Incab

Fiber Optics 101

Basics of Fiber Optics

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PURPOSE STATEMENT / COURSE DESCRIPTION

FIBER OPTICS 101 will teach attendees what optical fiber is, how it works, and why we use it.

We will describe its construction and discuss the underlying physics that make it work along with the electromagnetic spectrum over which it is used.

We will describe the two key fiber performance factors: attenuation and dispersion. We will discuss what attenuation is, what the two sources of it are, and real-world limits for it.

Then we will discuss what dispersion is and what the three types of it are. We will review the three mostly commonly used types of optical fiber today.

We will finish with a brief discussion of two newer, advanced fiber types: non-zero dispersion shifted and G654 fiber.

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LEARNING OBJECTIVES

After this class you will be able to:

1. Explain what an optical fiber is and the purpose of each of its three components: core, cladding, and coating.
2. Explain the meaning and importance "total internal reflection."
3. State the advantages of using fiber optics versus using copper cables.
4. Explain the meaning and importance of these concepts as they apply to optical fiber: Snell's Law, index of refraction, and angle of incidence.
5. Explain the meaning and importance of wavelength and frequency as they apply to optical fiber and know those most used.
6. Explain what attenuation is, what its two sources are, and what its typical limits are.
7. Explain what dispersion is and what three types of it there are.
8. Name two newer, advanced fiber types and why they are used.

Learning Hub

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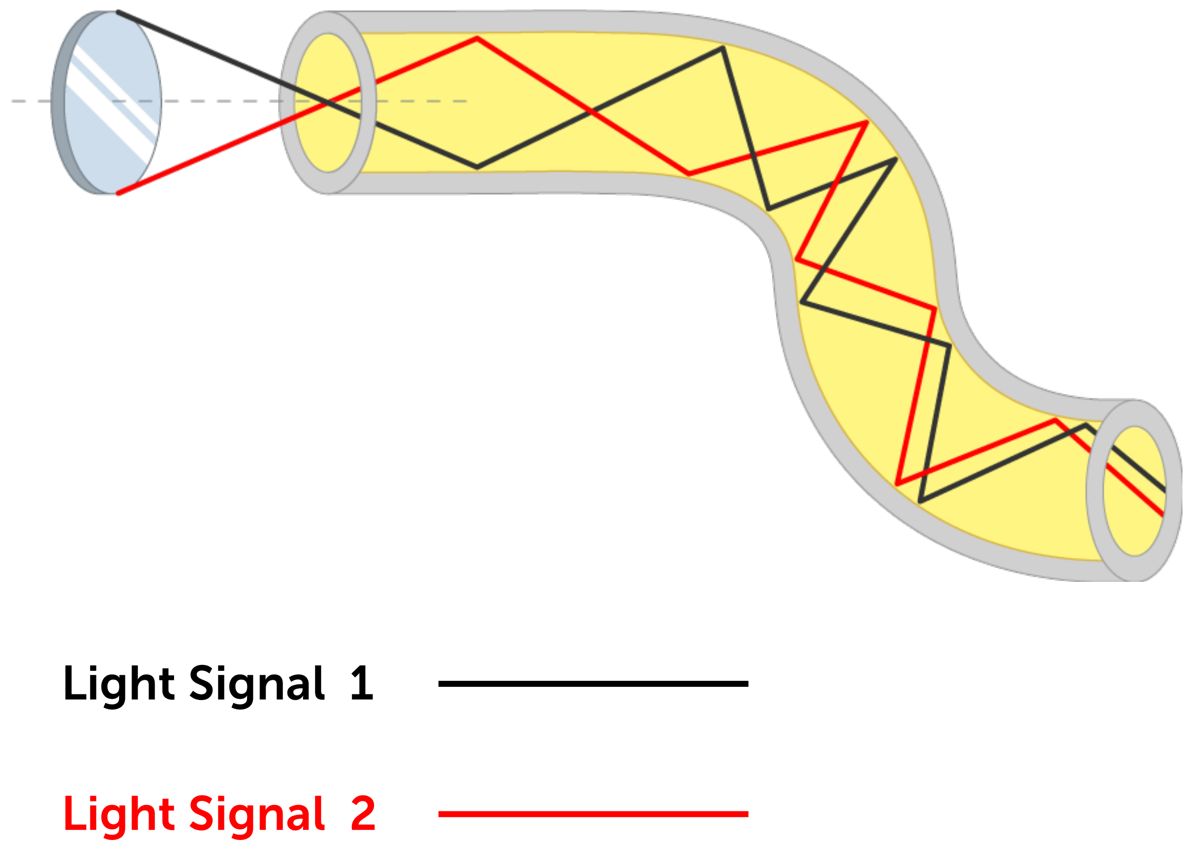
Webinar Rules

- Introduction and sound check
- Presentation: 60 min
- Use chat for questions during presentation
- Q&A (NB! Technical questions only)
- Let’s start!

Fiber optics. General definition

- The technology used to transmit information as pulses of light through thin strands of glass or plastic fibers over long distances

- Light constantly bounces from the cladding back into the core as it travels down the fiber



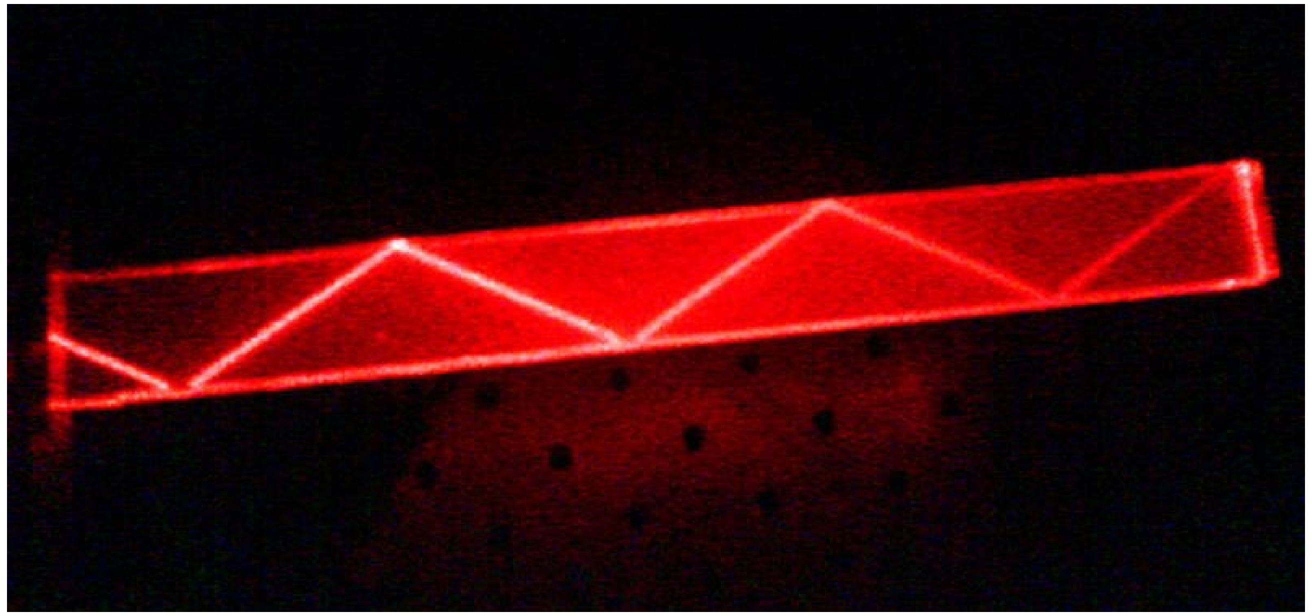
Total internal reflection (TIR)

TIR occurs in nature with light, electromagnetic wave, sound, and even water waves.

With light, TIR occurs when the light reaches the boundary of two mediums and:

1. The angle it hits at ("angle of incidence") is greater than the "critical angle"
2. The light is going from a dense medium to a less-dense one (example: water to air)

