OPTICAL FIBER COMMUNICATION

Fiber-optic communication

- is a method of transmitting information from one place to another by sending light through an optical fiber.
- The light forms an electromagnetic carrier wave that is modulated to carry information.

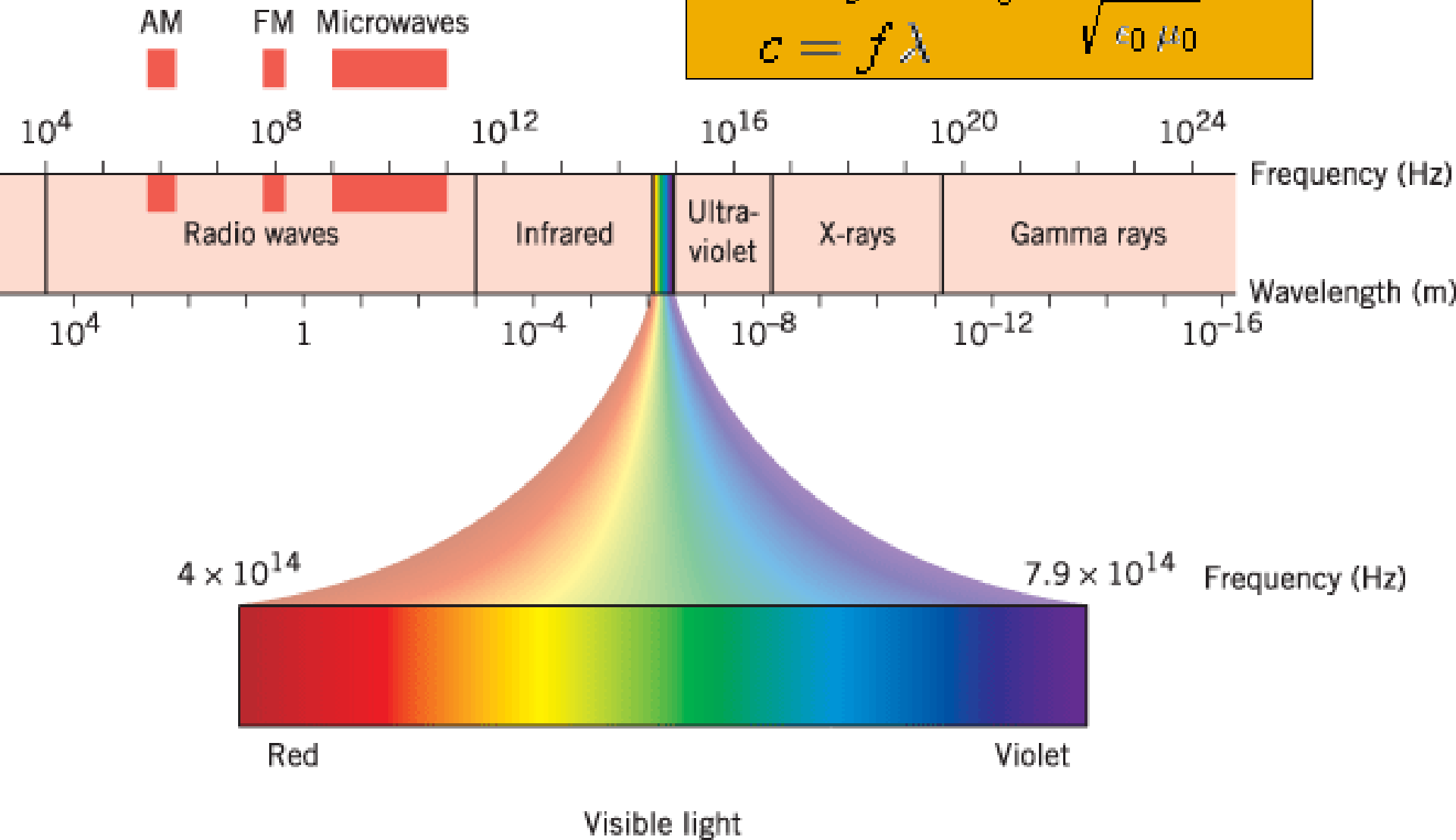
Fiber-optic communication

The process of communicating using fiber-optics involves the following basic steps:

- Creating the optical signal using a transmitter,
- relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak,
- and receiving the optical signal and converting it into an electrical signal.

Electromagnetic Spectrum

$$v = f\lambda \qquad c = f\lambda \qquad c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$



Evolution of Fiber

- 1880 – Alexander Graham Bell
- 1930 – Patents on tubing
- 1950 – Patent for two-layer glass wave-guide
- 1960 – Laser first used as light source
- 1965 – High loss of light discovered
- 1970s – Refining of manufacturing process
- 1980s – OF technology becomes backbone of long distance telephone networks in NA.

OPTICAL FIBER

- An **optical fiber** (or **fibre**) is a glass or plastic fiber that carries light along its length.

- Light is kept in the "core" of the optical fiber by total internal reflection.

Advantages of Optical Fibre

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

Advantages of fiber optics

- Much Higher Bandwidth (Gbps) - Thousands of channels can be multiplexed together over one strand of fiber
- Immunity to Noise - Immune to electromagnetic interference (EMI).
- Safety - Doesn't transmit electrical signals, making it safe in environments like a gas pipeline.
- High Security - Impossible to "tap into."

Advantages of fiber optics

- Less Loss - Repeaters can be spaced 75 miles apart (fibers can be made to have only 0.2 dB/km of attenuation)
- Reliability - More resilient than copper in extreme environmental conditions.
- Size - Lighter and more compact than copper.
- Flexibility - Unlike impure, brittle glass, fiber is physically very flexible.

Fiber Optic Advantages

- greater capacity (bandwidth up to 2 Gbps, or more)
- smaller size and lighter weight
- lower attenuation
- immunity to environmental interference
- highly secure due to tap difficulty and lack of signal radiation

DisAdvantages of fiber optics

- Disadvantages include the cost of interfacing equipment necessary to convert electrical signals to optical signals. (optical transmitters, receivers) Splicing fiber optic cable is also more difficult.

Fiber Optic Disadvantages

- expensive over short distance
- requires highly skilled installers
- adding additional nodes is difficult

Areas of Application

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

Fiber Optic Cable

- relatively new transmission medium used by telephone companies in place of long-distance trunk lines
- also used by private companies in implementing local data networks
- require a light source with injection laser diode (ILD) or light-emitting diodes (LED)
- fiber to the desktop in the future

Fiber Optic Cable

Fiber Optic Cable

A thin glass cable approximately a little thicker than a human hair surrounded by a plastic coating and packaged into an insulated cable.

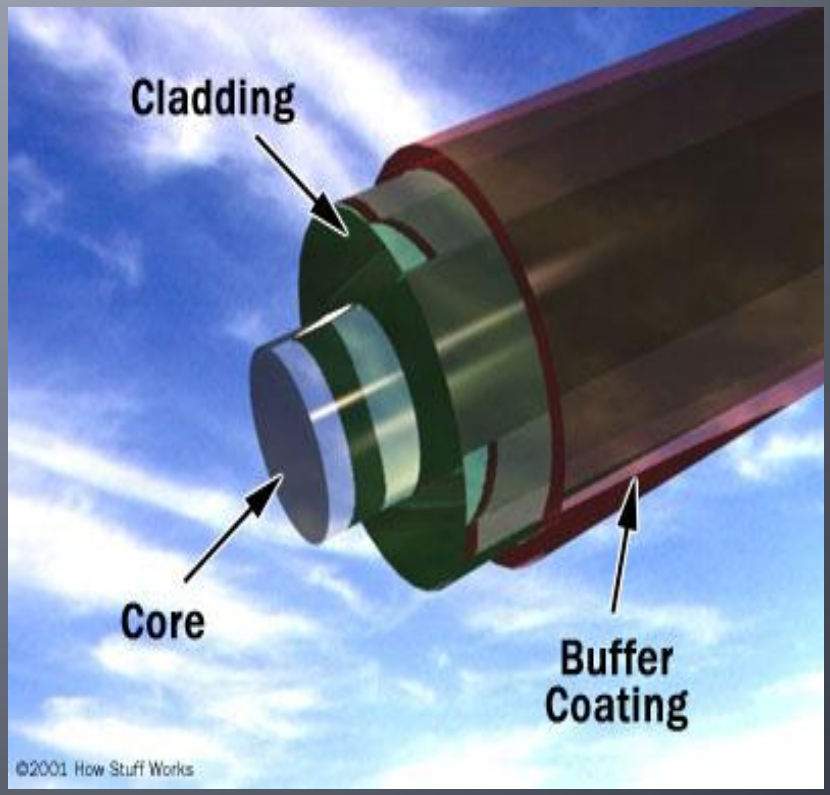
A photo diode or laser generates pulses of light which travel down the fiber optic cable and are received by a photo receptor.

OPTICAL FIBER

- Optical fiber consists of a core, cladding, and a protective outer coating, which guides light along the core by total internal reflection.

OPTICAL FIBER CONSTRUCTION

Core – thin glass center of the fiber where light travels.
Cladding – outer optical material surrounding the core
Buffer Coating – plastic coating that protects the fiber.

