DWDM Optical Networking **R/Evolution**

The Magic of Photonics
Module 2

Fiber Optic Communication Fundamentals

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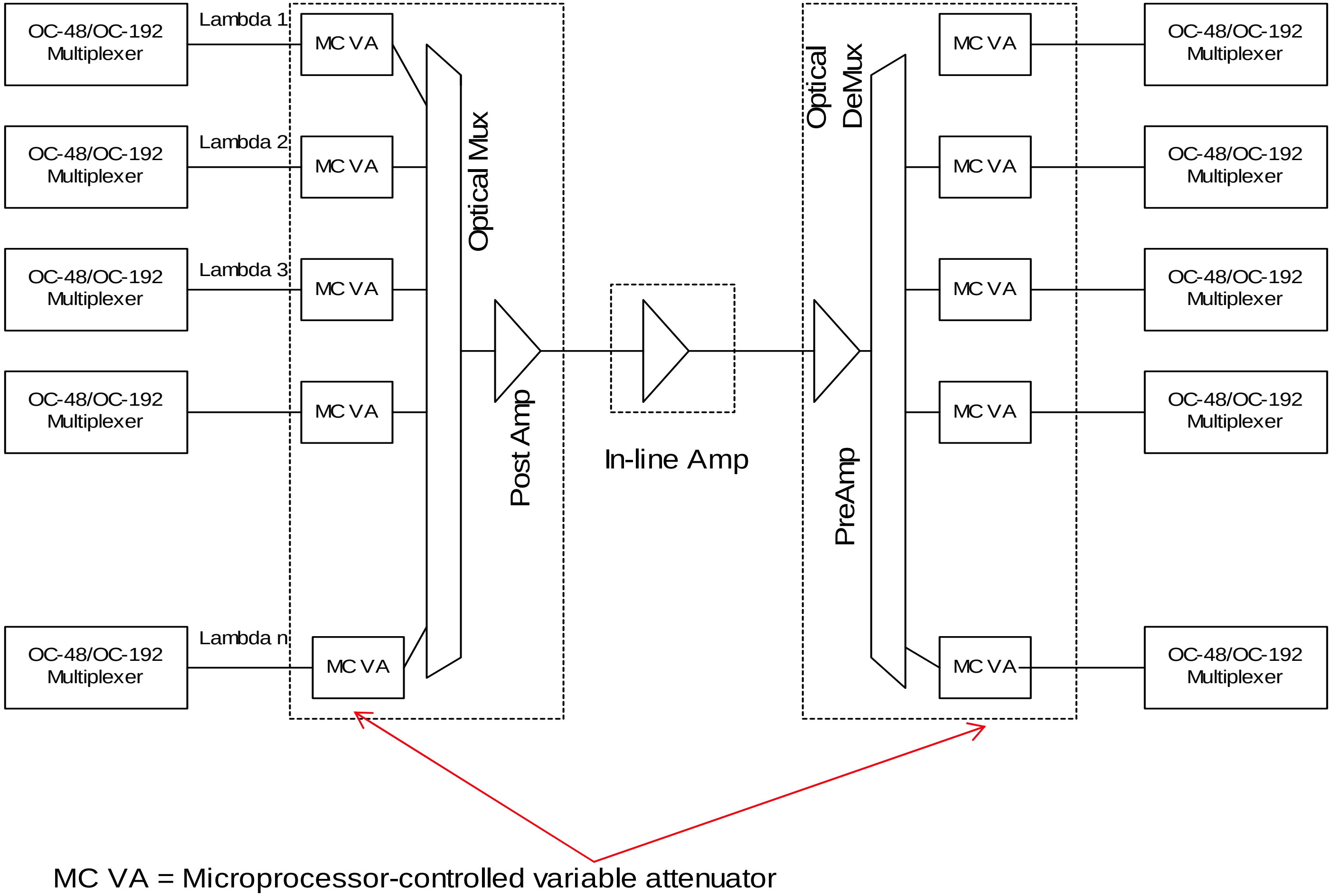
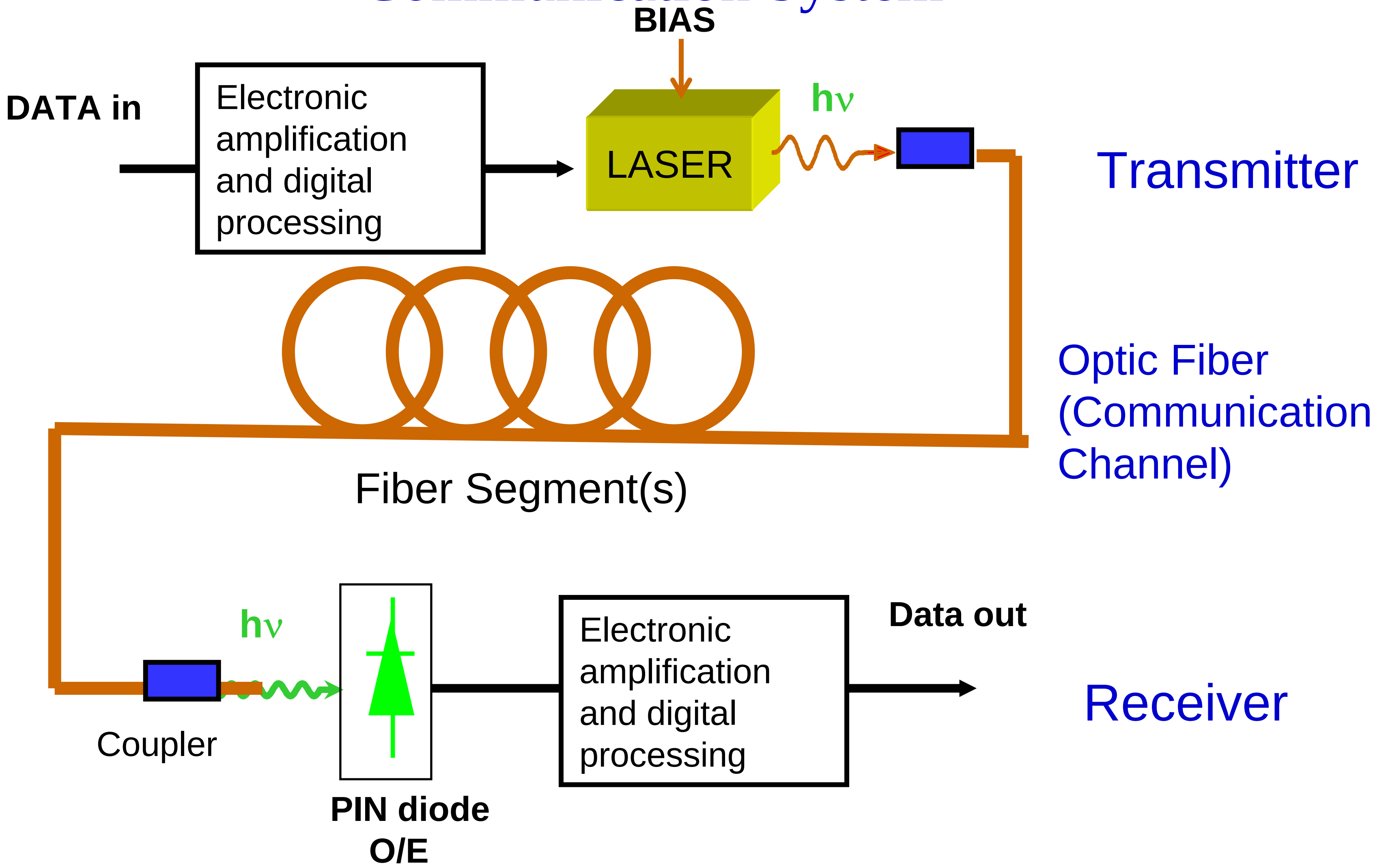
A typical DWDM Transport System Architecture



For now, just look at this figure to get a feel for the components involved in WDM optical transport system. No more than that for now. We will get into the details later.