TIR in everyday life

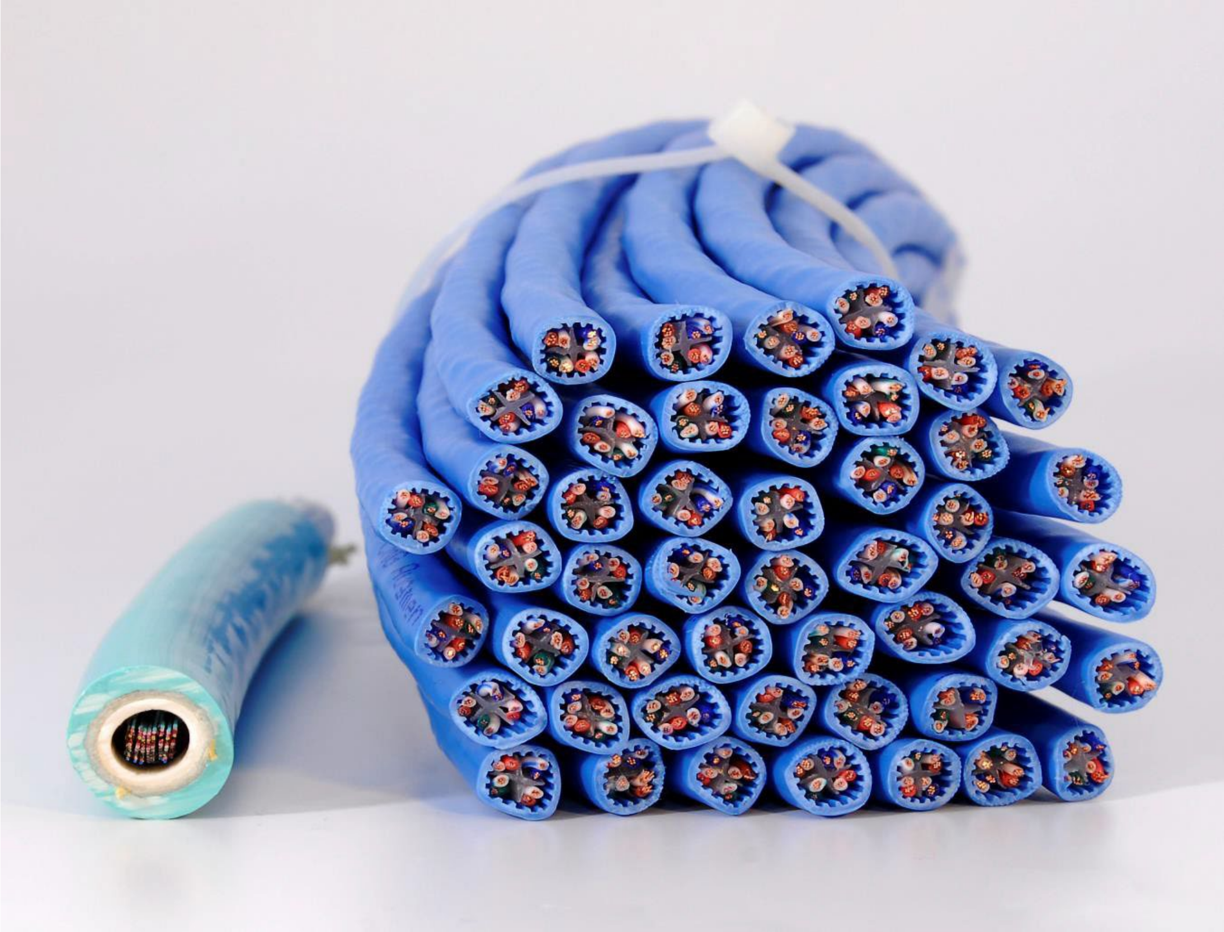


TIR in an acrylic rod

Why use Fiber Optic Cable?

- Reason 1 — requires much less space

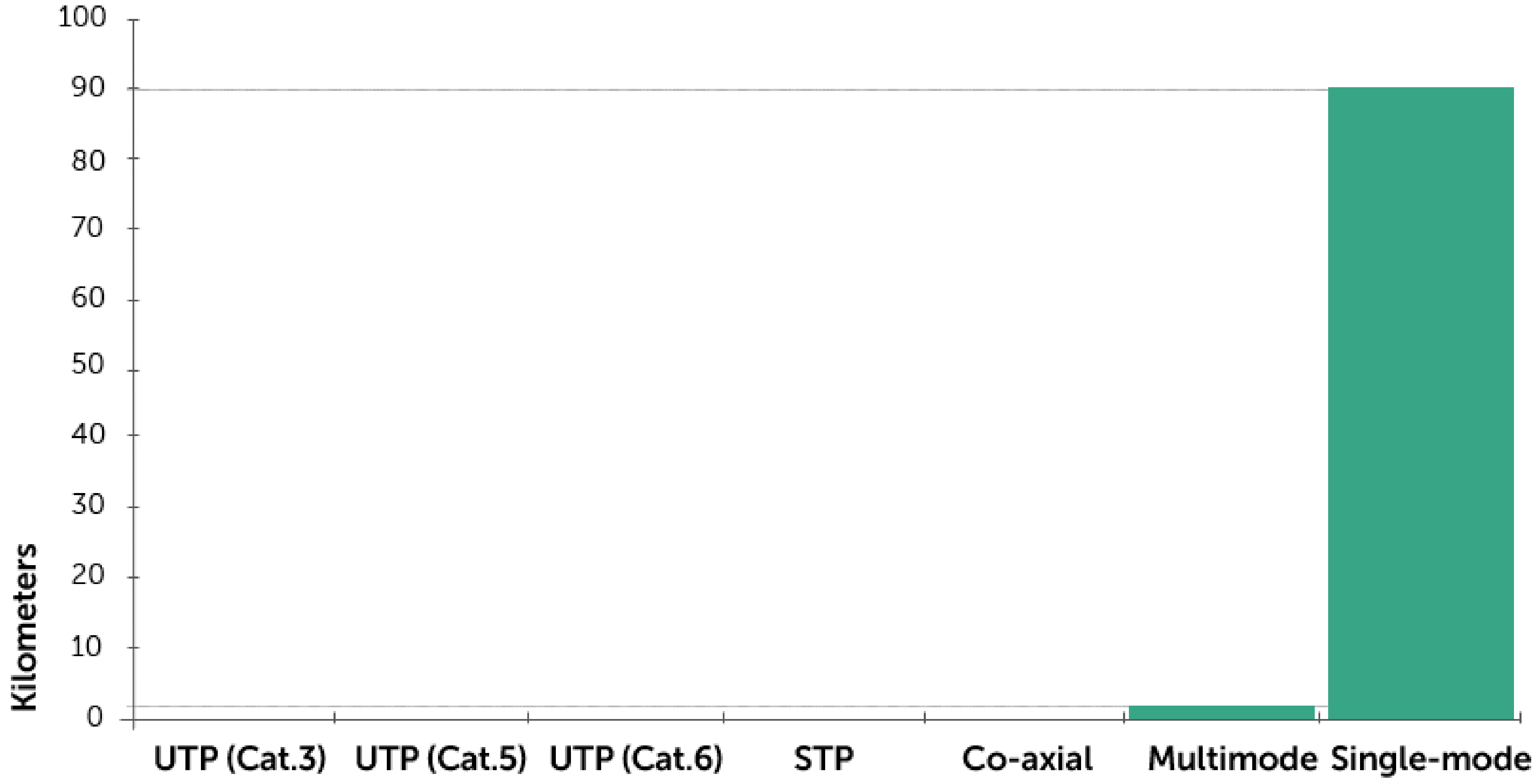
A fiber optic cable with the same bandwidth capacity as a comparable copper cable is less than 1% of both the size and weight



Fiber optic cable vs CAT6 copper cable

Why use Fiber Optic Cable?

- Reason 2 — can go much farther than copper cables for a given "bandwidth" (amount of information transmitted)



* Typical distance for 1 Gbps system capability

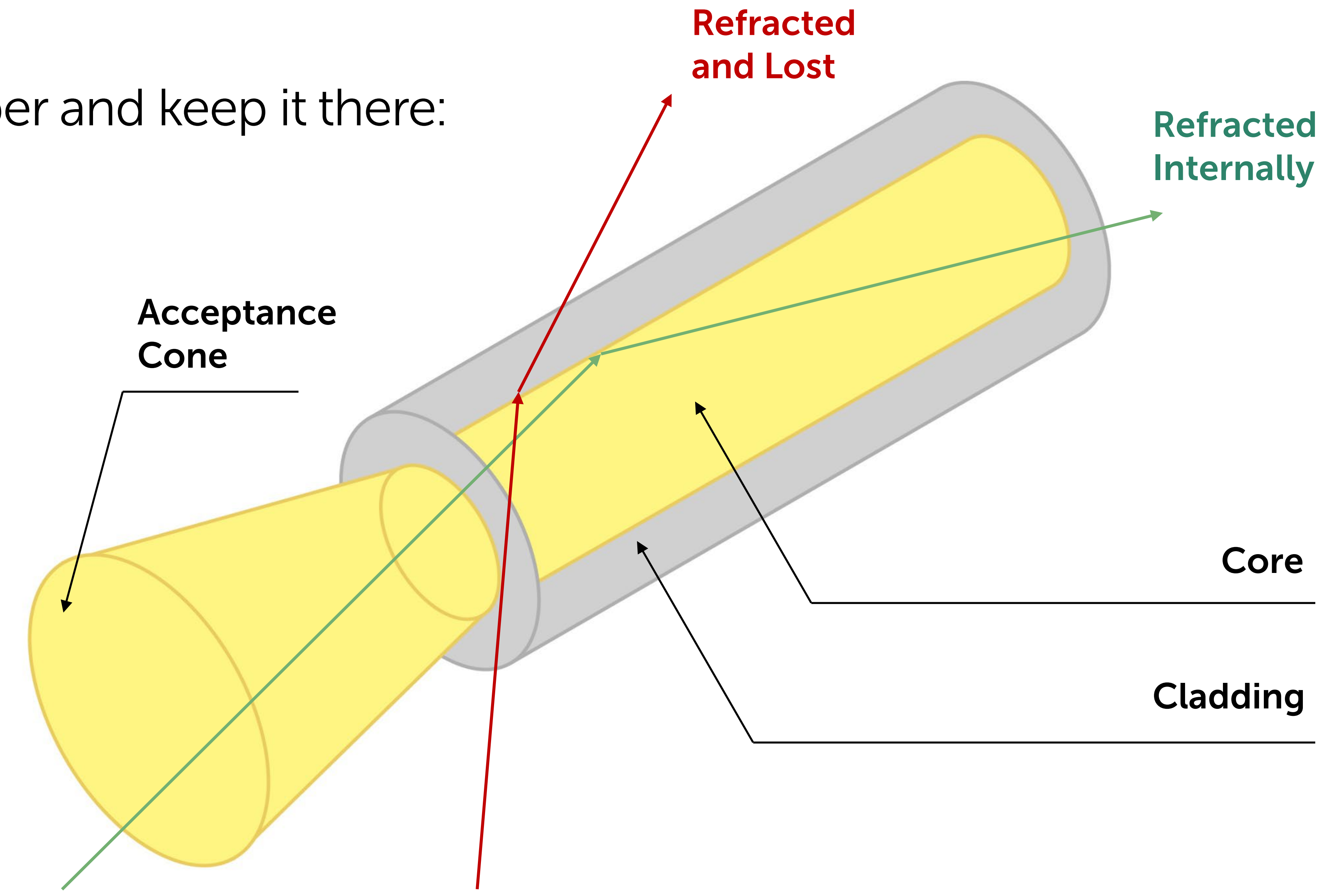
Why use Fiber Optic Cable?