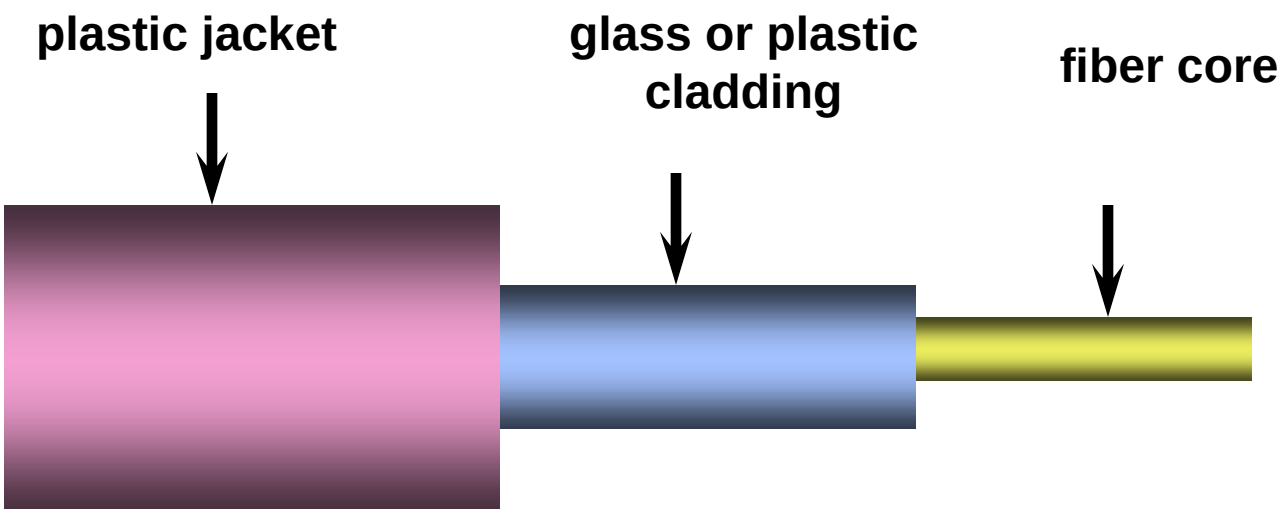


OPTICAL FIBER

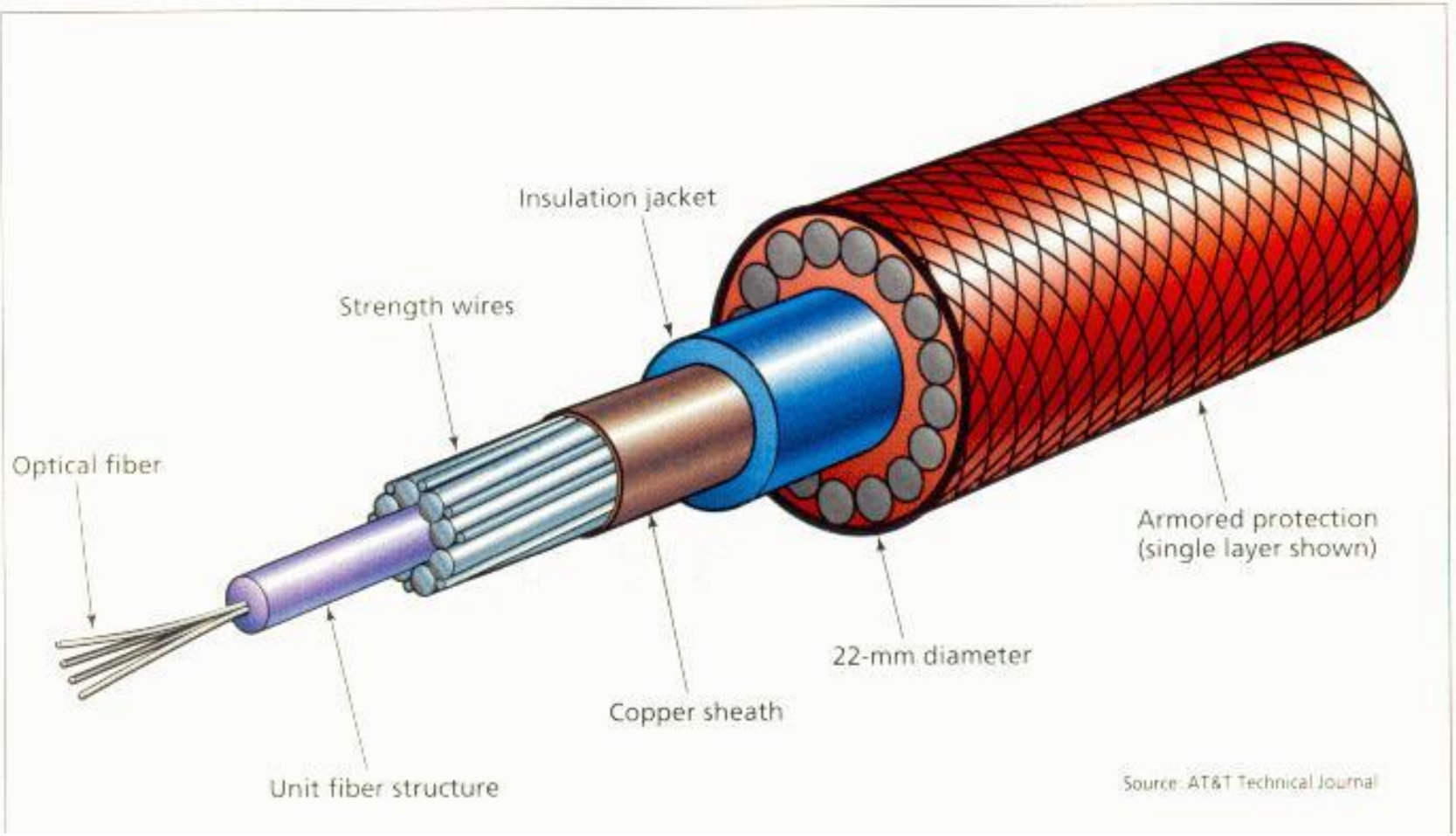
- The core, and the lower-refractive-index cladding, are typically made of high-quality silica glass, though they can both be made of plastic as well.

Fiber Optic Layers

- consists of three concentric sections

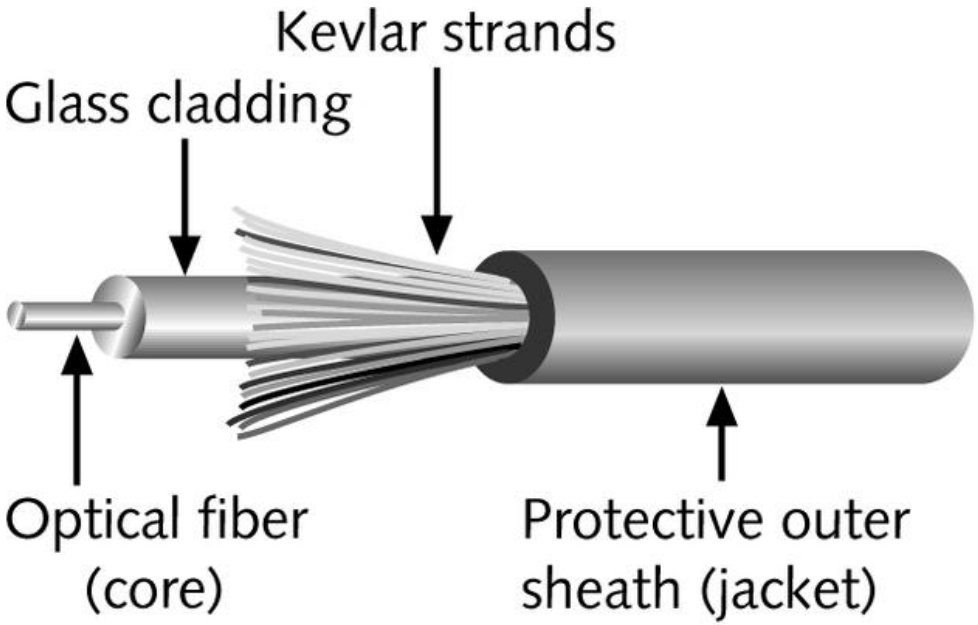


Fiber Optic Cable

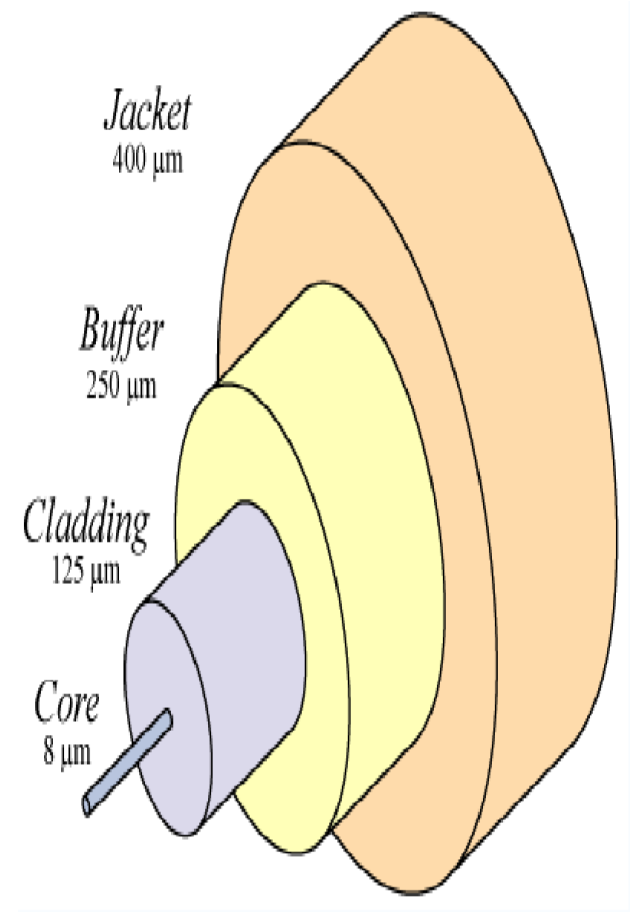


Fiber-Optic Cable

- Contains one or several glass fibers at its **core**
  - Surrounding the fibers is a layer of glass called **cladding**



Fiber-Optic Cable



1. Plastic core and cladding
2. Glass core with plastic cladding (called PCS fiber- Plastic Clad Silica)
3. Glass core and glass cladding (called SCS - Silica Clad Silica)

PHYSICS OF LIGHT

- **Photons (light "particles")**

  light represented by tiny bundles of energy (or quanta), following straight line paths along the rays.