A Simplified Point-to-point Fiber Optic Communication System



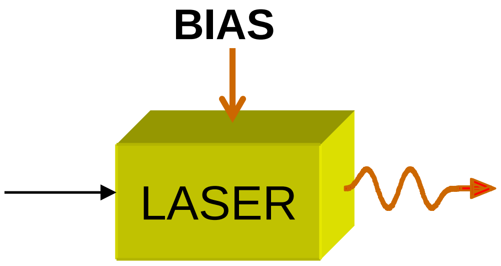
Key Components of Fiber Optical Transmissions Systems

- •Optical Fiber
- •Transmitter/Source (Lasers)
- •Modulators
- •Receivers
- •Optical Passives couplers, connectors, etc.)

In designing (engineering) a system, characteristics of these components must match one another and must meet the design requirements.

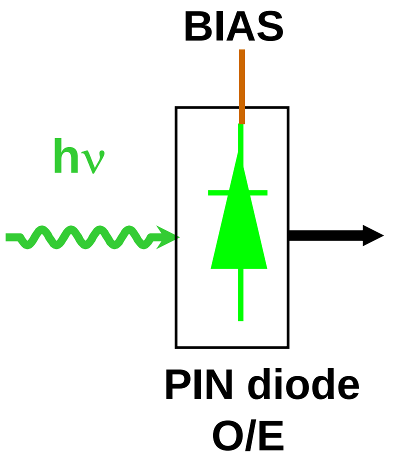
Transmitter/Source

- LEDs: Not used in long distance transmission. Used in low-cost short-reach systems.
- Lasers (Semiconductor laser diodes or LD). Key characteristics are:
  - Power
  - Line width
  - Stability



Receivers

- Types
  - PIN (stands for P-type, Intrinsic-type, and N-type diode)
  - APD (stands for Avalanche Photo diode)
- Characteristics
  - Sensitivity
  - dynamic range
  - stability



Modulators: Modulate Digital Data on Optical Signal

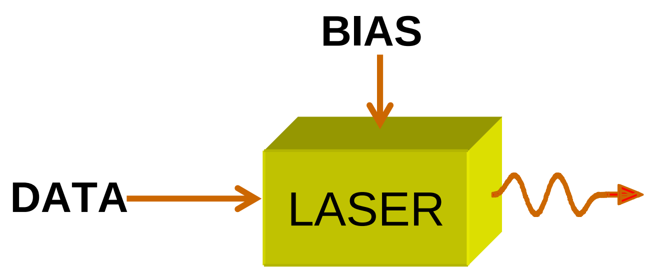
Major types

- Direct modulation
- External modulators *(Light shutters)*
  - **Electro-absorption modulators**
  - **Mach-Zehnder Modulators**