Other Reasons:

- No Interference -Immune to electromagnetic interference (EMI) and radio frequency interference (RFI) so there’s no “crosstalk” as with copper cables
- More Secure - Difficult to tap

How does it work?

How to couple the light into the fiber and keep it there:



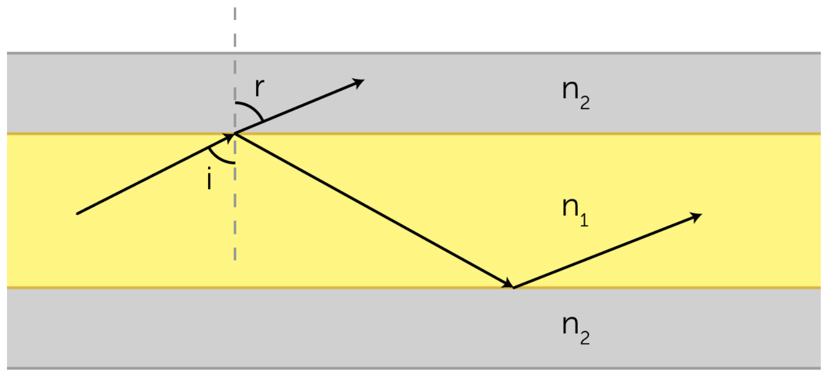
Remember:
Total Internal Reflection

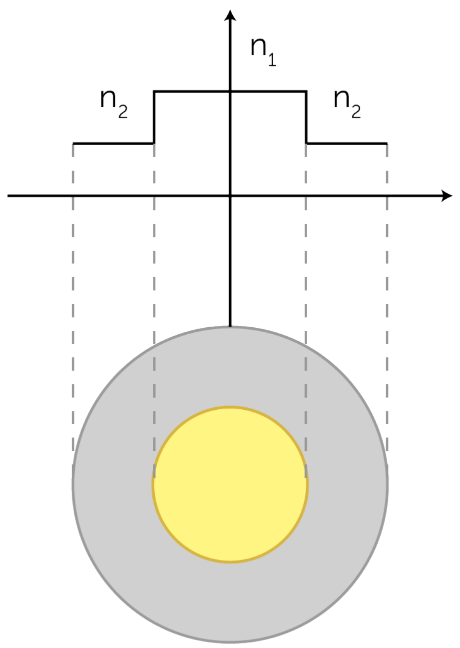
The physics behind fiber optics

- An optical fiber is composed of two concentric layers with different indices of refraction:
  Core – refractive index = n_1
  Cladding – refractive index = n_2

- The index of refraction is a way of measuring the speed of light in a material.

- Light travels fastest in a vacuum.





Refractive index of the medium = [Speed of light in a vacuum / Speed of light in the medium]

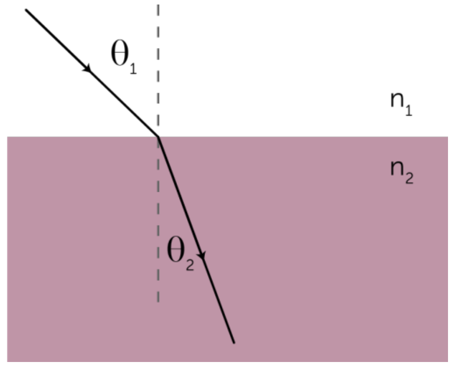
The physics behind fiber optics

Snell's Law

Discovered by Willebrord Snell in 1621.

A relationship relating the index of refraction in a given a medium and incident light angle to the index of refraction in the new medium and the refracted light angle.

$$n_1\sin\theta_1 = n_2\sin\theta_2$$

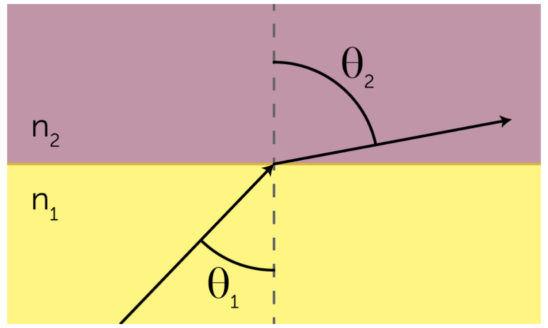


n_1: index of refraction of medium 1
n_2: index of refraction of medium 2

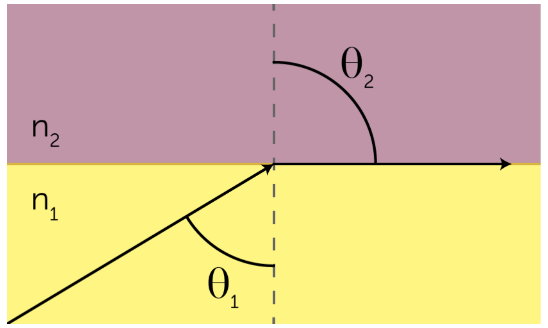
θ_1: the angle of light in medium 1
θ_2: the angle of light in medium 2

Light bends towards the normal when going from a medium with a smaller index of refraction to a larger index of refraction. (Light will have the smaller angle in the medium with the greater index of refraction).