PHYSICS OF LIGHT

PLANCK'S LAW

$$Ep = hf$$

Where,

Ep – energy of the photon (joules)
h = Planck's constant = 6.625×10^{-34} J-s
f – frequency o f light (photon) emitted (hertz)

INDEX OF REFRACTION

Index of Refraction

- When light travels in materials, the speed is modified:

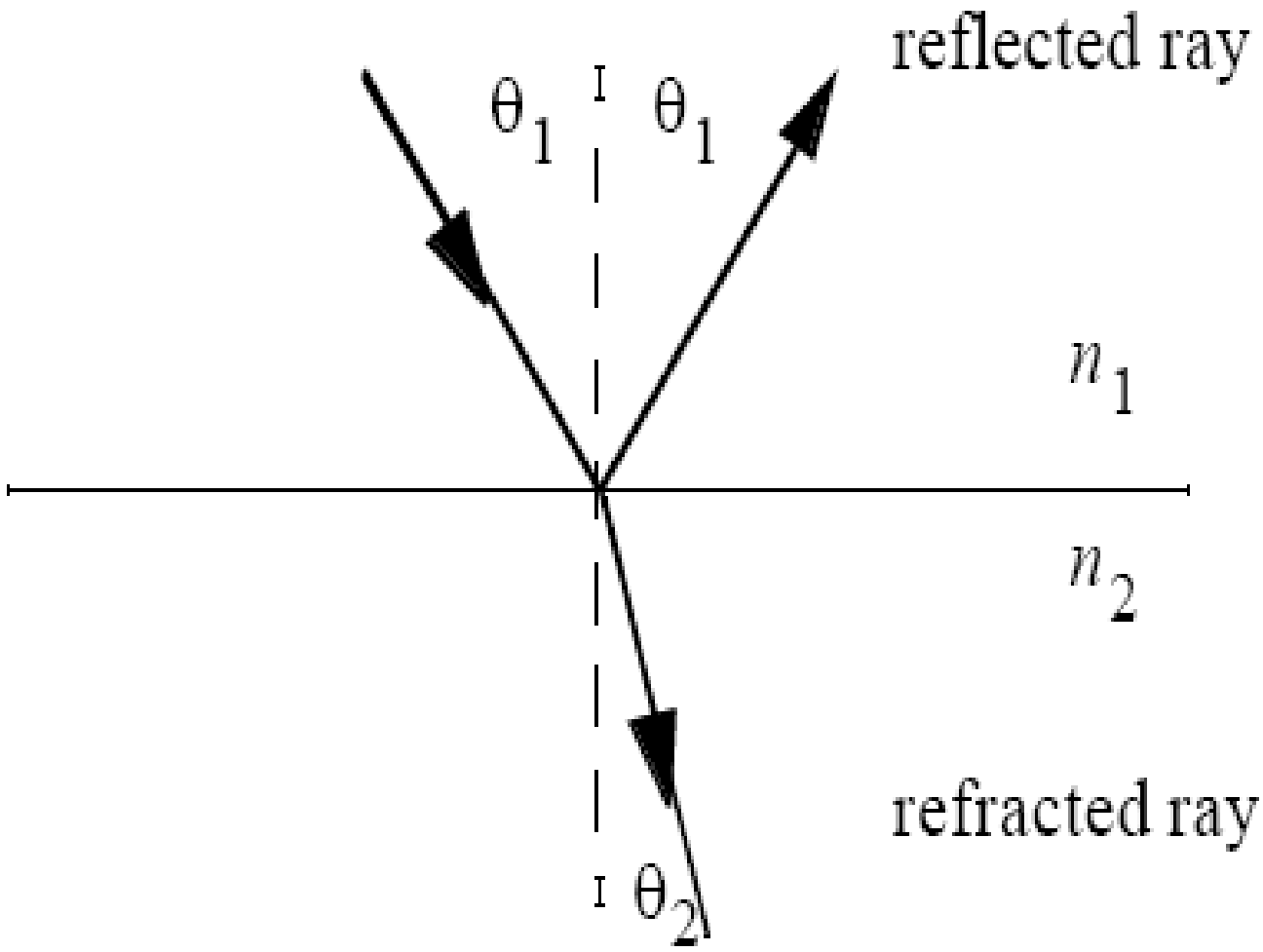
$$v = \frac{c}{n} = \lambda f$$

Usually $n \geq 1$. (It can be < 1)

Snell's Law

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} \rightarrow \begin{array}{ll} \text{if } n_2 > n_1 & \theta_2 < \theta_1 \\ \text{if } n_1 > n_2 & \theta_2 > \theta_1 \end{array}$$

Snell's Law



Example:

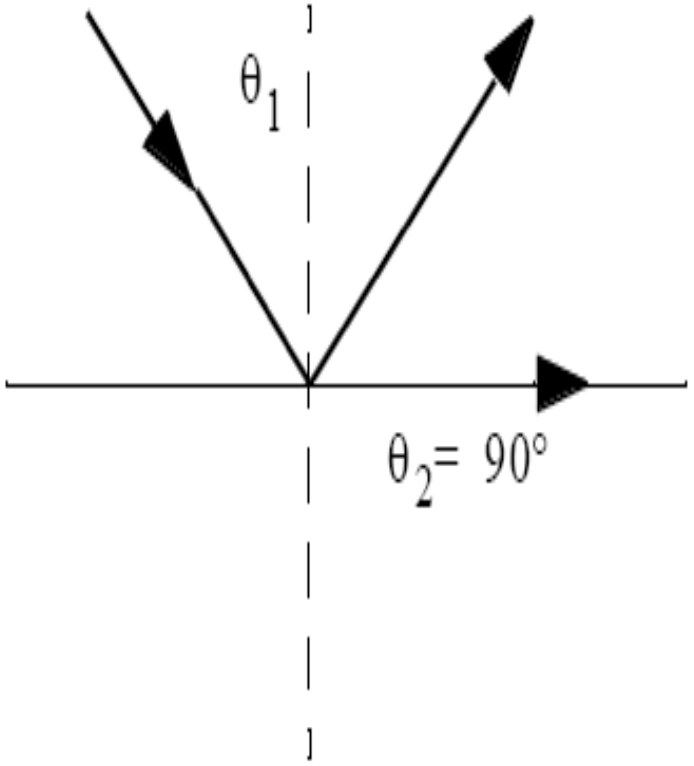
- Let medium 1 be glass (n1 = 1.5) and medium 2 by ethyl alcohol (n2 = 1.36). For an angle of incidence of 30°, determine the angle of refraction.

- Answer: 33.47°

Snell's Law

Total Reflection

If $n_1 > n_2$, then we can have

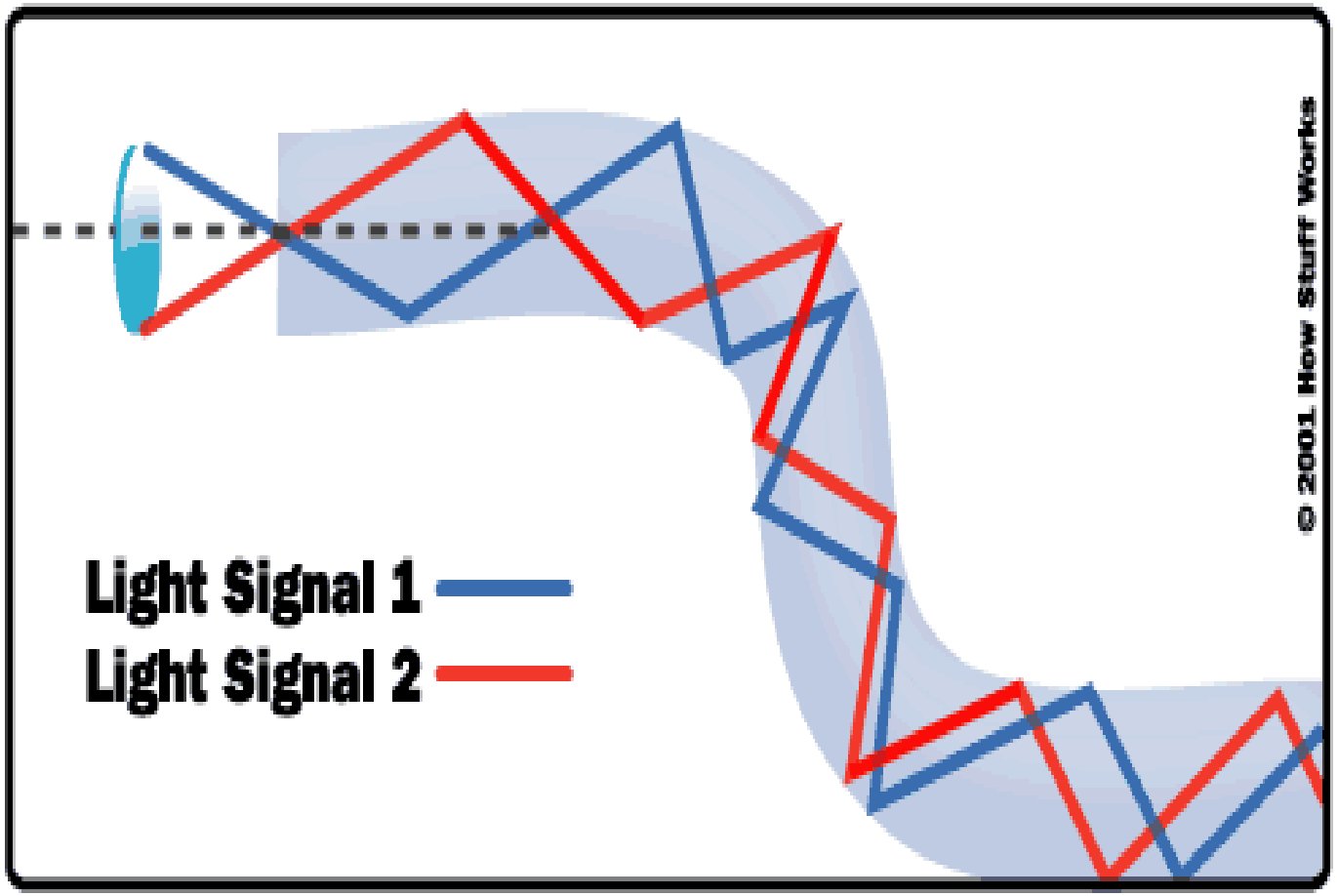


$$\theta_2 = 90°$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\theta_c = \sin^{-1}(n_2/n_1)$$

