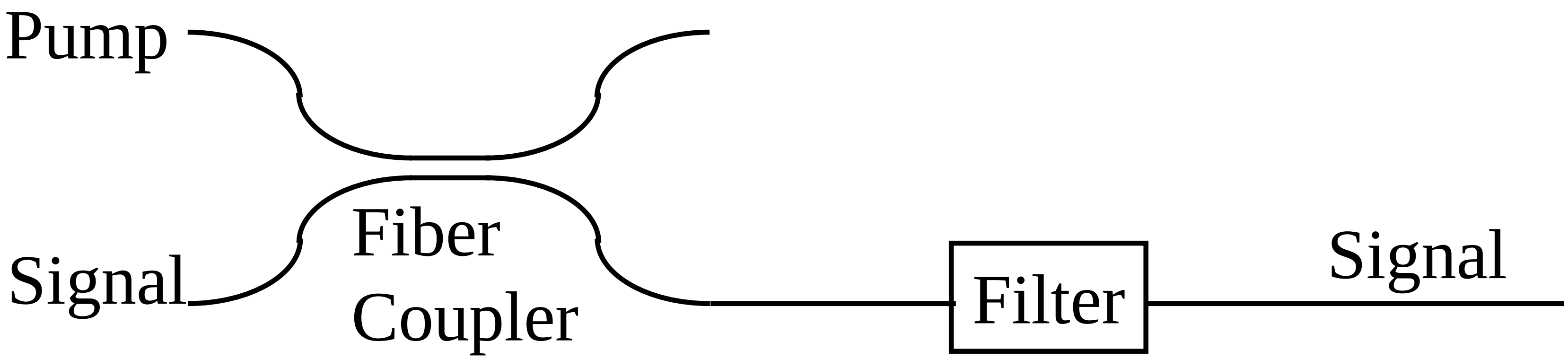
- Operational principle similar to lasers
- Erbium Doped Fiber Amplifier (EDFA) - 95% market
- Raman Amplifiers
- Semiconductor Optical Amplifiers (SOA)

EDFAs