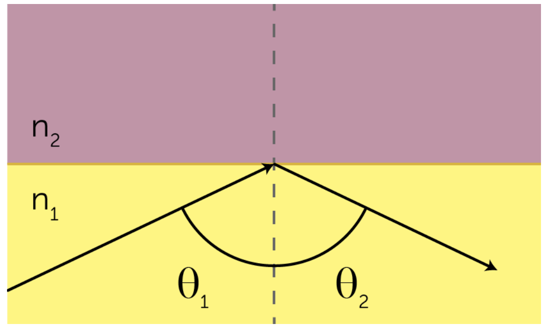
Refraction & Total Internal Reflection



(a) Angle of incidence less than critical angle



(b) Angle of incidence equal to critical angle

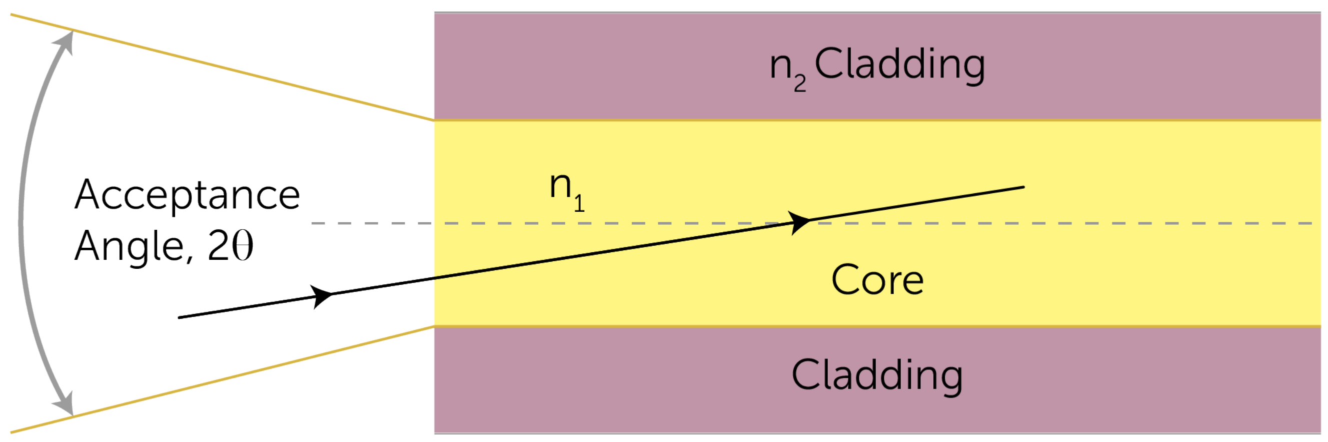


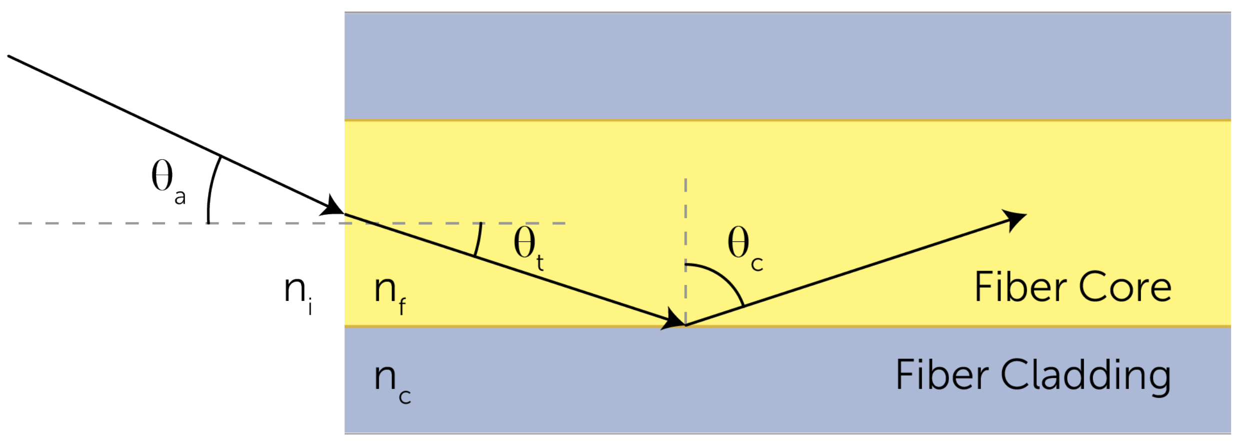
(c) Angle of incidence greater than critical angle

The physics behind fiber optics

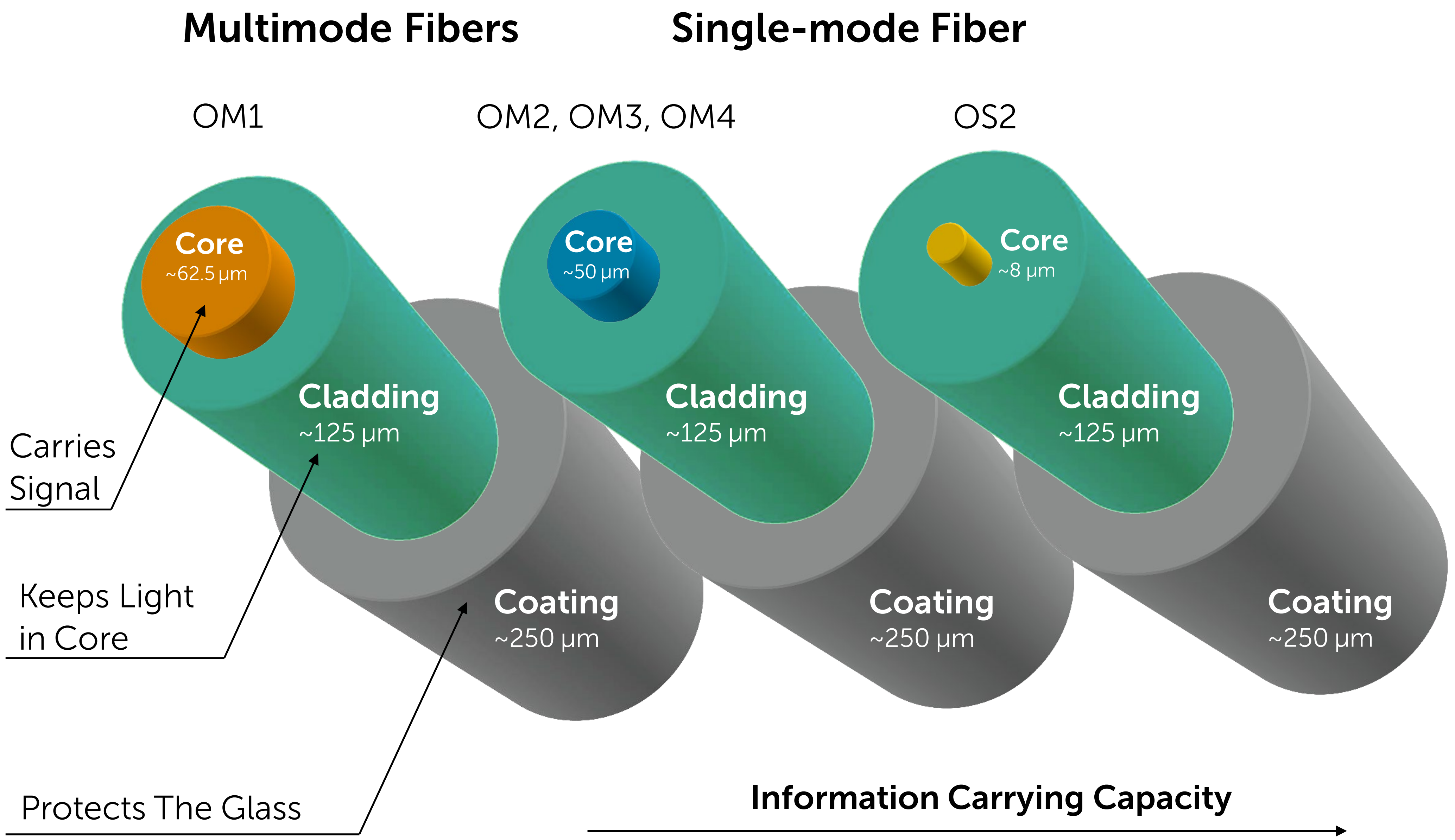
- **Acceptance angle**
  The maximum angle at which a ray of light will enter the core and propagate through it in a zigzag pattern

- **Numerical Aperture**



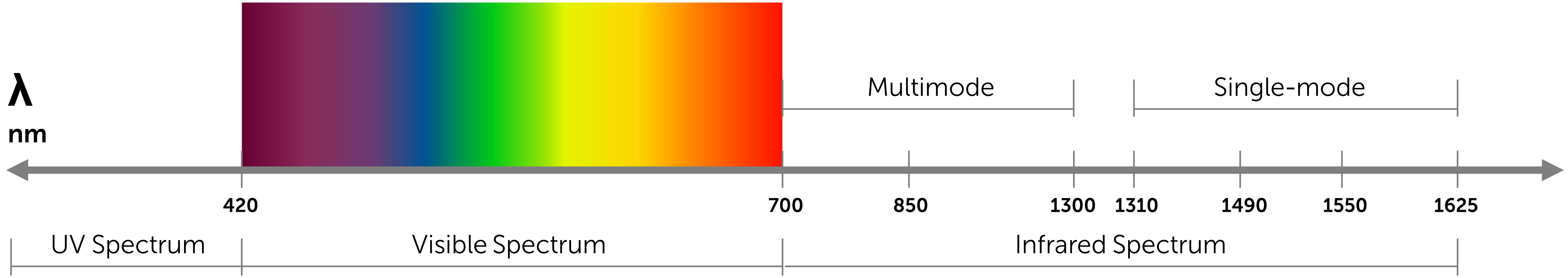


Basic types of fiber



Electromagnetic spectrum

Wavelength



Operating Wavelengths:

850 nm = Short Wave Multimode

1300 nm = Long-Wave Multimode

1310 nm = Traditional Standard Single-mode

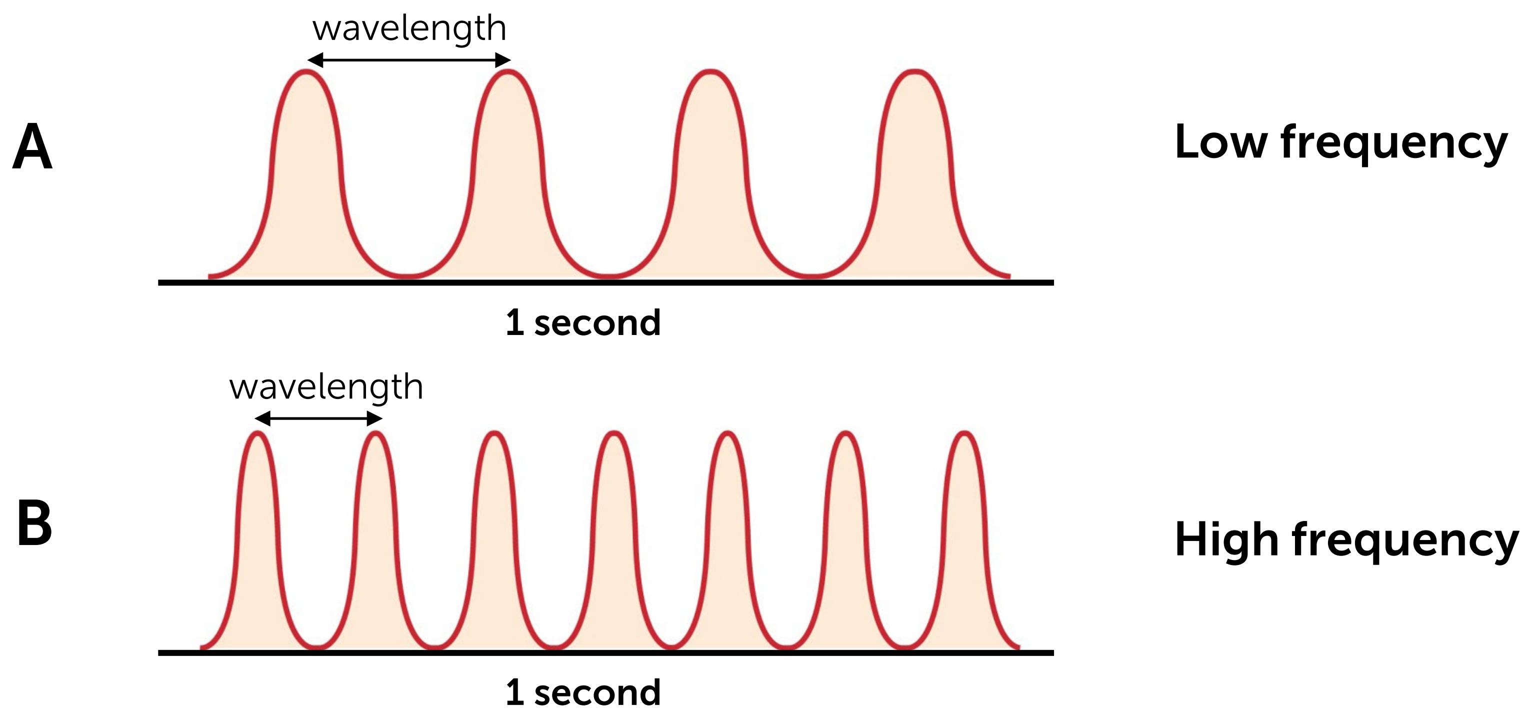
1490 nm = FTTx (Downstream Data/Voice)

1550 nm = Long-Wave Single-mode

1625 nm = Extra Long-Wave Single-mode (WDM)

Properties of electromagnetic signals

- **Wavelength**
  The distance between identical points on a wave (typically expressed in nanometers or “nm”)



“B” represents a shorter wavelength than “A”

Fiber performance factors

The two key optical fiber performance factors are:

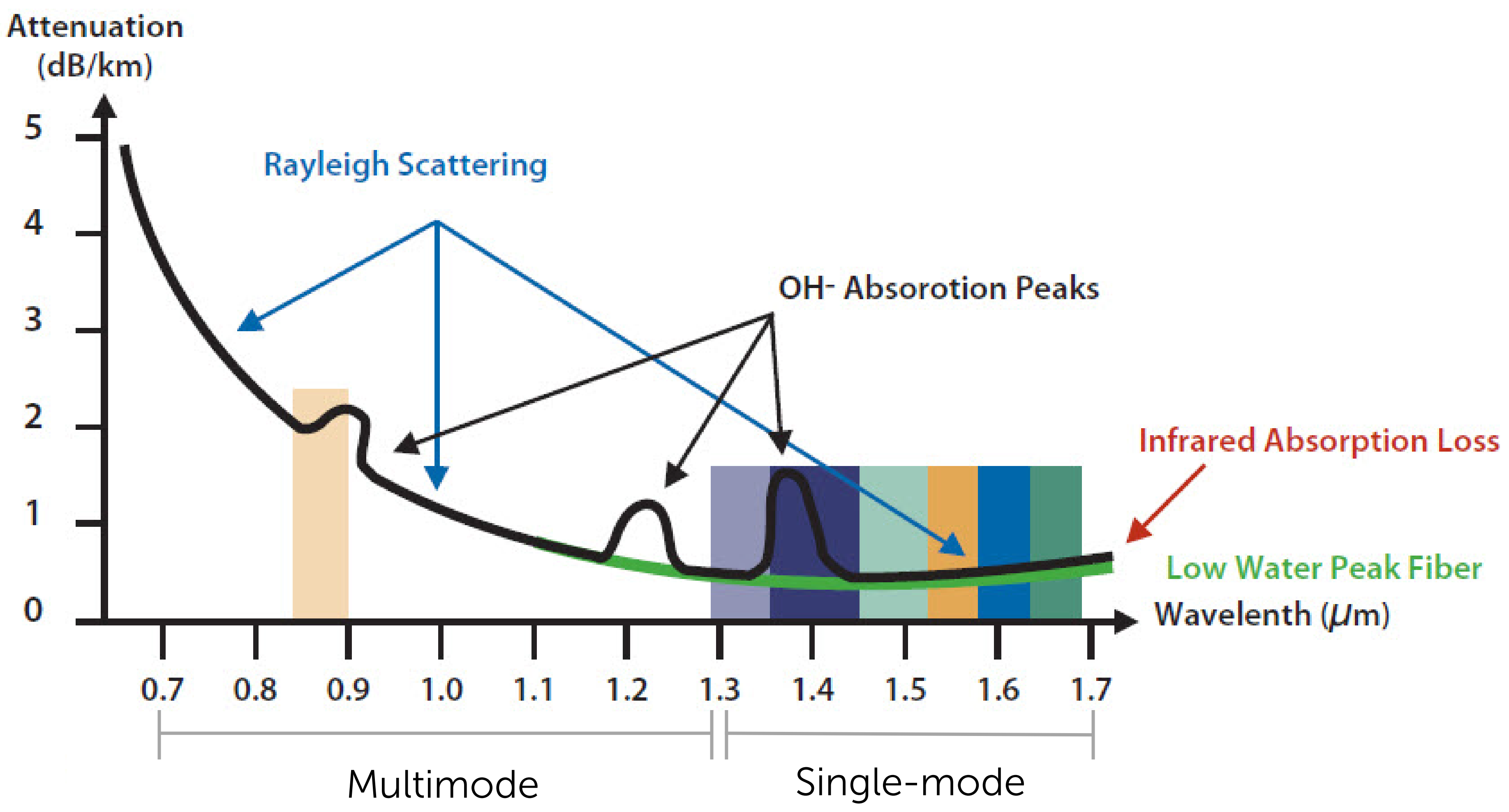
- **Attenuation — loss of signal strength**
  - Expressed in decibels of power lost (dB)
  - Intrinsic Attenuation
  - Extrinsic Attenuation
  - Impacts ability to reach the receiver with sufficient power
  - A 3dB loss in power equates to a 50% loss from what you started with

- **Dispersion — spreading of signal pulses**
  - Modal Dispersion
  - Chromatic Dispersion
  - Polarization Mode Dispersion
  - Impacts the ability to distinguish discreet signal pulses

Fiber performance

Intrinsic Attenuation – loss of signal strength

1. Caused by substances within the optical fiber
2. Expressed in decibels of power lost (dB)
3. Impacts ability to reach the receiver with sufficient power
4. A 3dB loss in power equates to a 50% loss from what you started with



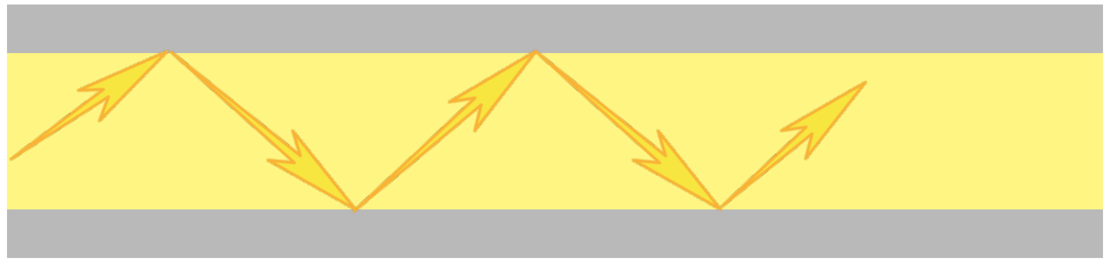
Fiber attenuation as a function of wavelength

Fiber performance. Intrinsic attenuation

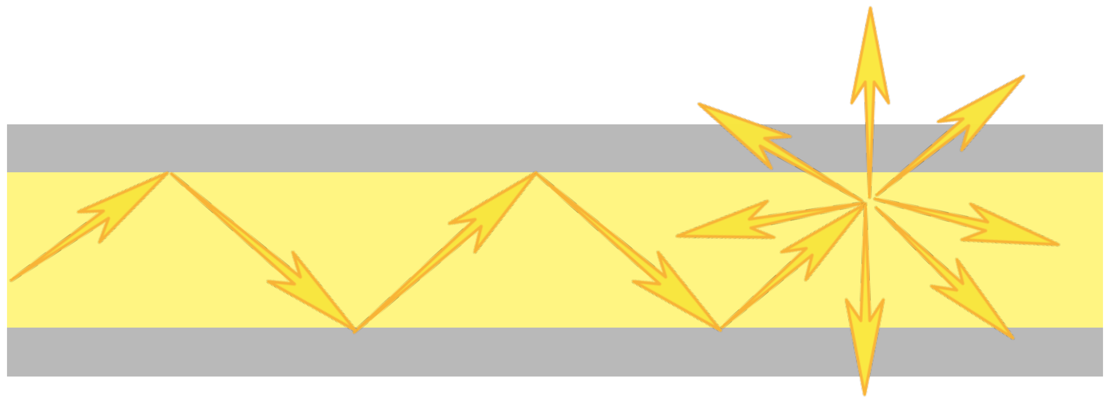
Intrinsic Attenuation

Internal — Can’t be affected by outside influences

- **Absorption**
  A photon will give up kinetic energy when it interacts with an electron and excites it to a higher energy level.