Total Internal Reflection in Fiber



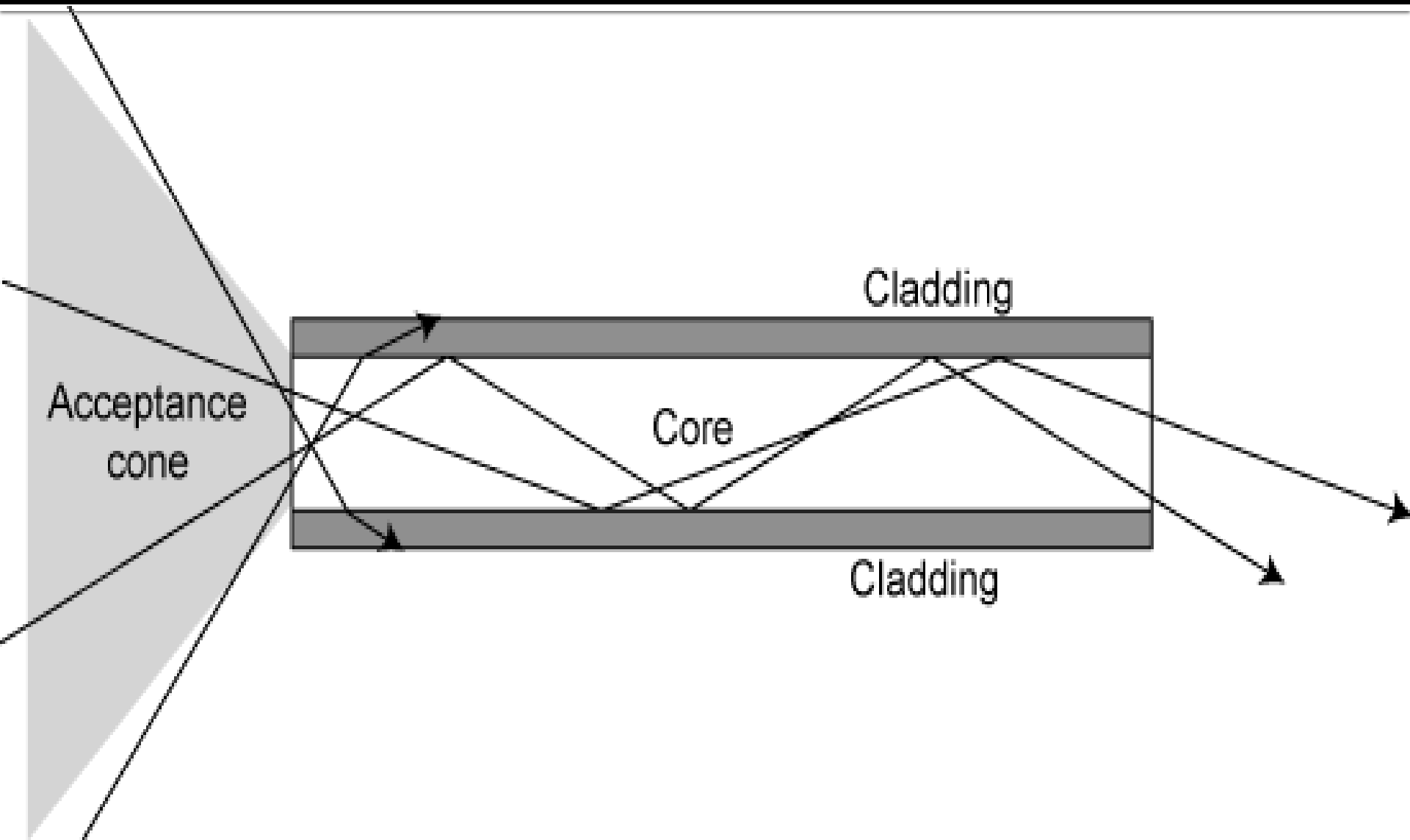
Critical angle, θc

- The minimum angle of incidence at which a light ray ay strike the interface of two media and result in an angle of refraction of 90° or greater.

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.

Acceptance angle /cone half-angle

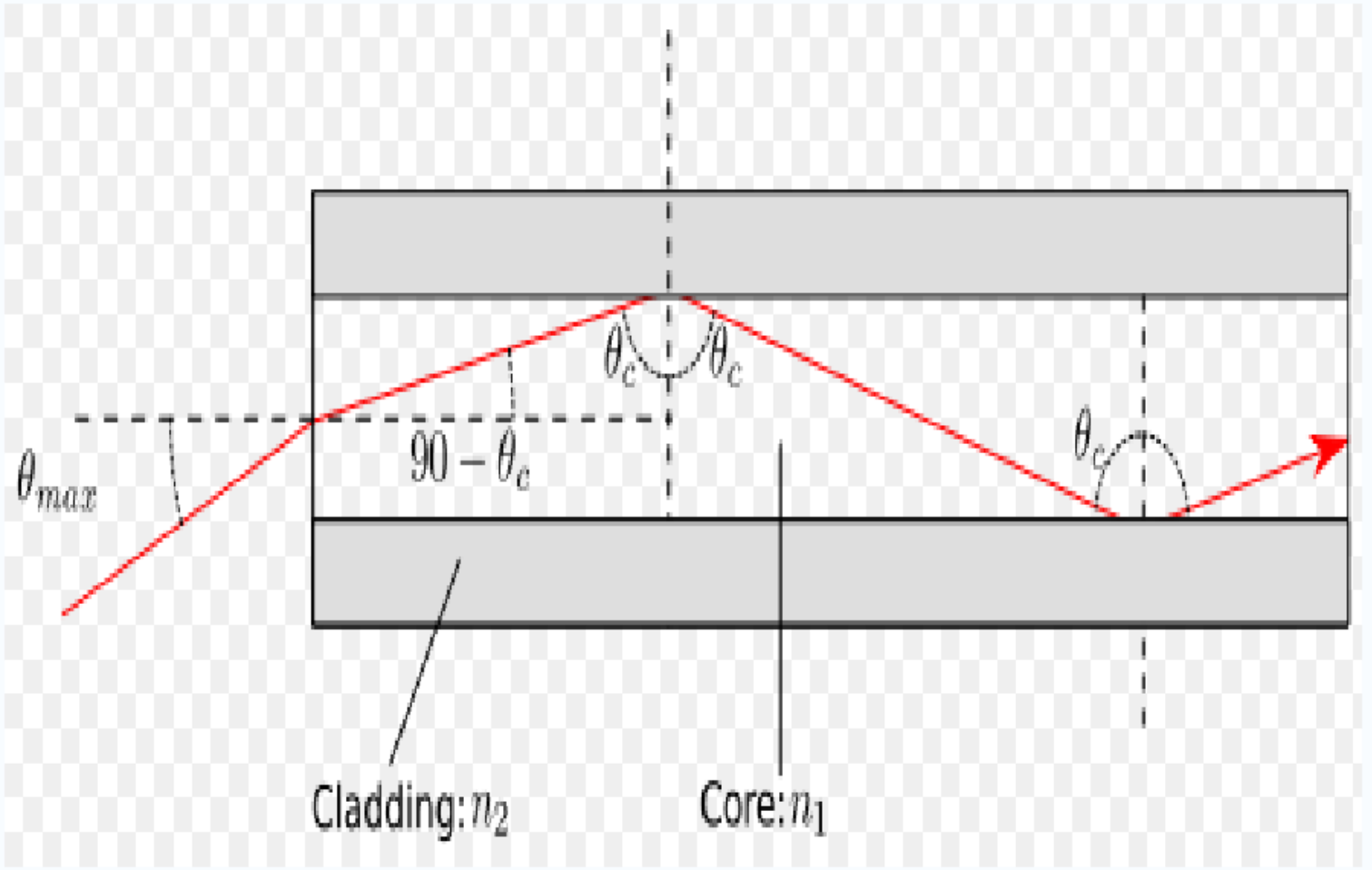


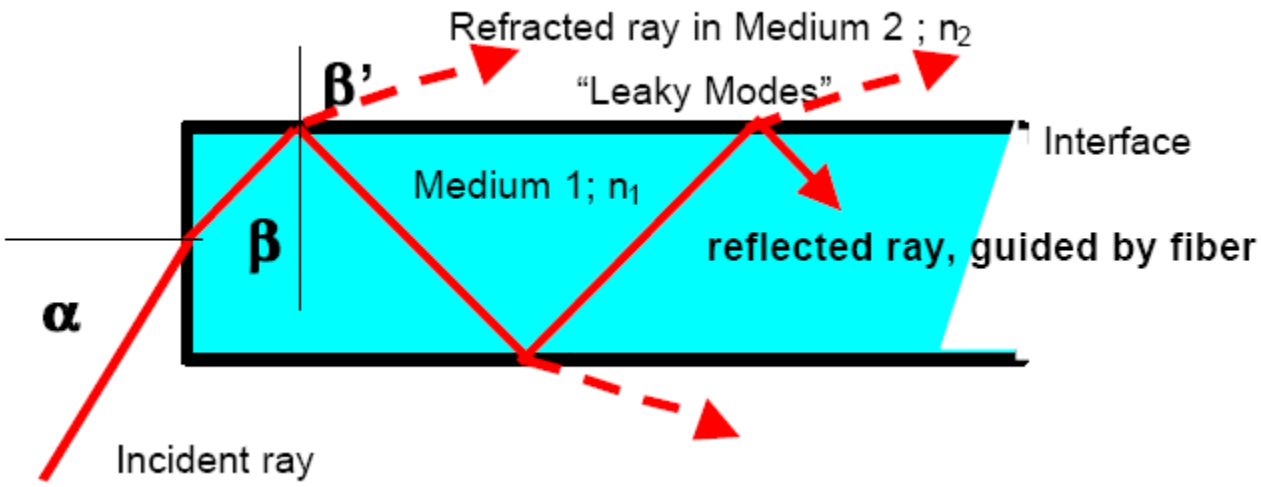
Acceptance angle /cone half-angle

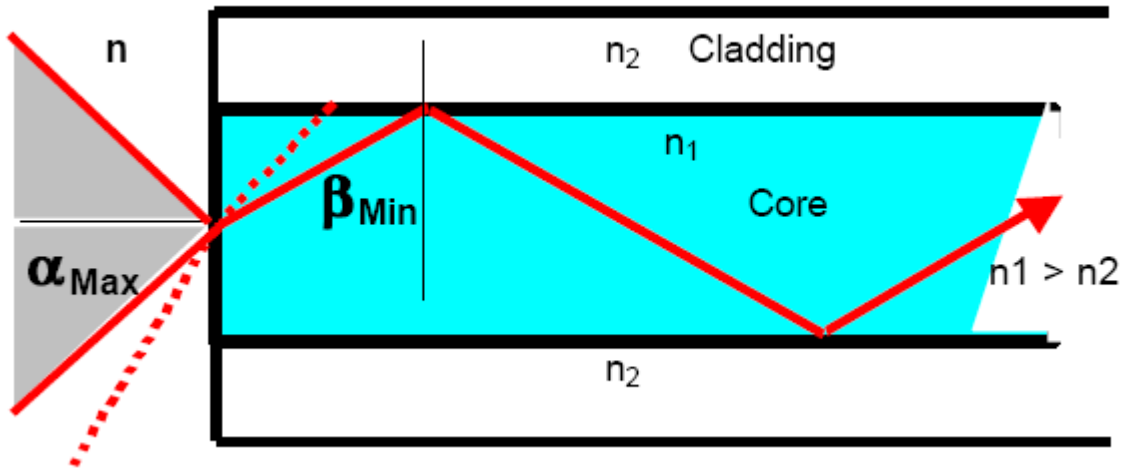
- θin (max) = sin-1 $\sqrt{n_1^2 - n_2^2}$,

- Where,
- θin (max) – acceptance angle (degrees)
- n1 – refractive index of glass fiber core (1.5)
- n2 – refractive index of quartz fiber cladding (1.46)