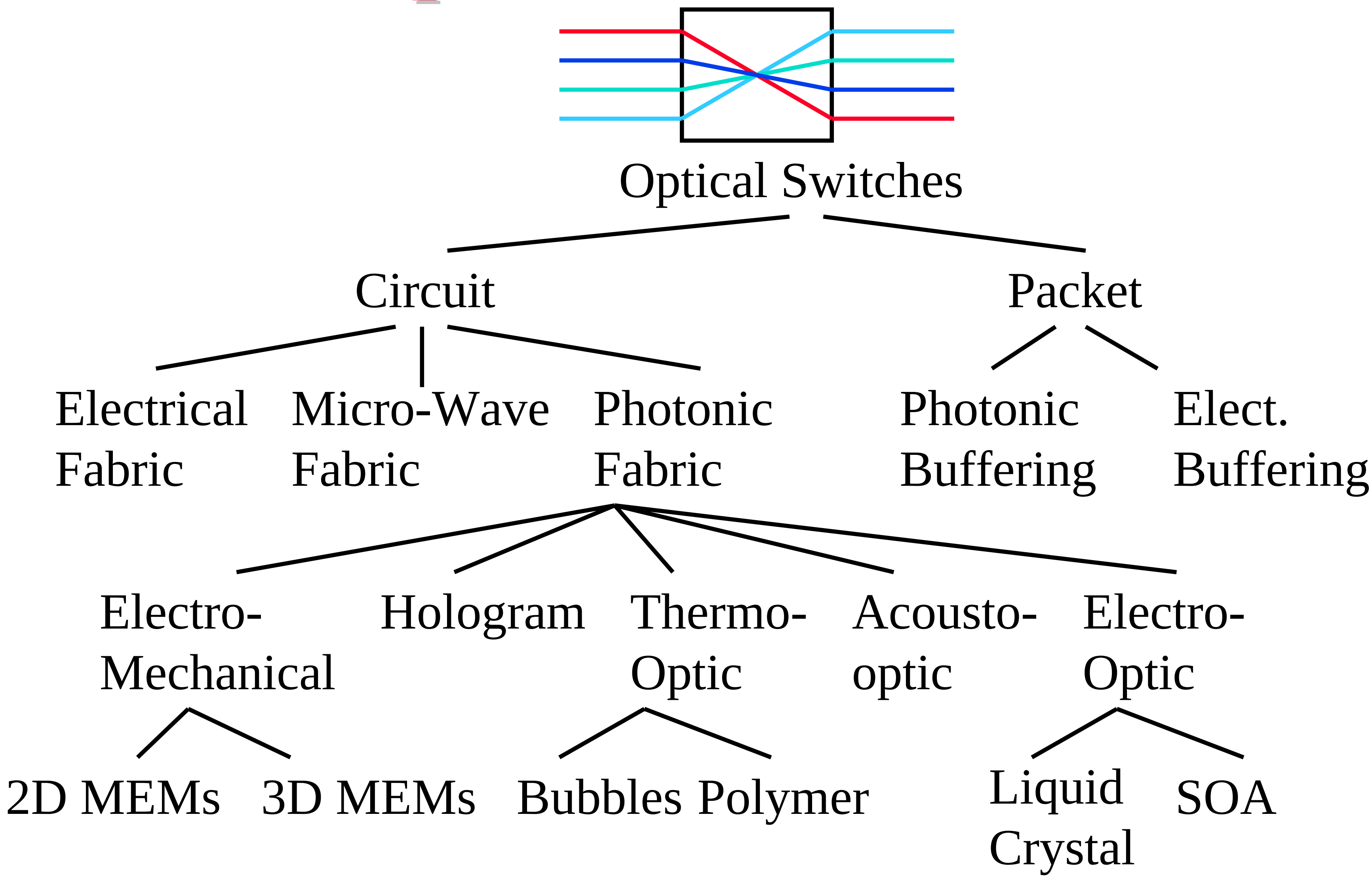
- Erbium-Doped Fiber Amplifiers (EDFAs)
- Up to 30 dB amplification
- Flat response in 1535-1560 nm
  Fiber loss is minimum in this region
  Can be expanded to 40 nm width