Key characteristics

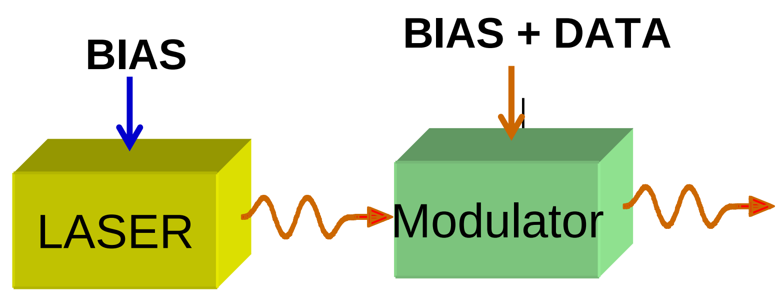
- Speed
- Extinction ratio
- Chrip

● Direct Modulation of Laser



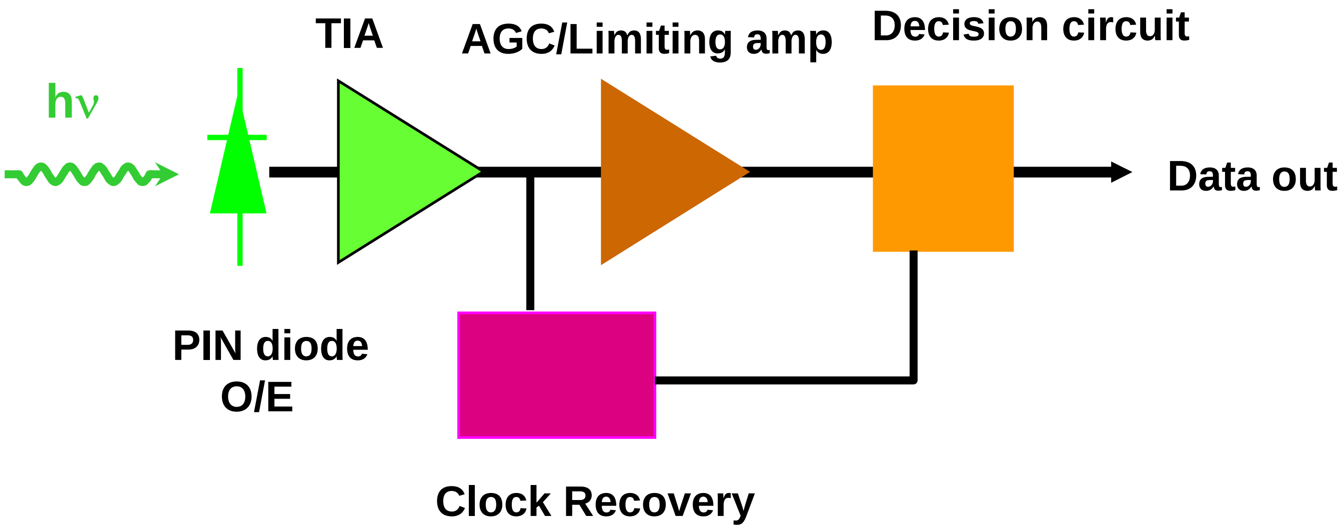
Issues: - Complex Dynamics, Yield

● External Modulation of Laser

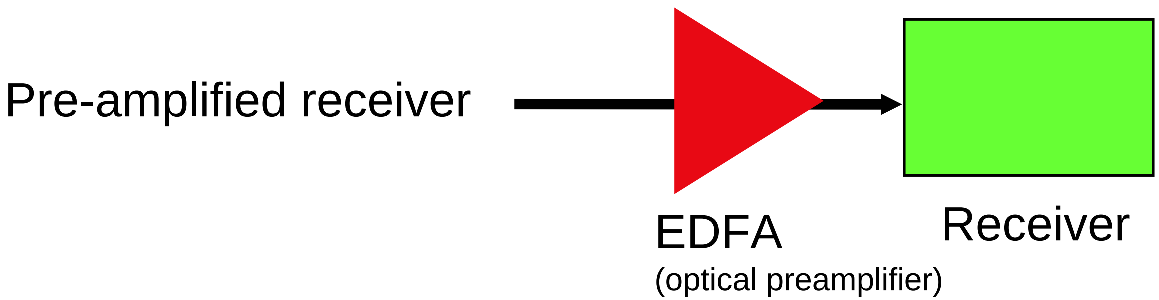


Issues: - Additional Element, New Technology

Receiver



Receiver sensitivity can be improved significantly by placing an EDFA in front of PIN.

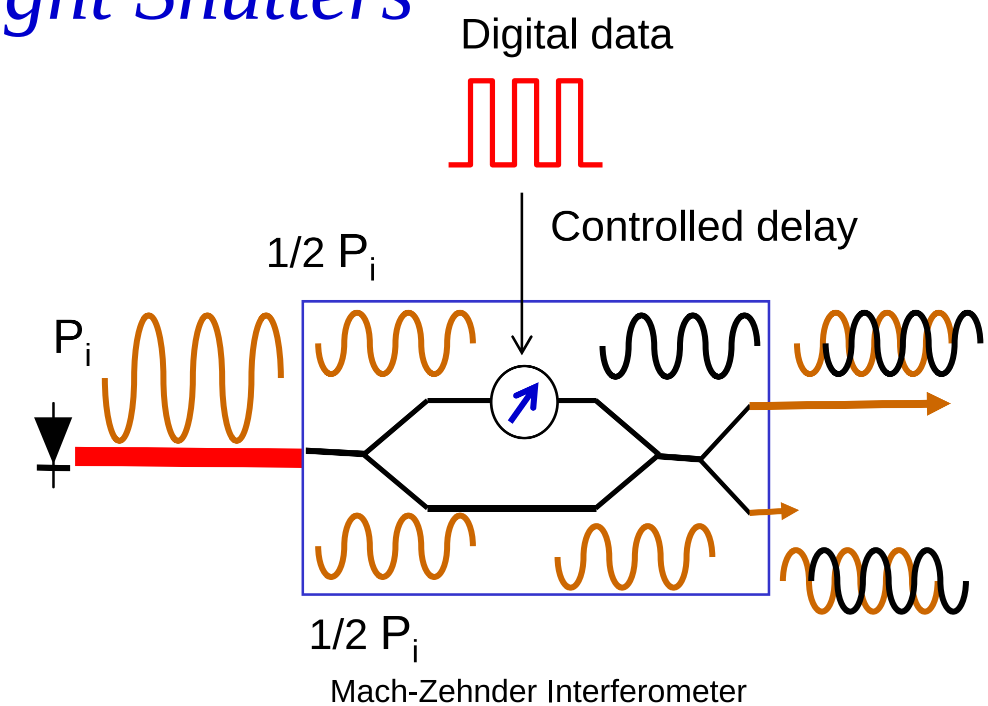


Mach-Zehnder External Modulators

Light Shutters

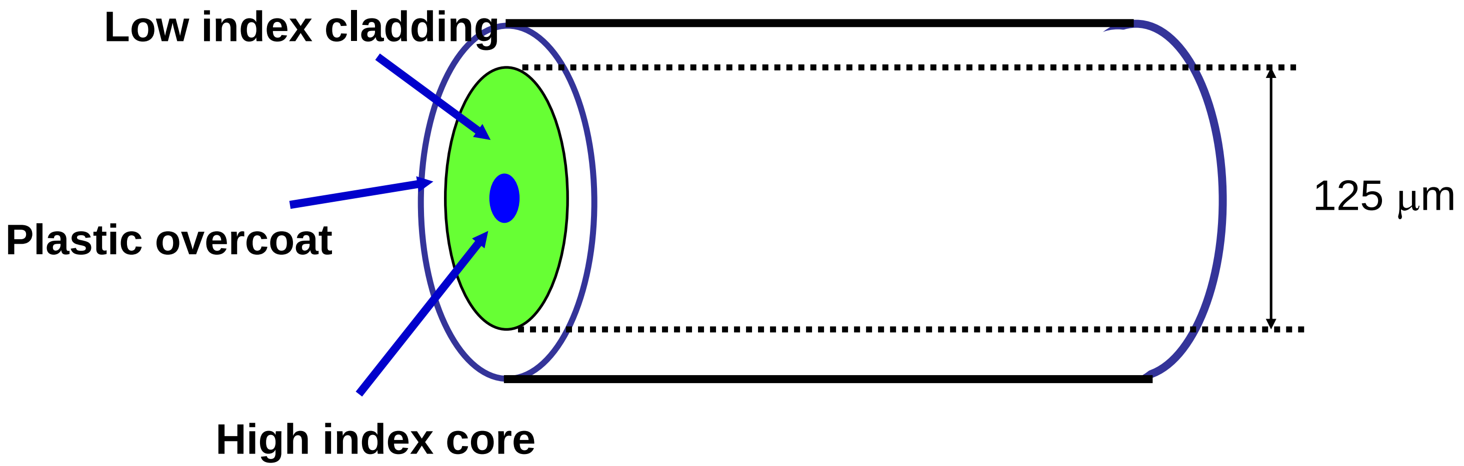
Mach-Zehnder Modulator:

- Widely used for analog and digital modulation
- Is the basis for other optical networking devices such as:
  - Arrayed Waveguide Grating routers (AWG)
  - Wavelength converts
- etc.



•If you can not figure out how it works, read about the operation of this modulator in your text #2 “Metro Optical networking”
•Other types of external modulators also exist such as electro-absorption modulators

Guiding Light in an Optical Fiber



Realized >100 years ago

Perfected 25 year ago

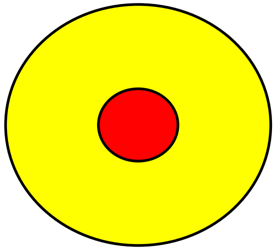
Started deployment ~ 15 years ago

The backbone of information technology today.