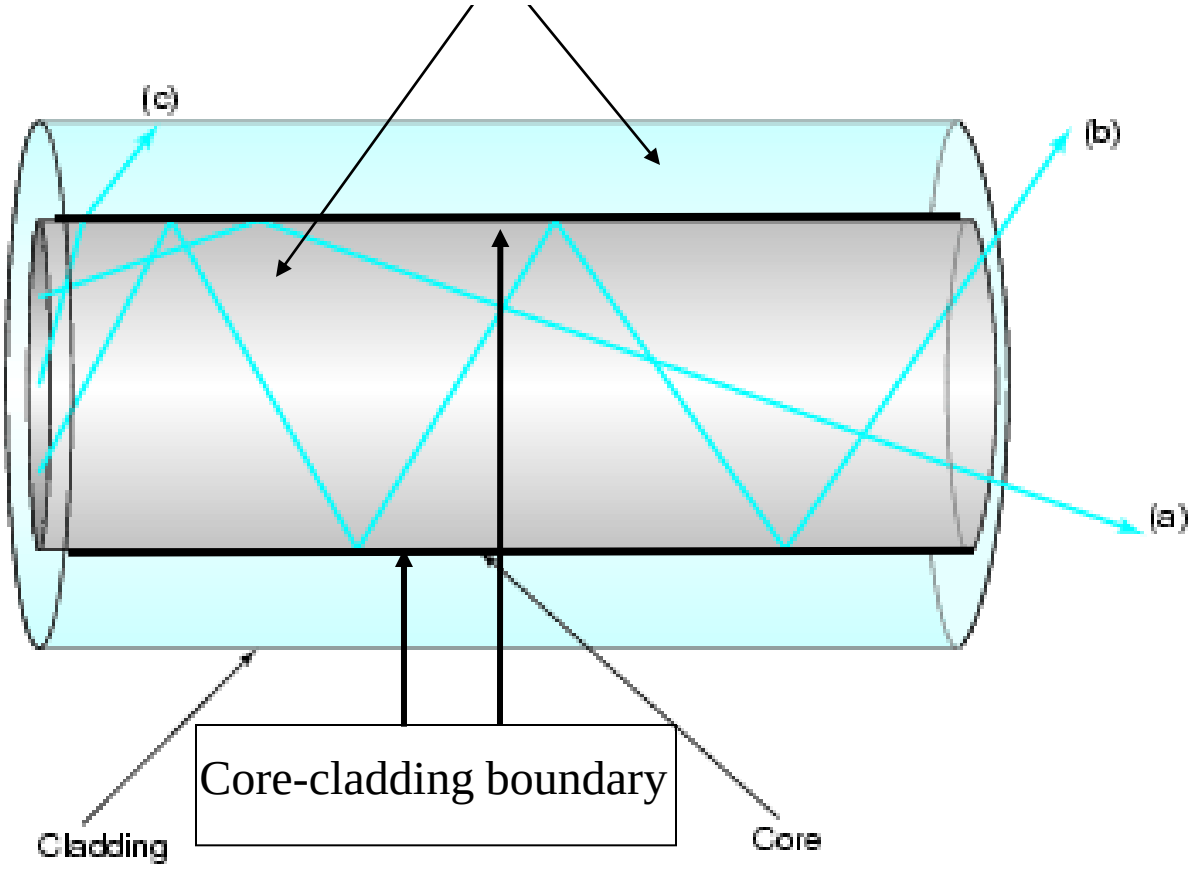
Acceptance angle /cone half-angle




Refracted ray in Medium 2 ; n_2
β'
"Leaky Modes"
Interface
Medium 1; n_1
β
reflected ray, guided by fiber
α
Incident ray


n
n_2 Cladding
n_1
β_{Min}
Core
α_{Max}
n1 > n2
n_2

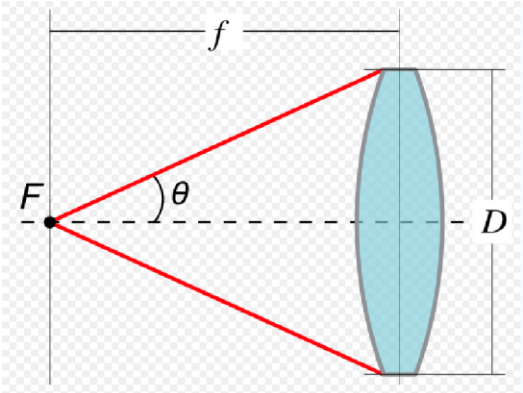
Core and cladding with different indices of refraction



Numerical Aperture (NA)

- Used to describe the light-gathering or light-collecting ability of an optical fiber.
- In optics, the **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

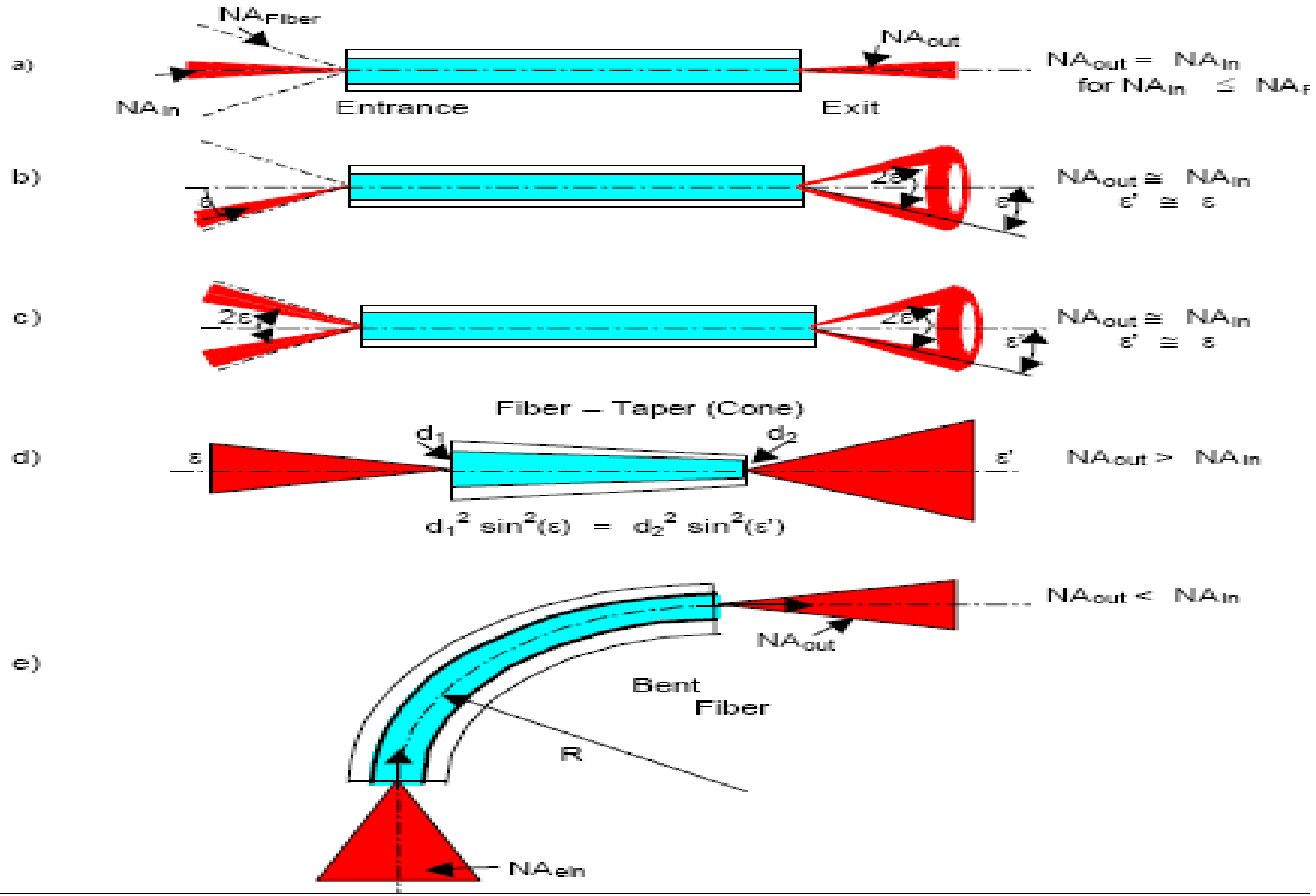
Numerical Aperture (NA)



$$\mathrm{NA} = \sqrt{n_1^2 - n_2^2},$$

The numerical aperture in respect to a point *P* depends on the half-angle *θ* of the maximum cone of light that can enter or exit the lens.

Numerical Aperture (NA)



MODE OF PROPAGATION

- Two main categories of optical fiber used in fiber optic communications are multi-mode optical fiber and single-mode optical fiber.

SINGLE-MODE FIBERS

- **Single-mode fibers** – used to transmit one signal per fiber (used in telephone and cable TV). They have small cores(9 microns in diameter) and transmit infra-red light from laser.

SINGLE-MODE FIBERS

- Single-mode fiber's smaller core (<10 micrometres) necessitates more expensive components and interconnection methods, but allows much longer, higher-performance links.

MULTI-MODE FIBERS

- **Multi-mode fibers** – used to transmit many signals per fiber (used in computer networks). They have larger cores(62.5 microns in diameter) and transmit infra-red light from LED.

MULTI-MODE FIBERS

- Multimode fiber has a larger core (≥ 50 micrometres), allowing less precise, cheaper transmitters and receivers to connect to it as well as cheaper connectors.

MULTI-MODE FIBERS

- However, multi-mode fiber introduces multimode distortion which often limits the bandwidth and length of the link. Furthermore, because of its higher dopant content, multimode fiber is usually more expensive and exhibits higher attenuation.

INDEX PROFILE

- The index profile of an optical fiber is a graphical representation of the magnitude of the refractive index across the fiber.
- The refractive index is plotted on the horizontal axis, and the radial distance from the core axis is plotted on the vertical axis.