- **Rayleigh Scattering**
  Light is scattered as the result of inhomogeneities and defects in the glass. These imperfections are microscopic and happen during production.

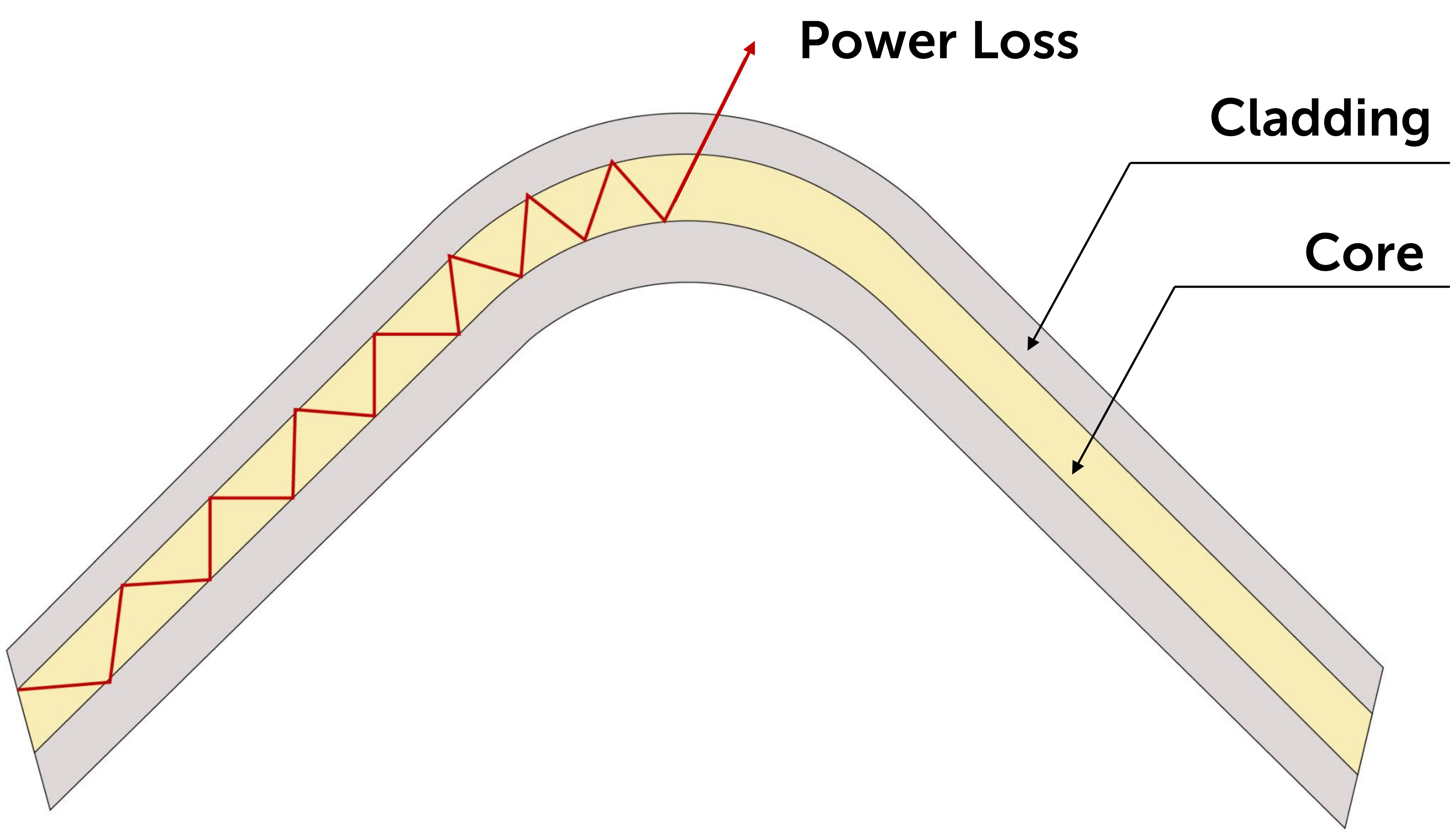


Fiber performance. Extrinsic attenuation

- **Macrobend**

  Caused by a large-scale bend of the fiber which is visible and less than the safe minimum bending radius.

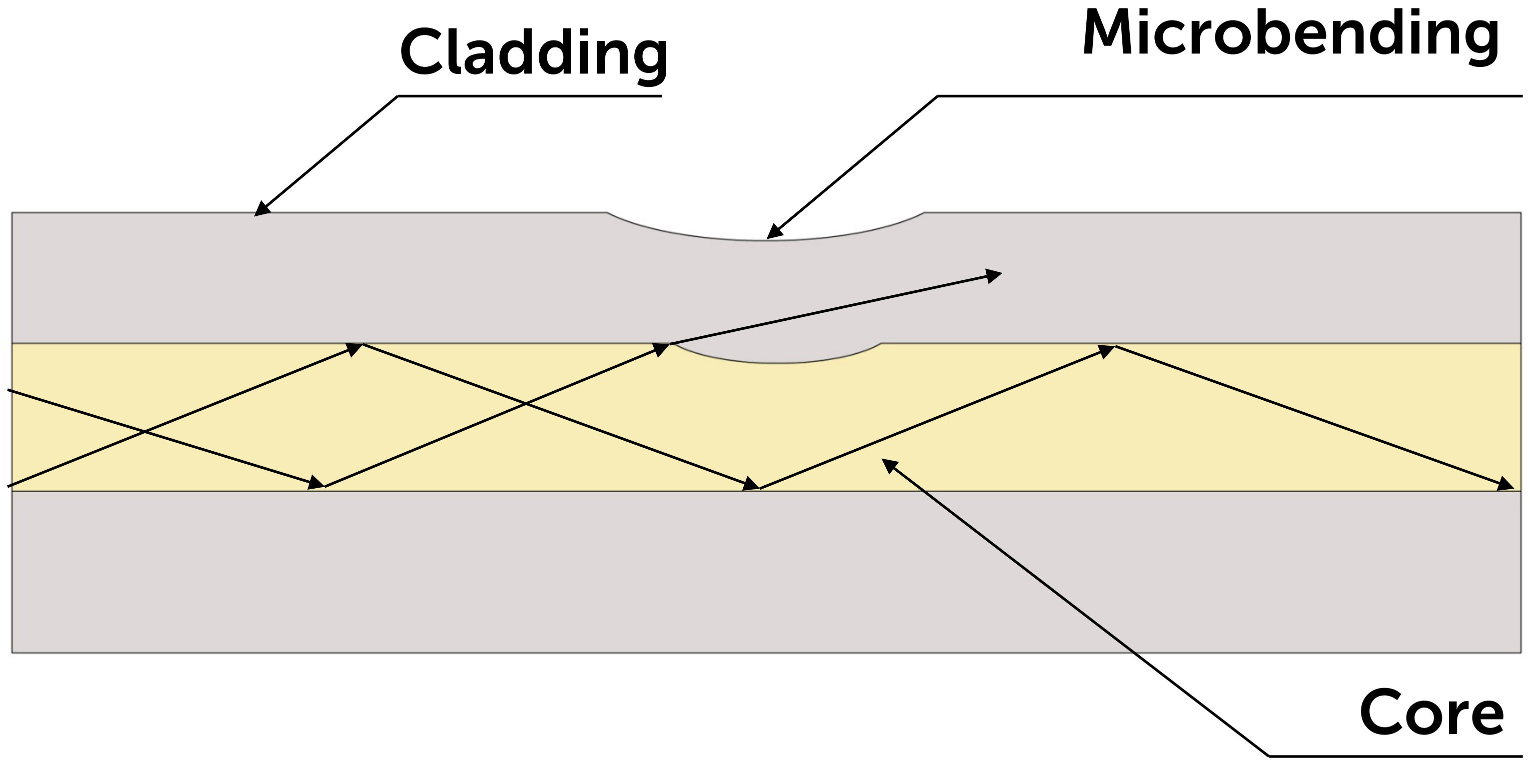
  The loss is generally reversible once the bend is removed.