Raman Amplifiers

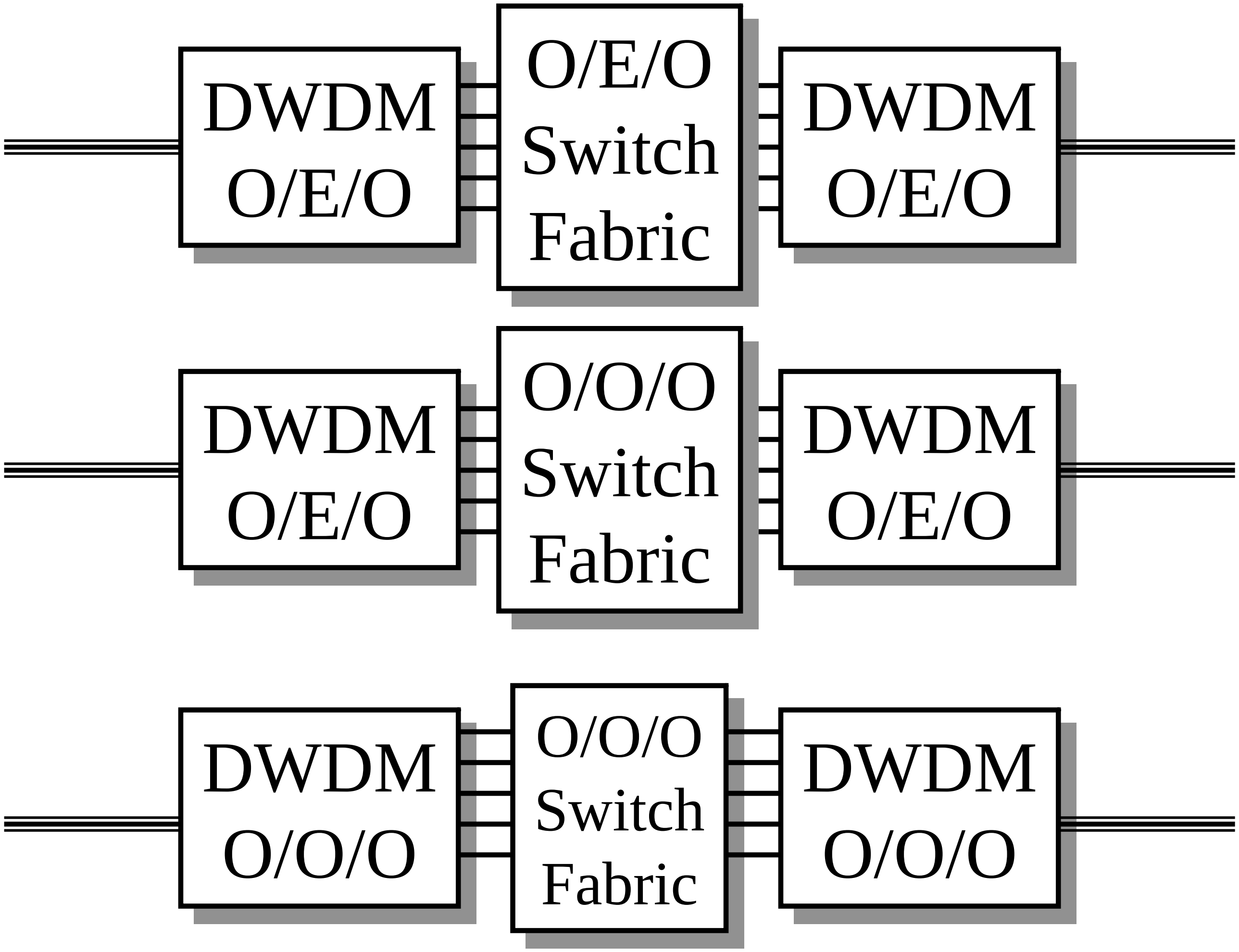


- Stimulated Raman Scattering: pump photon gives up its energy to create another photon of reduced energy at a lower frequency.
- Less noise, more expensive, and less gain than EDFA
- Less noise ⇒Critical for ultra-high bit rate systems
- Wider band than EDFA using appropriate pump

Optical Switches



Optical Crossconnect Architectures



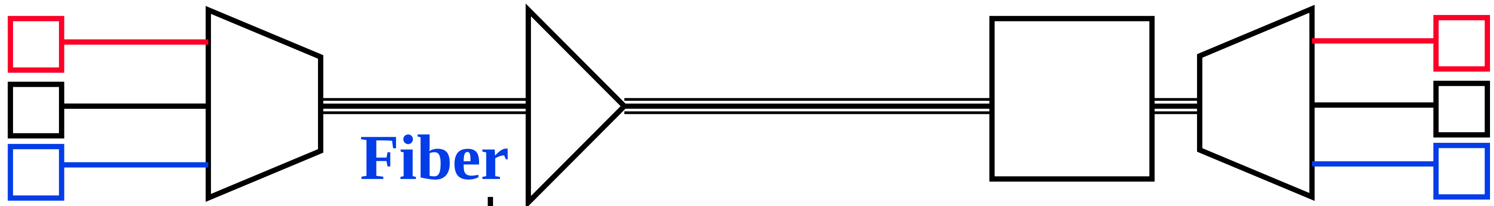
OEO vs OOO Switches

- OEO:
  - Requires knowing data rate and format, e.g., 10 Gbps SONET
  - Can multiplex lower rate signals
  - Cost/space/power increases linearly with data rate
- OOO:
  - Data rate and format independent
    $\Rightarrow$ Data rate easily upgraded
  - Sub-wavelength mux/demux difficult
  - Cost/space/power relatively independent of rate
  - Can switch multiple ckts per port (waveband)
  - Issues: Wavelength conversion, monitoring

New Developments

1. Higher Speed: 40 Gbps
2. More Wavelengths per fiber
3. Longer Distances

40 Gbps



Transmitter	Mux/Demux	Amplifier	Switching	Receivers
Sources	Filters	Gain Equalizers	ADM	Detectors
Modulators	Interleavers	Performance Monitors		
Wavelockers				