INDEX PROFILE

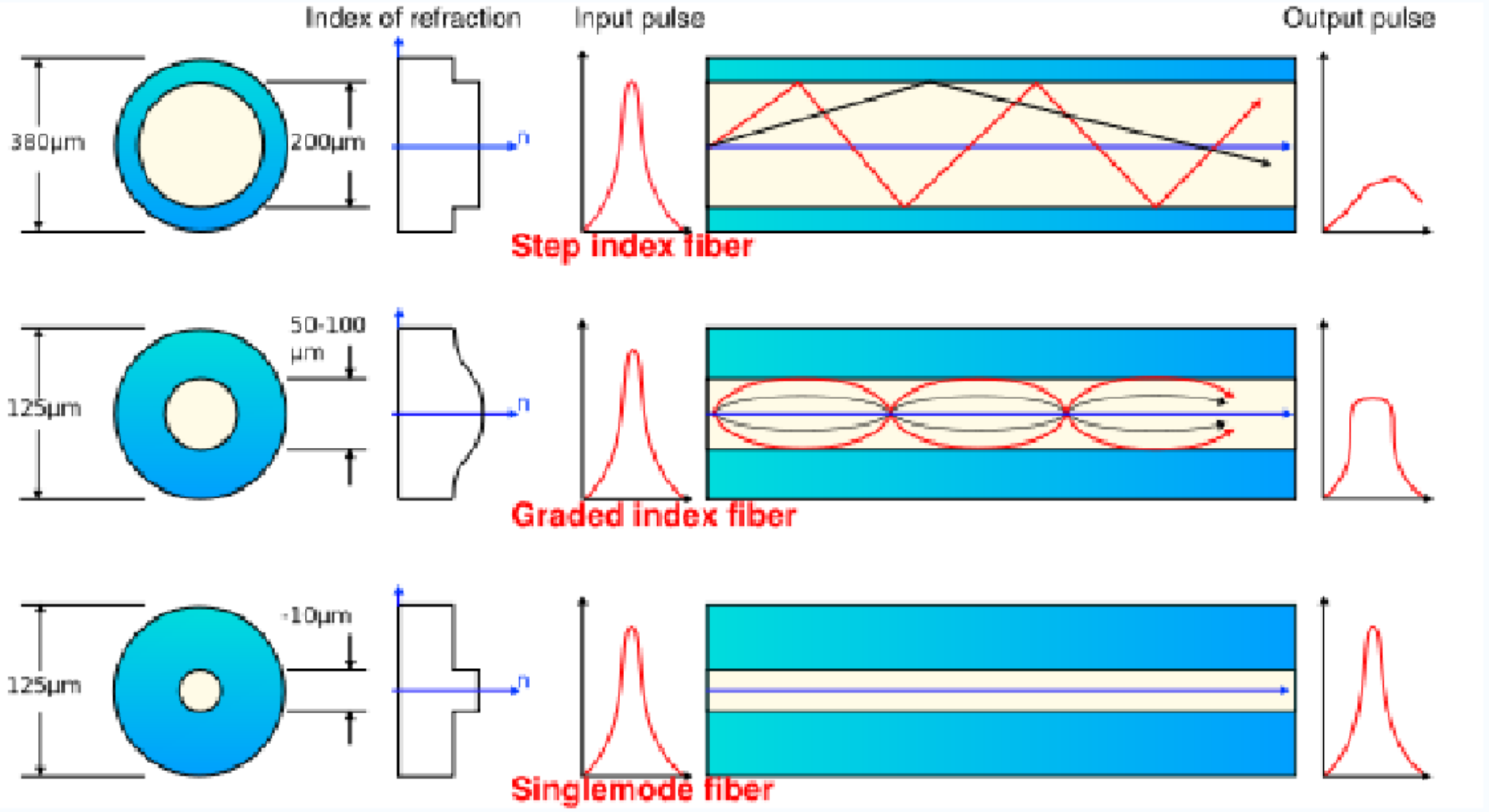
- The boundary between the core and cladding may either be abrupt, in ***step-index fiber***, or gradual, in ***graded-index fiber***.

STEP-INDEX

- A step-index fiber has a central core with a uniform refractive index. An outside cladding that also has a uniform refractive index surrounds the core;
- however, the refractive index of the cladding is less than that of the central core.

GRADED-INDEX

- In graded-index fiber, the index of refraction in the core decreases continuously between the axis and the cladding. This causes light rays to bend smoothly as they approach the cladding, rather than reflecting abruptly from the core-cladding boundary.

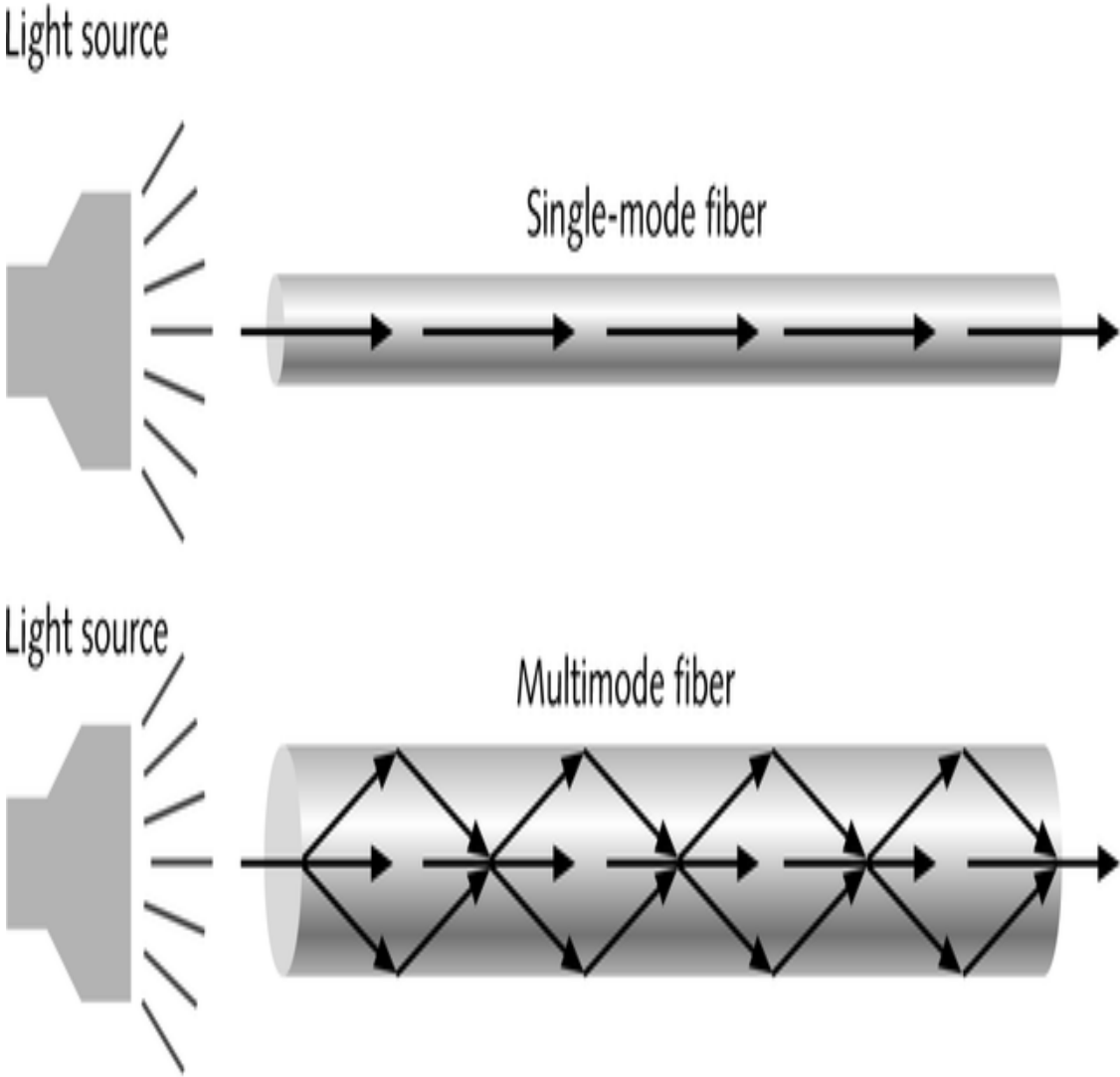

Index of refraction
Input pulse
Output pulse
380µm
200µm
n
Step index fiber
50-100
µm
125µm
n
Graded index fiber
10µm
125µm
n
Singlemode fiber

Fiber Optic Types

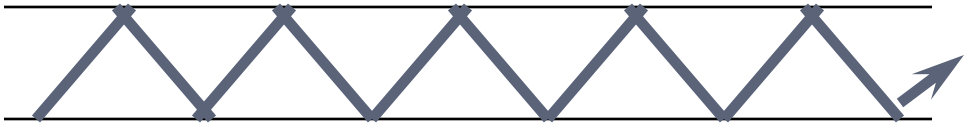
- multimode step-index fiber
  - the reflective walls of the fiber move the light pulses to the receiver
- multimode graded-index fiber
  - acts to refract the light toward the center of the fiber by variations in the density
- single mode fiber
  - the light is guided down the center of an extremely narrow core

Fiber-Optic Cable

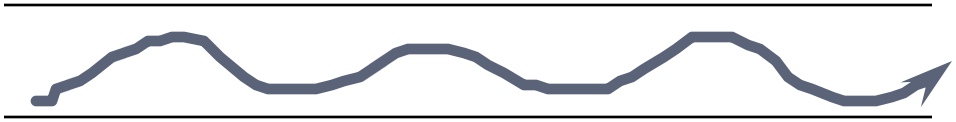
- Single-mode fiber
  - Carries light pulses along single path
- Multimode fiber
  - Many pulses of light generated by LED travel at different angles