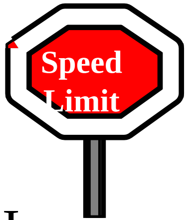
Review of Fundamentals

How light travels in a fiber

- An optical fiber consists of a cylindrical inner core and an outer shell called cladding
- Cladding is enveloped by a protective outer cable material, but this does not play a role in light propagation
- Core: high index of refraction; cladding: a relatively lower index



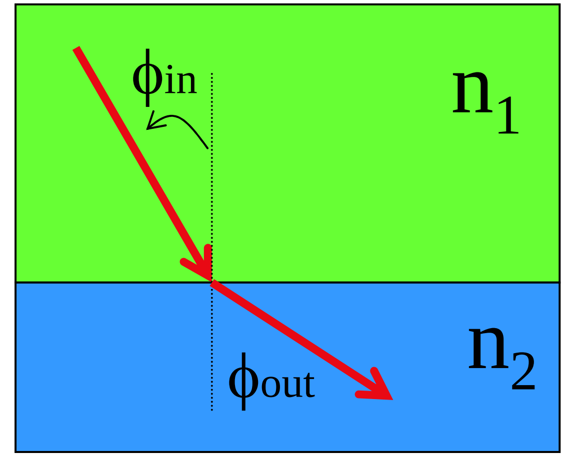
- Refraction occurs because light moves faster through materials than through others (n: Index of refraction)



- Maximum speed is in vacuum at 300,000 Km/Sec
- In case of glass to air interface a light ray approaching boundary at a relatively steep angle has its direction suddenly changed as it encounters a region where it can travel at a faster speed

Review of Fundamentals

How light travels in a fiber

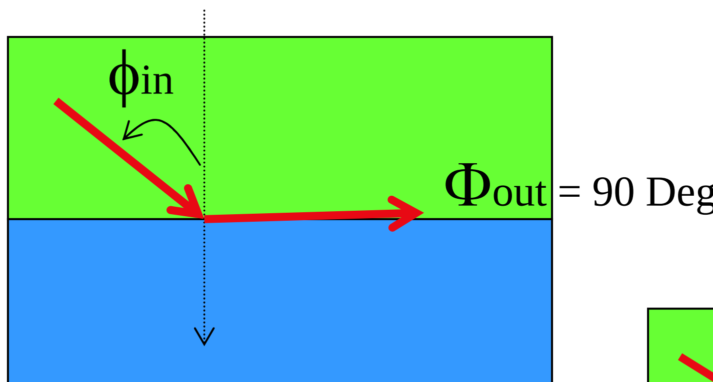


Mechanism:

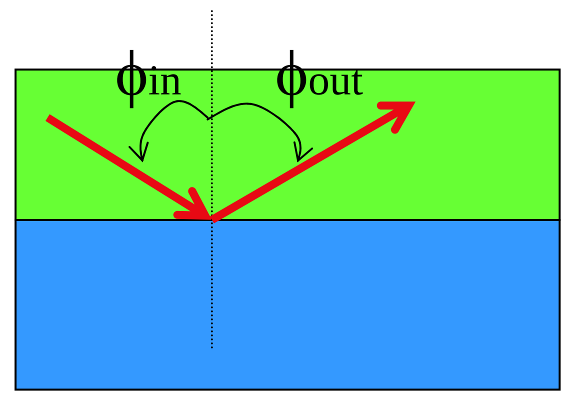
- Senll's law of refraction

  Sin ϕin / n2 = Sin ϕout / n1

- Critical Angle
  - For glass-to-air: ~42.5 degrees
  - A typical core/cladding: 8.5 degrees



$n_1 > n_2$



- Total Internal Refection
  - Light is trapped

$\sum_{i=1}^{N} \lambda_i$

Review (continued)

How light travels in a fiber (continued)

- Multiple internal at core/cladding interfaces, letting light be guided in fiber core and emerge from other end.

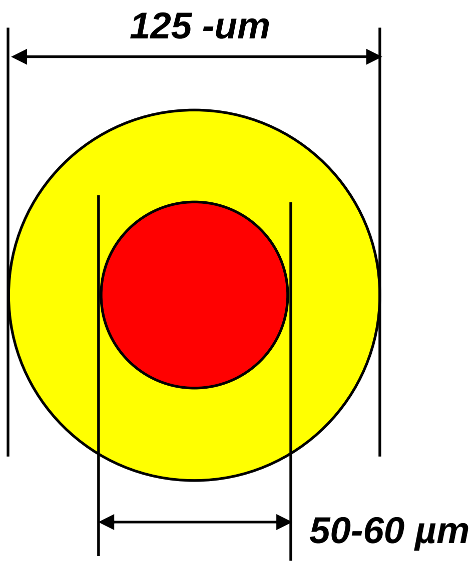
Demo: See laser beam propagation in a transparent rod.
Point your laser pointer into a transparent rod. What do you see?

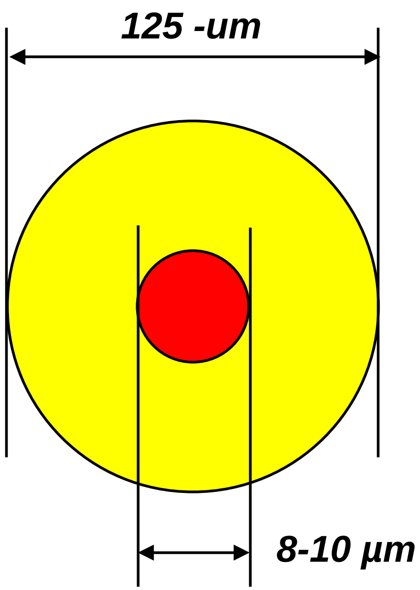
- Two major subdivision of optical fibers are multi-mode and single-mode
  - A mode is a group of rays bouncing through fiber at a given incidence/reflectance angle

Demo continued

Optical Fiber ***Basics***

The basis for high speed terrestrial communication...





Multimode

- Lower Cost Optics *(LEDs)*
- Premises Applications
- Bandwidth & Distance Limited

Single Mode

- Higher Cost Optics *(Lasers)*
- Metropolitan and Long Haul Applications
- High Bit Rate Applications

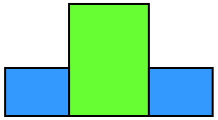
Review (continued)

Step-index and Graded-index fiber

- Multi-mode fibers are differentiated by profile of refraction index across fiber's

  diameter
- Step-index multi-mode fiber has an abrupt transition of refraction index at

  core/cladding boundary
- Graded-index multi-mode fiber has an index of refraction that reaches a peak in center of core and monotonically tapers off to a lower value
- Single-mode fiber has a step-index profile, but has a much smaller diameter



Optical Fiber: ***Single Mode Evolution***

- Conventional Unshifted Fiber (USF) ITU G.652
  - Invented in late 1970's, bulk of fiber installed today
  - Optimized for transmission at 1310 nm wavelength
  - **Allows multiwavelength transmission (DWDM) in 1550 nm band**
  - High dispersion makes very expensive to use at high bit rates (10 Gb/s +)
- Dispersion Shifted Fiber (DSF) ITU G.653
  - Invented in mid 1980's, some installed in US, high percentage in Japan
  - Optimized for transmission at 1550 nm wavelength
  - **Does not allow multiwavelength transmission (DWDM) in 1550 nm band**
  - Zero dispersion enables high bit rates (10 Gb/s +), but only a few allowed
- Nonzero-dispersion Fiber (NZDF) ITU G.655
  - Invented in mid 1993, now dominates US long distance market
  - Optimized for DWDM transmission at 1550 nm wavelength
  - **Small, but finite dispersion enables high bit rates (10 Gb/s +) & DWDM**
- **New AllWave Fiber**