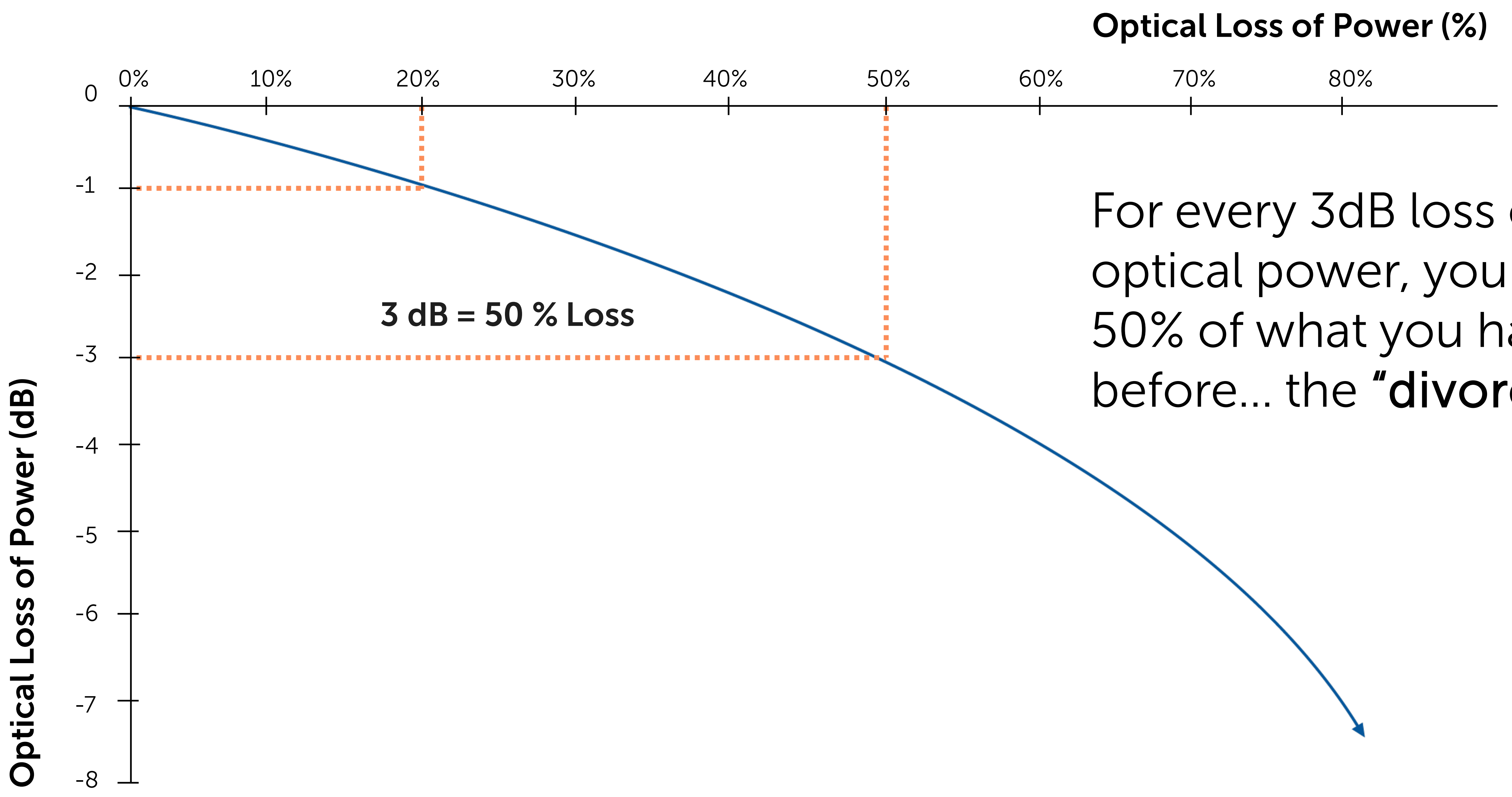
Fiber performance. Extrinsic attenuation

Microbend

- Small-scale distortions in the geometry of the fiber core
- Can be caused during the manufacturing process, or by “cross-overs” in a tube
- Can be reversible, unless the core has been permanently deformed



Fiber performance. Impact of dB loss



For every 3dB loss of optical power, you lose 50% of what you had before... the **"divorce law"**

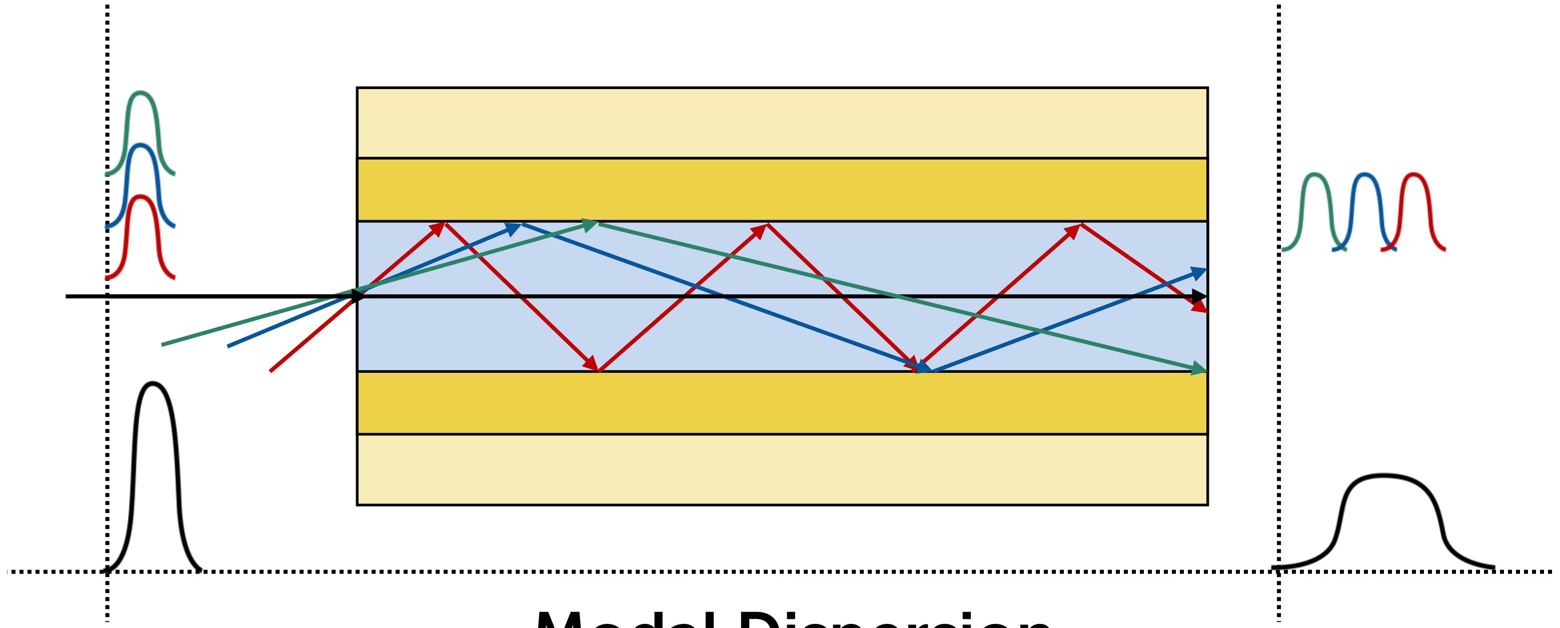
Dispersion

- Dispersion is the spreading out of a light pulse as it travels through the fiber

- Three types of dispersion:
  1. Chromatic Dispersion
  2. Modal Dispersion
  3. Polarization Mode Dispersion (PMD)

Dispersion

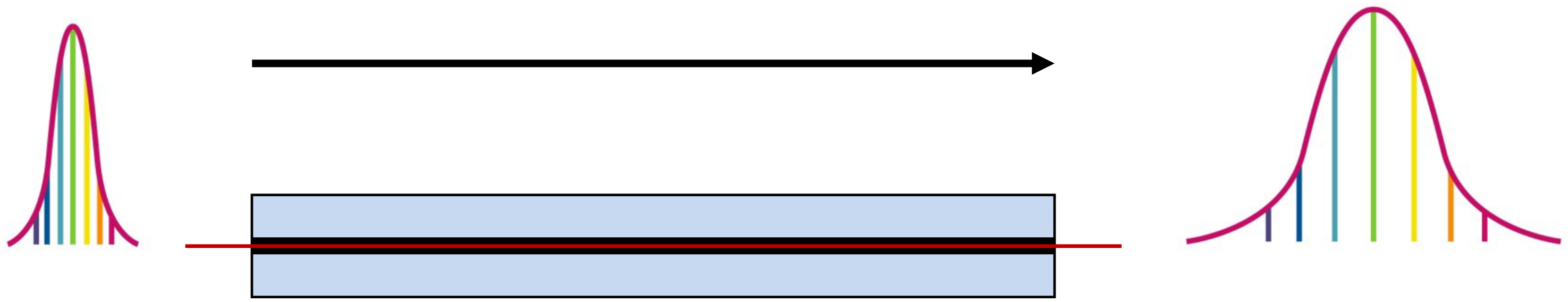
- **Modal (a.k.a. Intermodal) Dispersion in Multimode (MM) Fiber**
  Spreading of signal pulses as they travel down the fiber
  (May cause pulses to overlap as they arrive at the receiver, and cause bit errors)



Modal Dispersion

Dispersion

- **Chromatic Dispersion**
  The phenomenon of pulse spreading due to the different colors of light (wavelengths) travelling at slightly different speeds through the fiber.