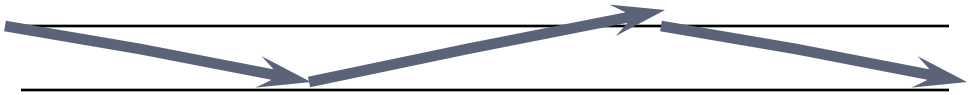
Fiber Optic Signals



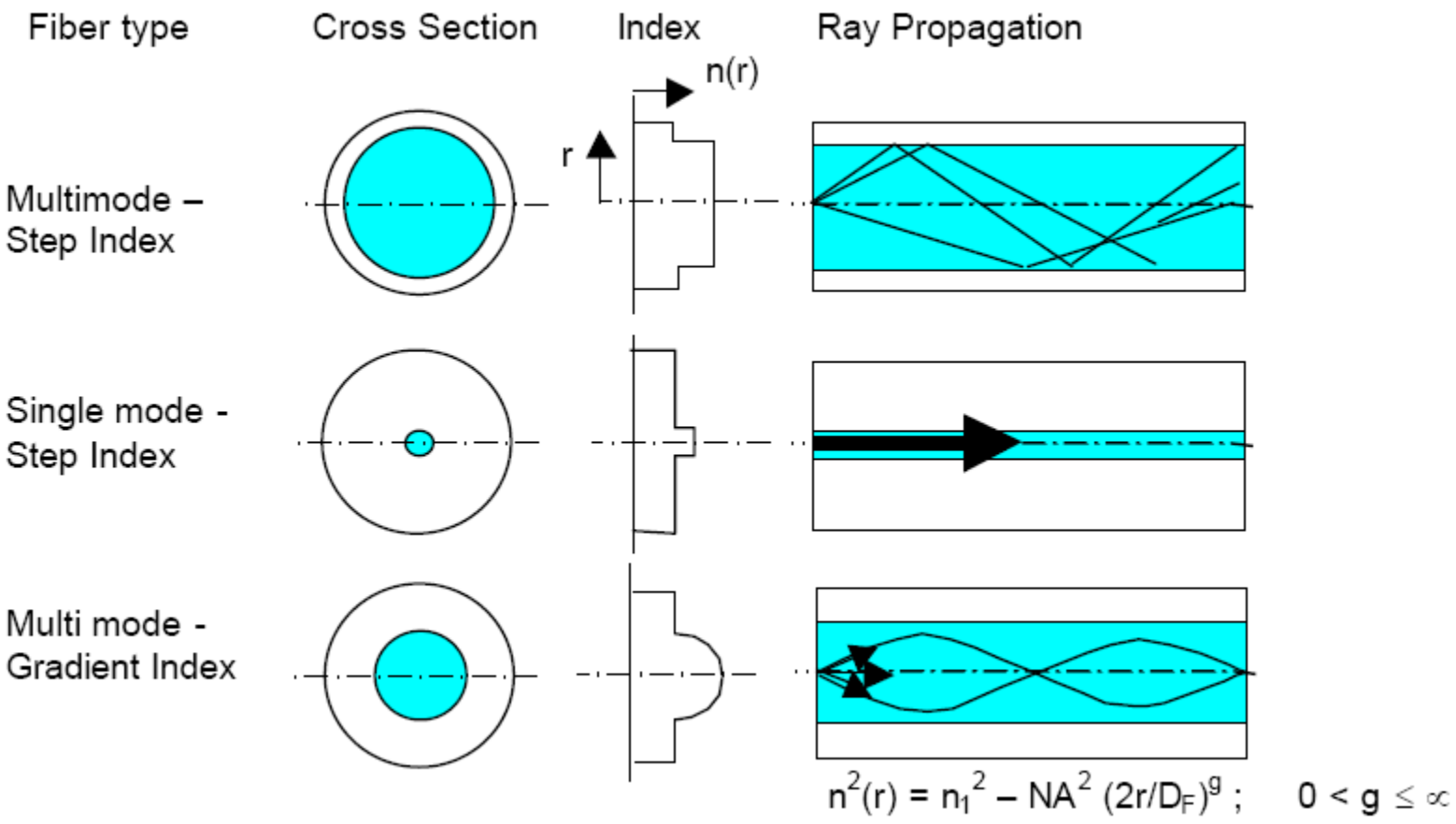
fiber optic multimode
step-index



fiber optic multimode
graded-index



fiber optic single mode


Fiber type
Cross Section
Index
Ray Propagation
n(r)
r
Multimode –
Step Index
Single mode -
Step Index
Multi mode -
Gradient Index
$n^2(r) = n_1^2 - NA^2 (2r/D_F)^g$;
$0 < g \leq \infty$

Transmitters

- light-emitting diodes (LEDs)
- laser diodes

Transmitters

- LEDs produce incoherent light
- laser diodes produce coherent light.

LED

- LED is a forward-biased p-n junction, emitting light through spontaneous emission, a phenomenon referred to as electroluminescence.
- The emitted light is incoherent with a relatively wide spectral width of 30-60 nm.

LED

- LED light transmission is also inefficient, with only about 1 % of input power, or about 100 microwatts, eventually converted into «launched power» which has been coupled into the optical fiber.
- However, due to their relatively simple design, LEDs are very useful for low-cost applications.

LED

- Communications LEDs are most commonly made from gallium arsenide phosphide (GaAsP) or gallium arsenide (GaAs)
- Because GaAsP LEDs operate at a longer wavelength than GaAs LEDs (1.3 micrometers vs. 0.81-0.87 micrometers), their output spectrum is wider by a factor of about 1.7.

LED

- LEDs are suitable primarily for local-area-network applications with bit rates of 10-100 Mbit/s and transmission distances of a few kilometers.
- LEDs have also been developed that use several quantum wells to emit light at different wavelengths over a broad spectrum, and are currently in use for local-area WDM networks.

LASER

- A semiconductor laser emits light through stimulated emission rather than spontaneous emission, which results in high output power (~100 mW) as well as other benefits related to the nature of coherent light.

LASER

- The output of a laser is relatively directional, allowing high coupling efficiency (~50 %) into single-mode fiber. The narrow spectral width also allows for high bit rates since it reduces the effect of chromatic dispersion. Furthermore, semiconductor lasers can be modulated directly at high frequencies because of short recombination time.

LASER

- Laser diodes are often directly modulated, that is the light output is controlled by a current applied directly to the device.

Receivers

- The main component of an optical receiver is a photodetector that converts light into electricity through the photoelectric effect.

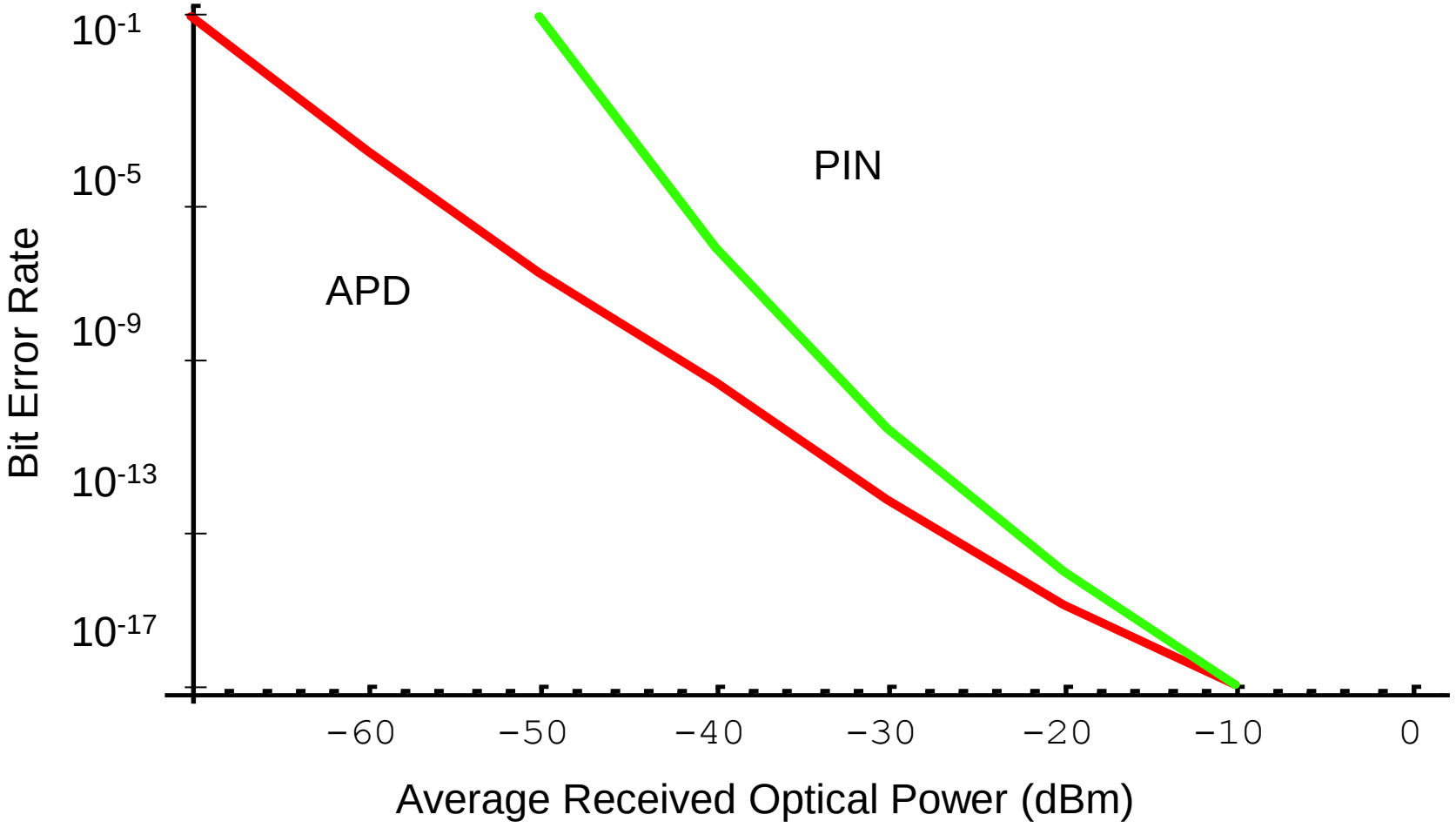
Receivers

- The photodetector is typically a semiconductor-based photodiode, such as a p-n photodiode, a p-i-n photodiode, or an avalanche photodiode.