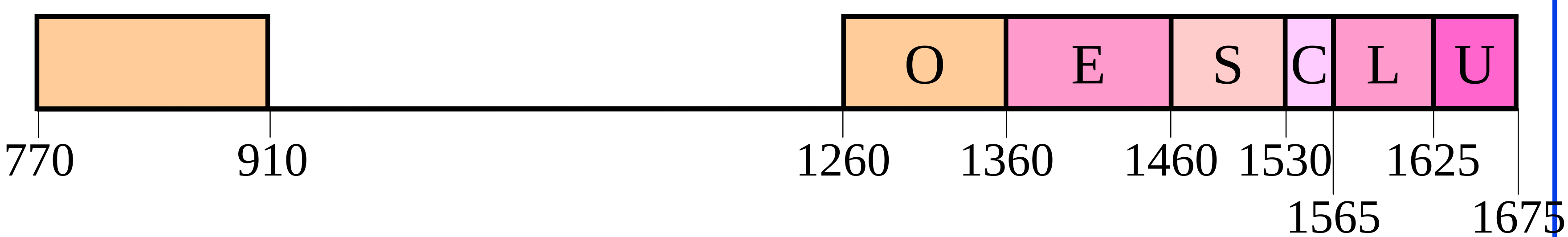
Dispersion compensators
PMD compensators

- Need all new optical and electronic components
- Non-linearity's reduce distance by square of rate.
- Deployment may be 2-3 years away
- Development is underway. To avoid 10 Gbps mistake.
- Cost goal: 2.5×10 Gbps

More Wavelengths

- C-Band (1535-1560nm), 1.6 nm (200 GHz) ⇒ 16 λ's
- Three ways to increase # of wavelengths:

1. **Narrower Spacing**: 100, 50, 25, 12.5 GHz
   Spacing limited by data rate. Cross-talk (FWM)
   Tight frequency management: Wavelength monitors, lockers, adaptive filters
2. **Multi-band**: C+L+S Band
3. **Polarization Muxing**



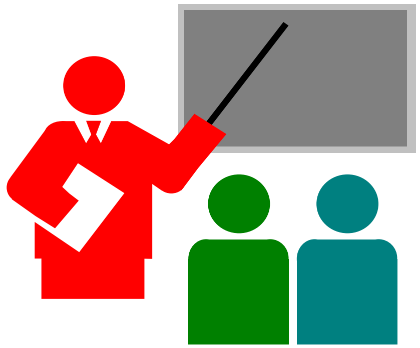
More Wavelengths (Cont)

- More wavelengths ⇒ More Power
  ⇒ Fibers with large effective area
  ⇒ Tighter control of non-linearity's
  ⇒ Adaptive tracking and reduction of polarization mode dispersion (PMD)

Ultra-Long Haul Transmission

1. Strong out-of-band Forward Error Correction (FEC)
   Changes regeneration interval from 80 km to 300km
   Increases bit rate from 40 to 43 Gbps
2. Dispersion Management: Adaptive compensation
3. More Power: Non-linearity's $\Rightarrow$ RZ coding
   Fiber with large effective area
   Adaptive PMD compensation
4. Distributed Raman Amplification:
   Less Noise than EDFA
5. Noise resistant coding: 3 Hz/bit by Optimight

Summary



- Non-zero dispersion shifted fiber for DWDM
- LED's for low speed/short distance. Lasers for high speed and long distance.
- DWDM systems use 1550 nm band due to EDFA
- Raman Amplifiers for long distance applications
- O/O/O switches are bit rate and data format independent

Homework 3

True or False?

T F

❑ ❑ Optical communication uses infrared light

❑ ❑ C band is used commonly because of EDFAs.

❑ ❑ Graded index fiber has a lower modal dispersion than step index fiber

❑ ❑ Plastic fiber is cheaper than glass fibers

❑ ❑ Dispersion shifted fiber is used in DWDM systems

❑ ❑ If a signal can travel 1600 km at 10 Gbps, due to PMD it can travel 400 km at 40 Gbps

❑ ❑ Fiber becomes multimode above its cutoff wavelength

❑ ❑ Lasers are never used with multimode fibers

❑ ❑ Raman amplifiers are used in ultra-long haul systems

❑ ❑ O/O/O switches are commonly used in today's networks

❑ ❑ Most DWDM systems currently use 12.5 nm spacing

❑ ❑ Ultra-long haul transmission requires precise dispersion management

Marks = Correct Answers _____ - Incorrect Answers_____ = ______