Transmission Impairments in Optical Fiber

- Attenuation (Loss)
  - Limits Span Distance *(Typical loss allowed 0.25 db/km)*
- Dispersion (Pulse Spreading)
  - Limits Span Distance
  - Bit-Rate Dependent
- Nonlinearities
  - Causes Noise & Distortion (unless we use it against dispersion; Dispersion management)
- Connectorization & Splicing
  - Introduces additional loss

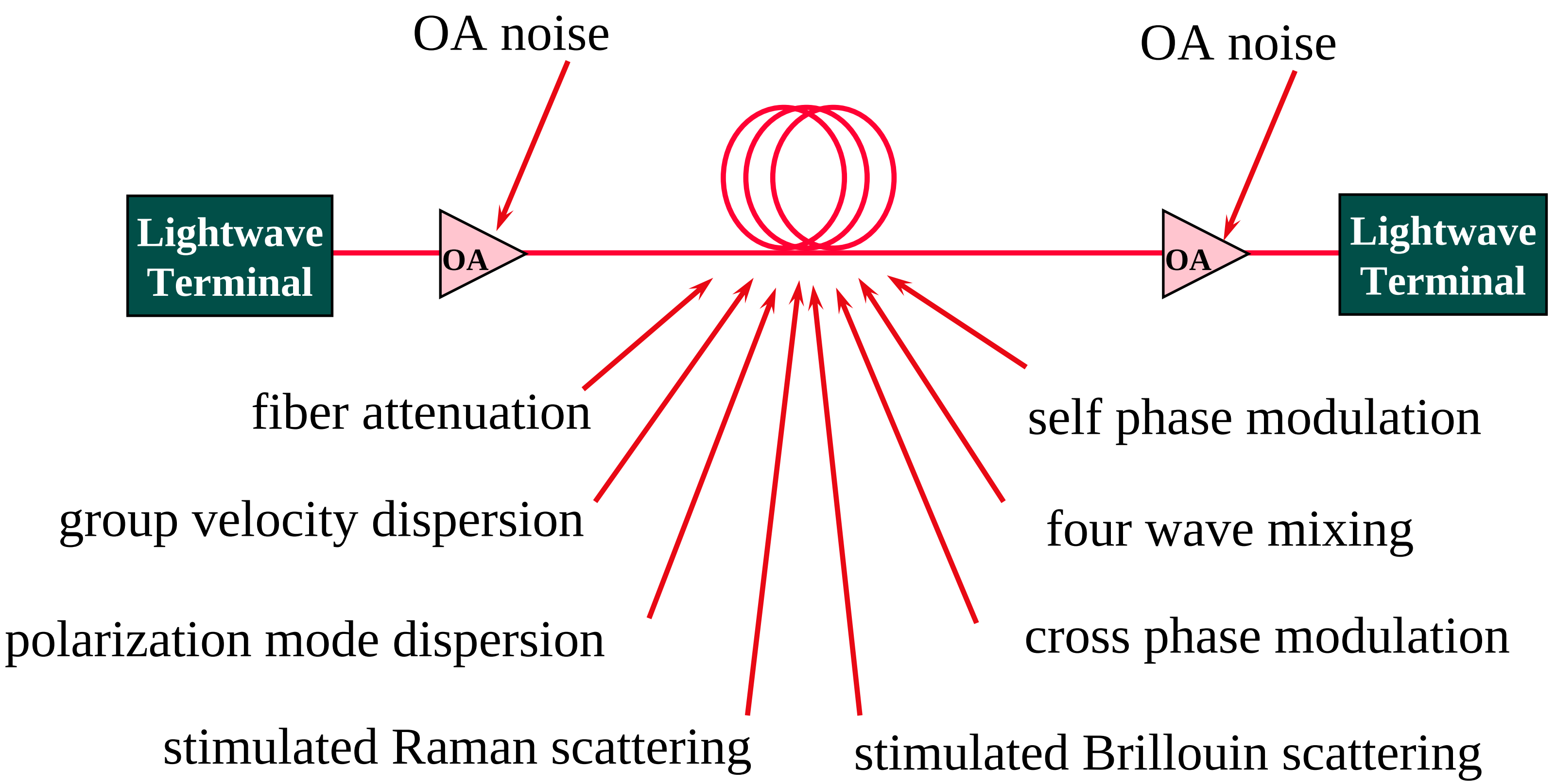
OC-192-related issues

- **Technical aspects relate to non-linearities**
- Progress being made:

  - **Polarization mode dispersion (PMD),** caused by combination of intrinsic effects (birefringence and mode coupling) and extrinsic effects on cable (bends, twists)... Studies show that transmission up to 250 miles is possible at OC-192
  - **Stimulated Brillouin Scattering (SBS),** limits power that can be injected into a siglemode fiber... As more and more OC-48/OC-192 systems are placed over a fiber, the output power of the EDFAs can cause SBS problems... Techniques are being developed to boost the SBS threshold
  - **Self-phase Modulation (SFM),** introduces chirping, in turn interacts with fiber dispersion to cause pulse broadnening or compression (depending on the dispersion profile of the fiber). Issue being looked at...
  - **Four-wave mixing**, limits multichannel transmission on dispersion-shifted fiber that has its zero dispersion in the EDFA bandwidth range.... Monitoring of input power levels into the EDFA can address problem when conventional fiber is used for transmission…. New fiber designs (including NZDSF) have been introduced to address issue