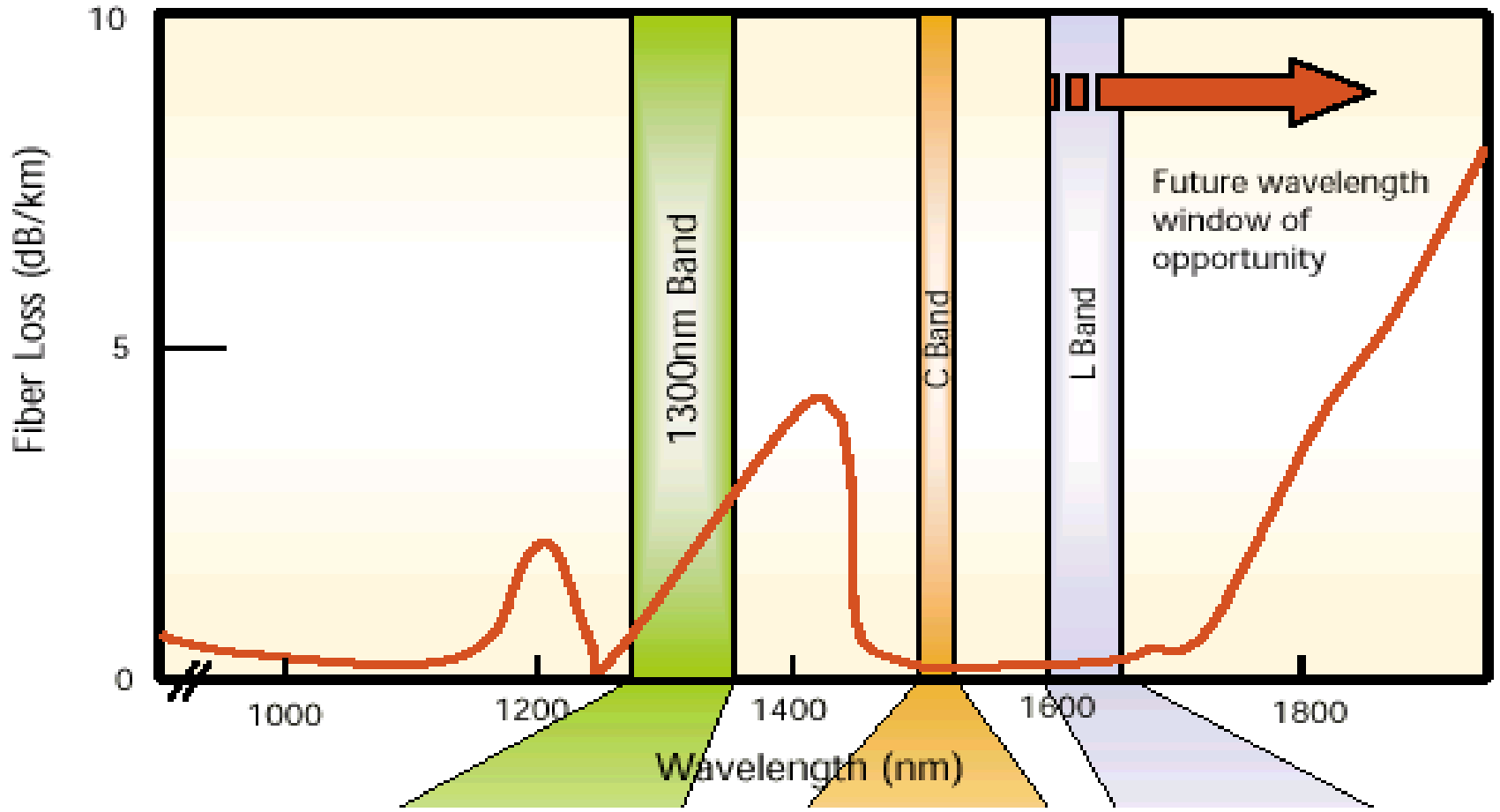
Receivers

- Metal-semiconductor-metal (MSM) photodetectors are also used due to their suitability for circuit integration in regenerators and wavelength-division multiplexers.

Receivers


Bit Error Rate
10-1
10-5
10-9
10-13
10-17
APD
PIN
−60
−50
−40
−30
−20
−10
0
Average Received Optical Power (dBm)

Fiber Transmission



Transmission windows

Band	Description	Wavelength Range
O band	original	1260 to 1360 nm
E band	extended	1360 to 1460 nm
S band	short wavelengths	1460 to 1530 nm
C band	conventional ("erbium window")	1530 to 1565 nm
L band	long wavelengths	1565 to 1625 nm
U band	Ultra-long wavelengths	1625 to 1675 nm

Fiber-Optic Cable

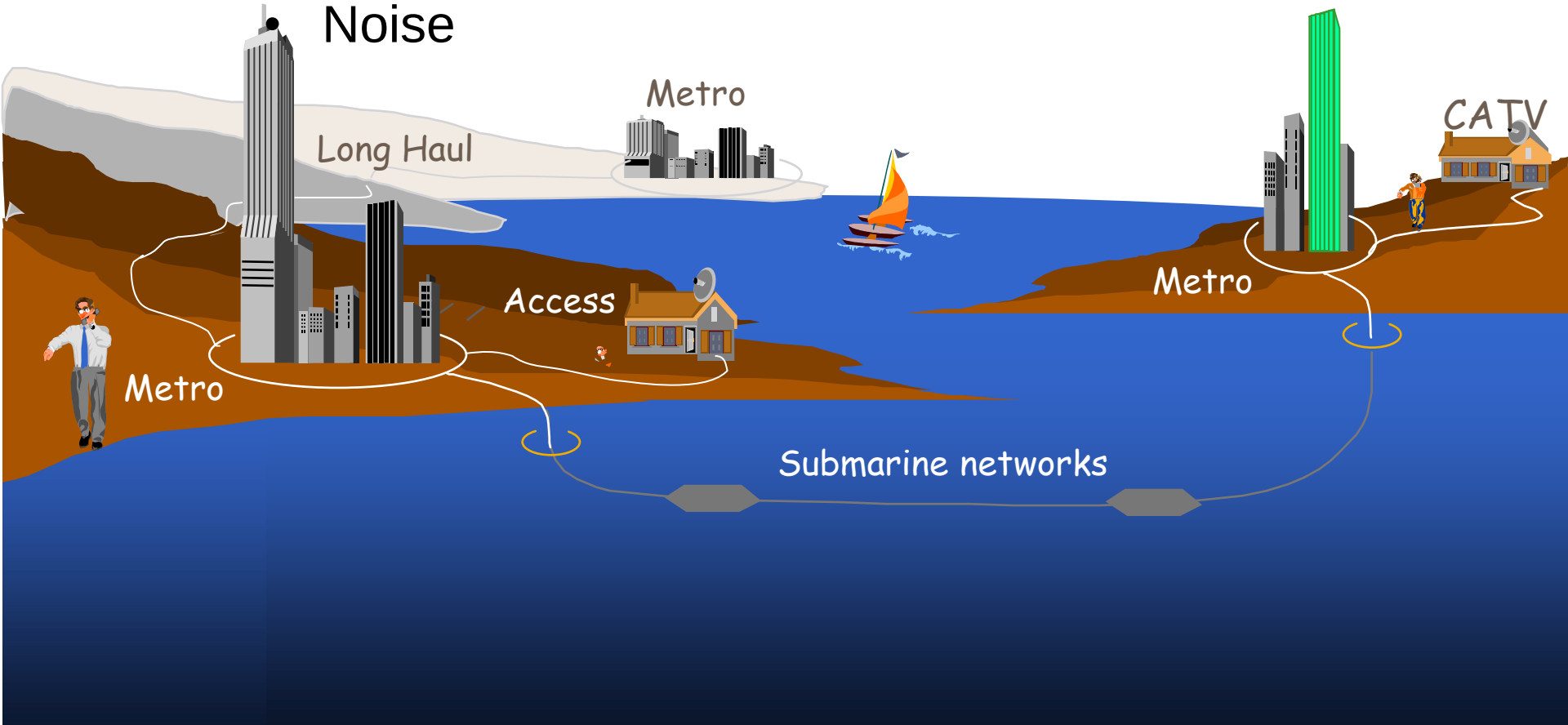
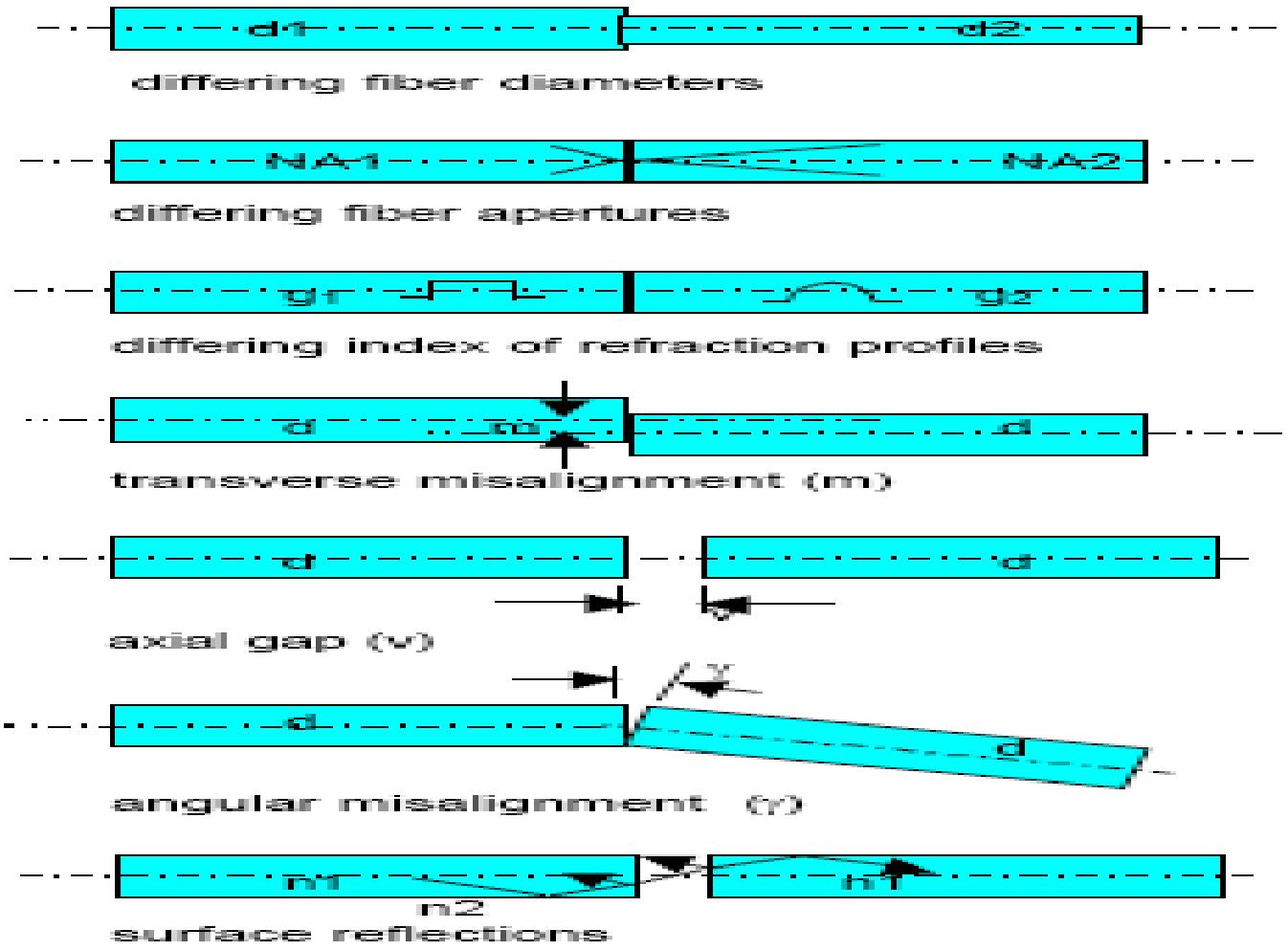
- Two popular connectors used with fiber-optic cable:
  - ST connectors
  - SC connectors

ST connectors

SC connectors

Long Haul Fiber System Overview

- Types of Systems
- Pulse quality
- Bit Error Rate
- Noise



COUPLING LOSSES