Pictorial --> next slide

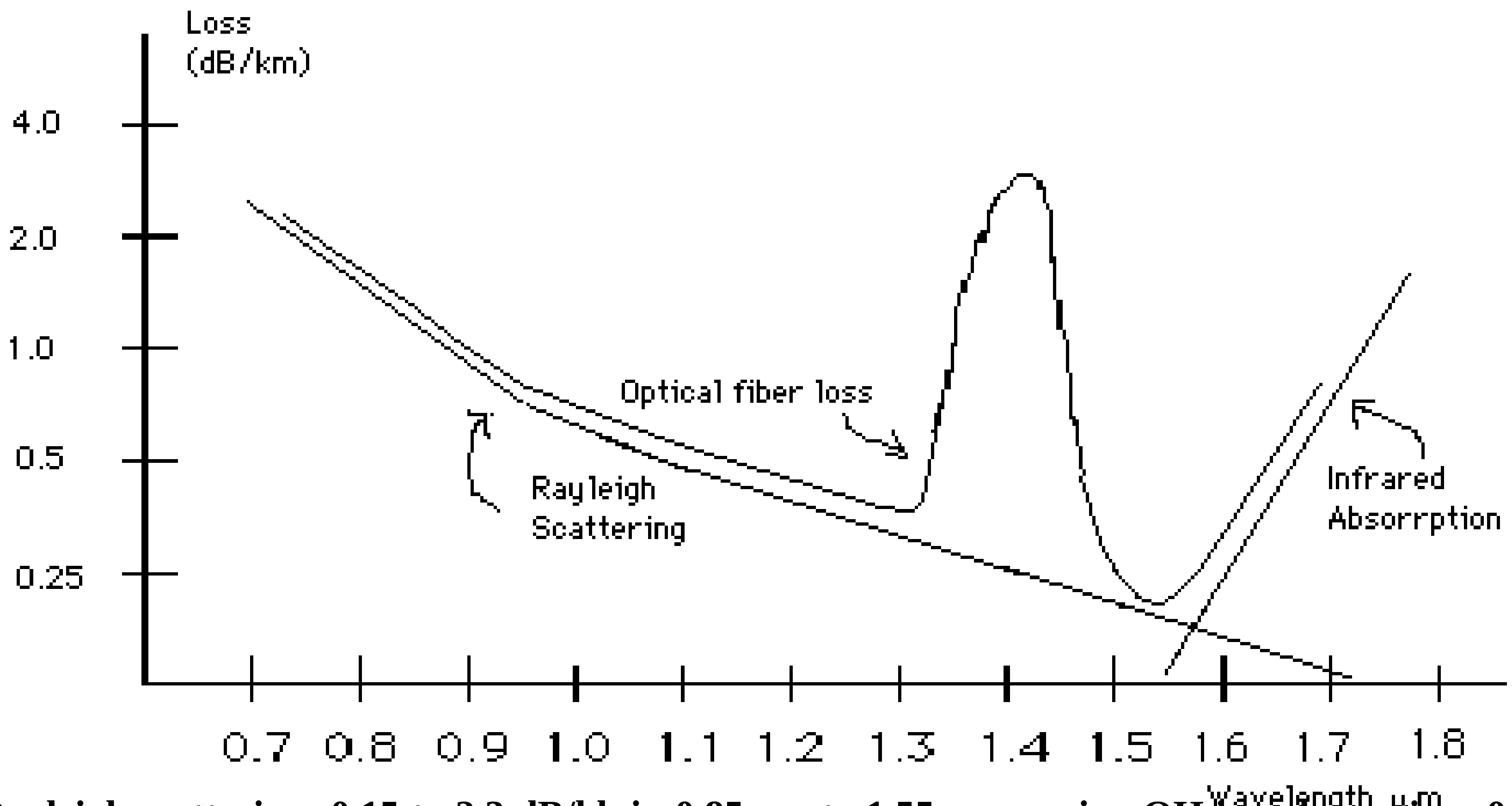
Transmission Challenges



Link Design: Balance effects for optimum performance

Review (continued)

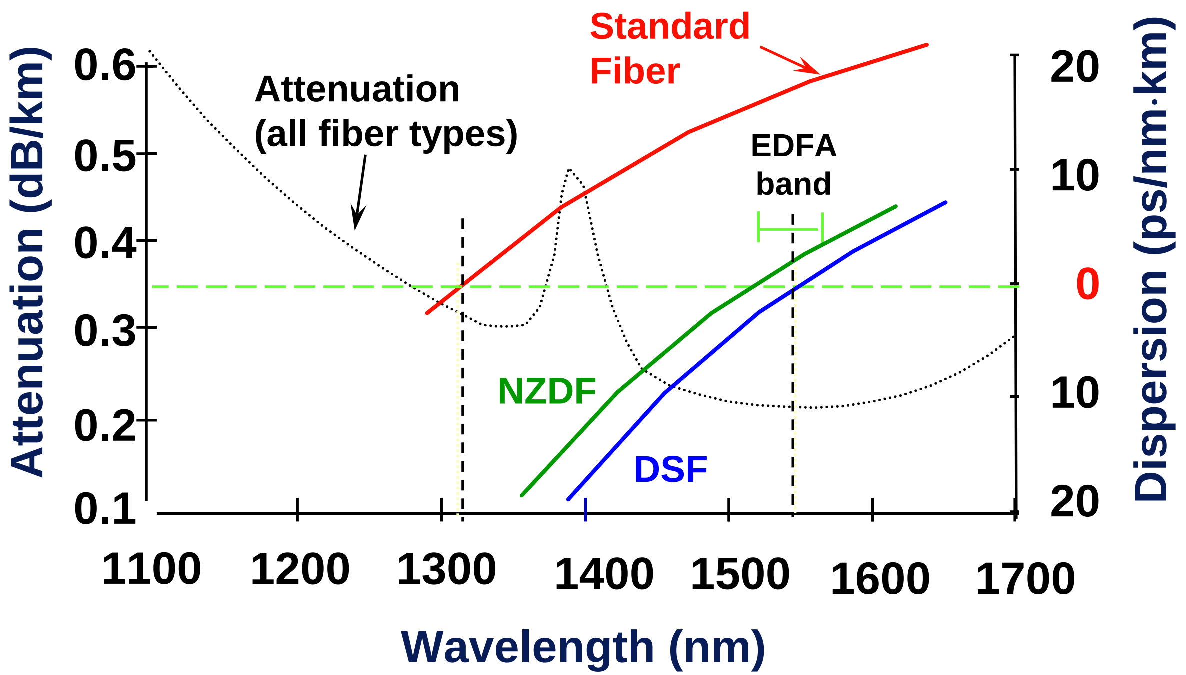
Typical light-absorption curve for a high-silica fiber is shown below:



•Rayleigh scattering: 0.15 to 2.3 dB/kb in 0.85mm to 1.55 mm region OH ion absorption: 0.01 to 5 dB/km (silica impurity)

•Infrared absorption: Sharply increases beyond 1.60 mm region Waveguide imperfections: up to 0.1 dB/km (other scattering problems: Brillouin scattering and Raman scattering)

Optical Fiber
Characteristics



Singlemode Fiber Types:

- Standard Fiber (dispersion unshifted) G.652
- Dispersion shifted fiber G.653
- Non-Zero Dispersion Fiber (NZDF) G.655

Review (continued)

Signal attenuation

- Fiber degrades signal quality, as is case in a copper medium, although degradation is much less than that of copper; this is why optical fiber can carry a signal over a longer distance or at much higher bandwidth than copper

Signal dispersion

- Either effect makes signal more difficult to decipher at remote end
- Dispersion is name of principal cause of waveform distortion

- principal types of dispersion:
  - modal dispersion (only in multi-mode fiber)
  - chromatic dispersion
  - polarization mode dispersion (PMD) difficult to handle

Review (continued)

$\sum_{i=1}^{N} \lambda_i$

Modal dispersion

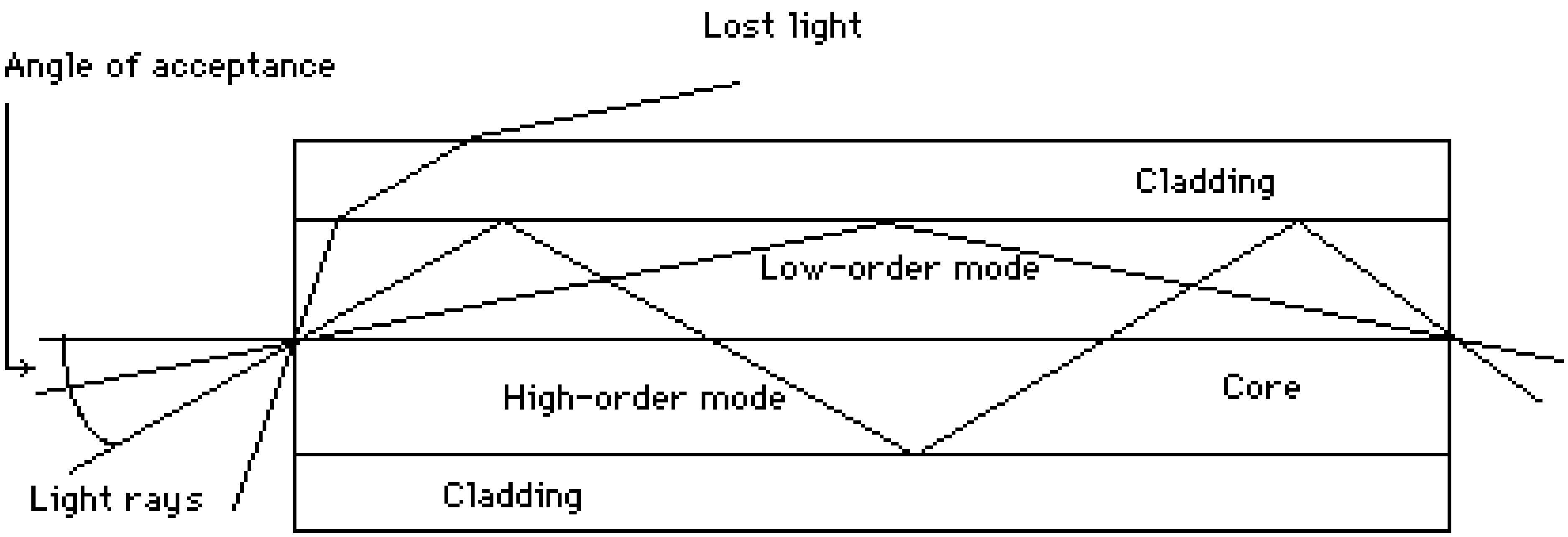
- When a very short pulse of light is put into an optical fiber, optical energy does not all reach far end at same time
  - Rays propagate through core at different angles
  - Causes exit pulse to be broadened or dispersed
- Optical fiber is a waveguide that oscillates in a number of different "modes," like a guitar string
  - These modes of oscillation carry energy down fiber; but they do it at different speeds
  - Hence, name is modal dispersion
  - Typical fiber with a 50-micrometer core may have several hundred modes
- In fiber, problem can be reduced by using a graded-index fiber
  - High-angle rays, with a longer physical distance to travel, spend more time in regions of glass with a lower index of refraction where speed of light is faster

Review (continued)

In a graded-index multi-mode fiber, rays travel through curved paths (see demo)

more sharply-curved paths of higher-order modes lie mostly in low-refraction areas near cladding, so that they propagate faster and arrive at same time as low-order modes

Light propagation in step-index multi-mode fiber is depicted in Figure



Review (continued)

dispersion

- If made small enough (but not too small), there is only *one mode* - *Single mode*
  - Modal dispersion disappears
- With a single-mode --> capacity is much higher
- However, more expensive light sources and connectors are required.
- Numerical aperture is a measure of fiber's ability to accept light
- Optical fibers are assigned dispersion ratings expressed either in
  - (a) bandwidth in megahertz (MHz) per kilometer or
  - (b) in time spread in nanoseconds per kilometer.

Review (continued)

$\sum_{i=1}^{N} \lambda i$

Chromatic dispersion

- Exists even in a single-mode fiber, Why?
- Although there is only one mode, pulse usually is composed of a small spectrum of wavelengths, and different wavelengths travel at different speeds in fiber
- Hence the name chromatic dispersion
- In visible spectrum of light, material dispersion causes longer wavelengths to travel faster than shorter ones
- But in near-infrared region around wavelengths of 1.1 to 1.3 microns, opposite beings to happen: longer wavelengths being to travel slower

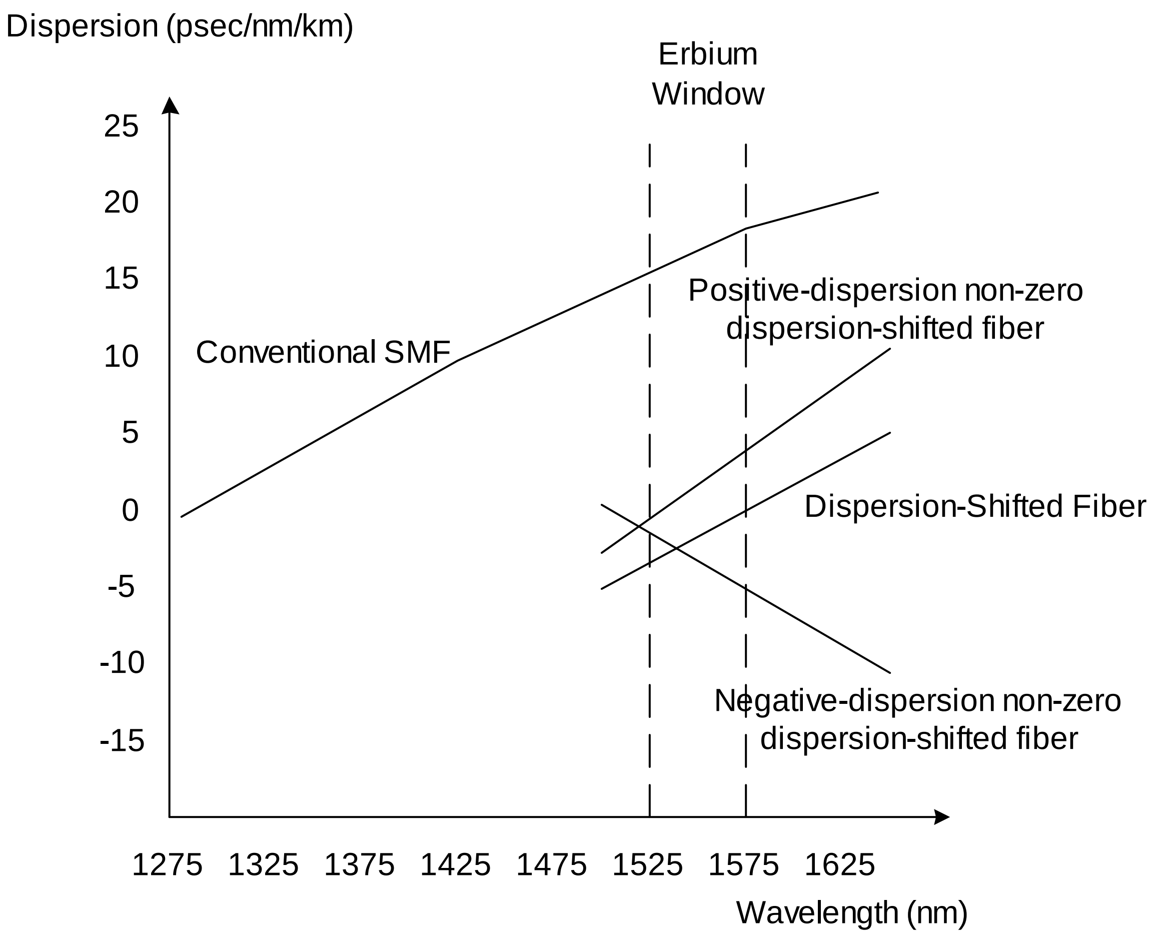
Review (continued)

$\sum_{i=1}^{N} \lambda_i$

Dispersion-shifted fiber

- For long distance applications it is desirable to operate at 1550 nm because of lower attenuation compared to 1300 nm
- However, simple step-index single-mode fiber shows a large chromatic dispersion at 1550 nm
- It is possible to design more sophisticated index profiles so that point where chromatic dispersion is zero falls near 1550 nm instead of 1300 nm
- This optical fiber is called a dispersion-shifted fiber
- Segmented-core fiber is an experimental new fiber that is designed to operate as a low-loss single-mode fiber at 1300 nm and 1550 nm while maintaining zero-dispersion wavelength in 1550 nm window

Dispersion Compensation



Chromatic Dispersion (continued)

- Dispersion Compensating Fiber (DCF)

- **Special fiber introduces high levels of negative dispersion over relatively short lengths, which offsets or cancels the positive dispersion accumulated by a pulse traveling through optically-amplified systems on standard single-mode fiber**

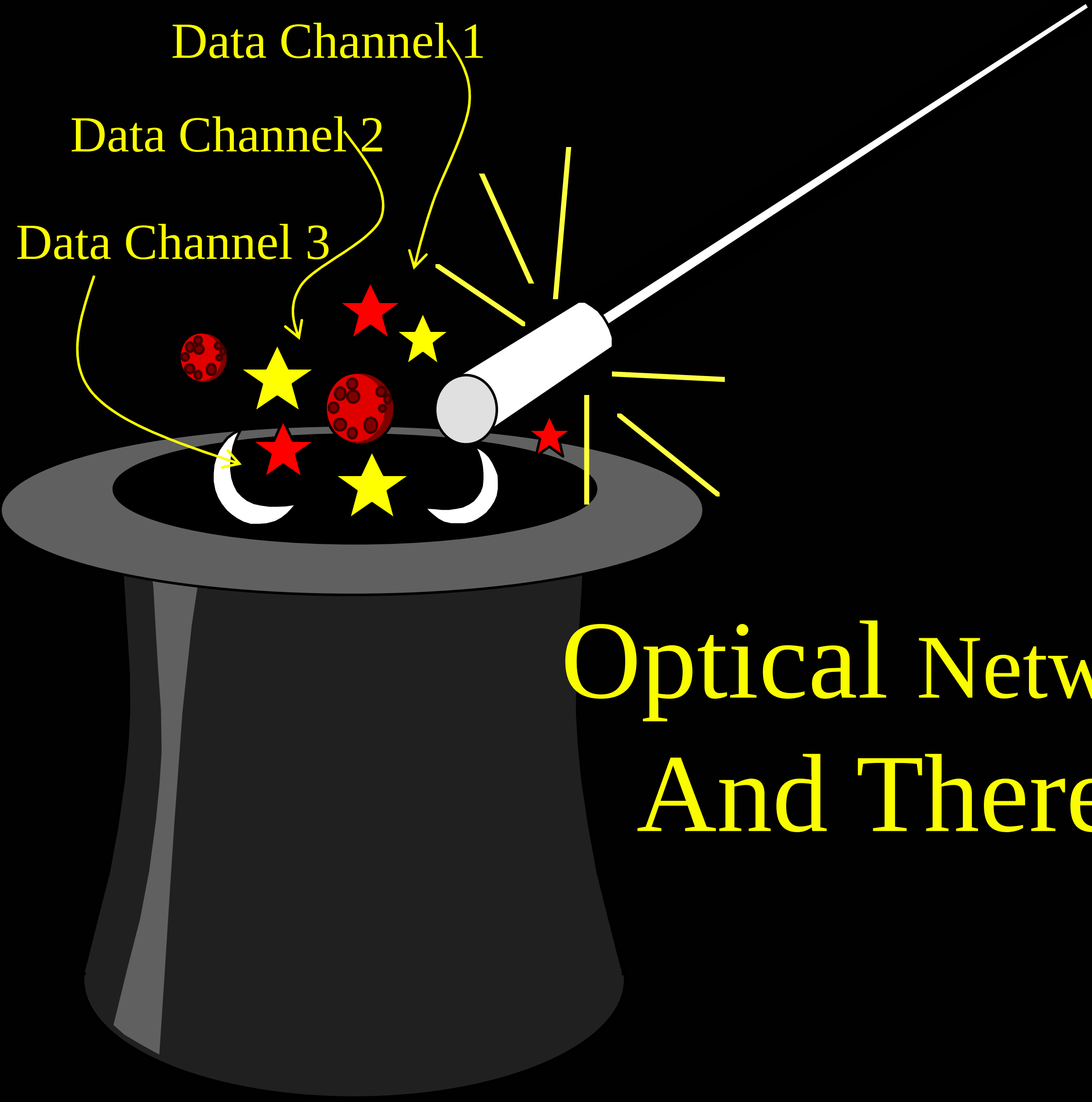
- Compensation is provided on a link by installing a specified length of dispersion-compensating fiber somewhere in the system (typically at the receive end), in the form of a small spool designed to minimize space within equipment racks
  - Signal light passes thru the span, then thru the dispersion-compensation fiber, and on to the receiver
  - Introduced in 1994
  - Widely used by people like MCI Worldcom
  - Advantages: broadband, fully passive, commercially available, and compatible with all-optical transparent network goals

Dispersion-compensating gratings

- Evolving method also applicable
- Basically: wavelength-selective mirrors written into the core of a SM fiber
- Invented by Nortel 1990… remained in lab until now
- Now working prototypes reaching marketplace for evaluation
- Compact, low-loss, and polarization-insensitive

End of Module 2

- Did you understand it all?
- Please provide a summary for this Module.
- Please read the assignments in preparation for Module 3.



Module 3

Optical Networking

And There Was Light ....