Chromatic Dispersion

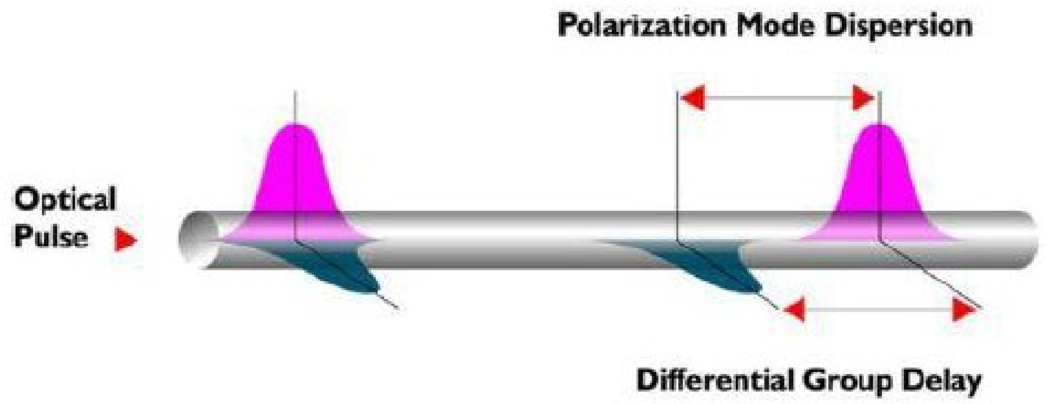
Dispersion

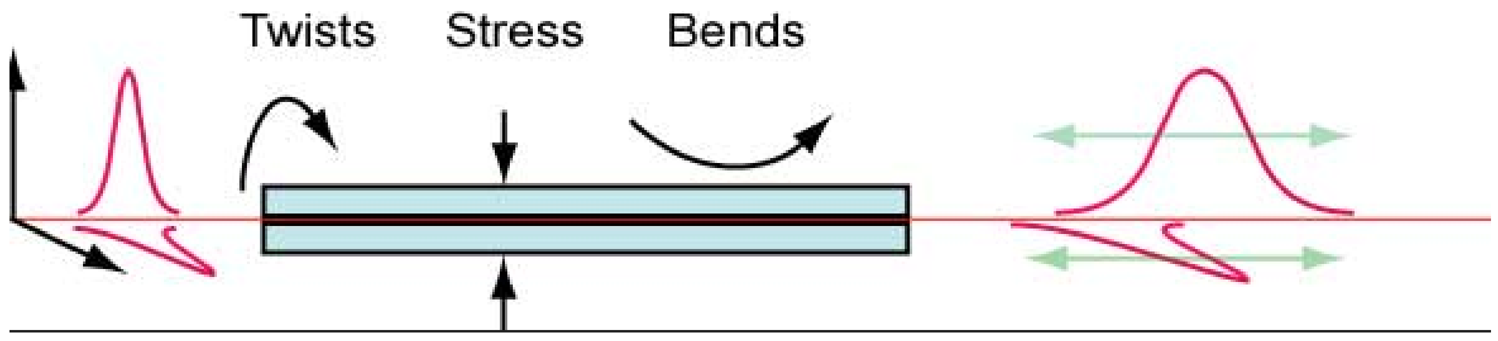
Polarization Mode Dispersion (PMD)

- Single-Mode optical fiber consists of one propagation mode, which in turn, is comprised of two orthogonal polarization modes.
- Asymmetrical differences in the fiber introduce small refractive index variations between the two modes. This is known as birefringence.

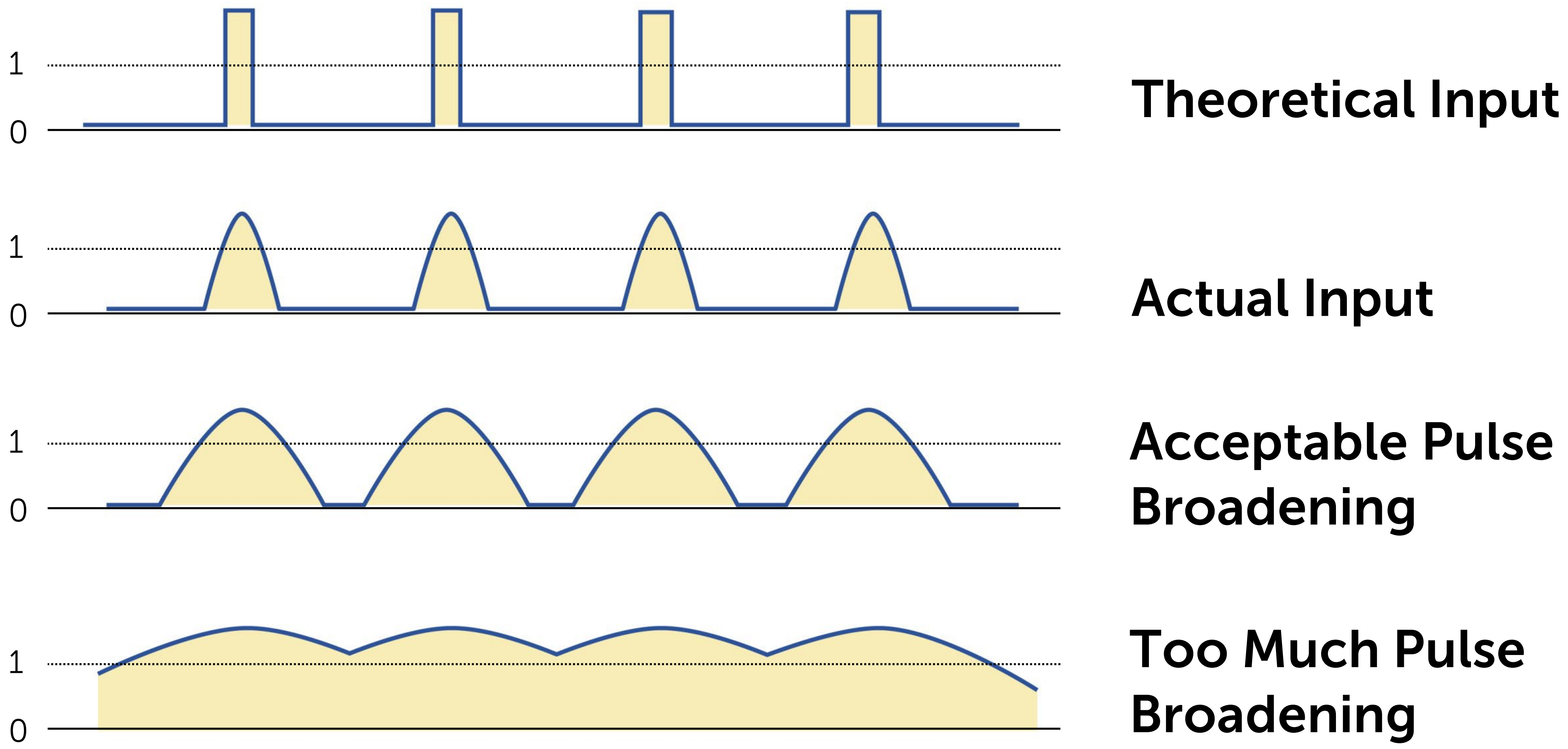
Caused by ovality of core due to:

- Manufacturing Process
- Internal Stress (Cabling)
- External Stress
- Not Discovered until the 1990's
- Becomes critical as transmission speeds increase





Dispersion leads to bit error



Applying those performance factors

- **Attenuation – recall: loss of signal strength**
  - Very much affected by cable manufacturing processes
  - Can’t get better (lower), only worse (higher)
- Typical maximum, individual, final values for single-mode fiber
  - At 1310 and 1550 nm = 0.35 and 0.25
  - Best practice = 0.34 and 0.20
- Typical maximum, individual, final values for multimode fiber
  - At 850 and 1300 nm = 3.5 and 1.5
  - Best practice = ? and ?

Applying those performance factors

- **Dispersion – recall: spreading of signal pulses**
- Overwhelmingly from the fiber manufacturing process
  - Specified by the fiber supplier
- Therefore, typically not affected by the cable design or manufacturing processes
  - "It is what it is" in a finished cable (unless a cable is very poorly made?)
  - Finished cable limits not used

Advanced fiber types

Increases in bandwidth demand and transmission distances have led to two special types of single-mode (SM) fiber:

1. **Non-Zero Dispersion Shifted (NZDS) SM Fiber**

   Recall "Chromatic Dispersion"
   - You can correct for dispersion much like eyeglasses do

   The two best known NZDS SM fibers are Corning® LEAF® and OFS TrueWave® RS
   - Standard is ITU-T G.655

   Designed for use with Dense Wavelength Division Multiplexing (DWDM) to boost bandwidth.

   Compare:
   - Standard SM fiber: Commonly 10Gbit/s, as much as 40 Gbit/s
   - NZDS SM fiber: 100 Gbit/s and more!

   Enable transmission over longer distances. **Compare:**
   - Standard SM fiber: 60 – 90 miles
   - NZDS SM fiber: up to 250 miles

But, the newer ITU-T G.654.E fiber (next slide) is replacing NZDS fiber

Advanced fiber types

2. Cut-Off Shifted SM Fiber or "G654" SM Fiber

An "ultra-low-loss" type fiber

Originally, used for transoceanic submarine cables

Current G.654.E fiber allows even higher data rates: 400 Gbit/s up to 1 Tbit/s

Longer distances too: Up to 900 km (560 miles)

Optimized for use between 1550 – 1625 nm

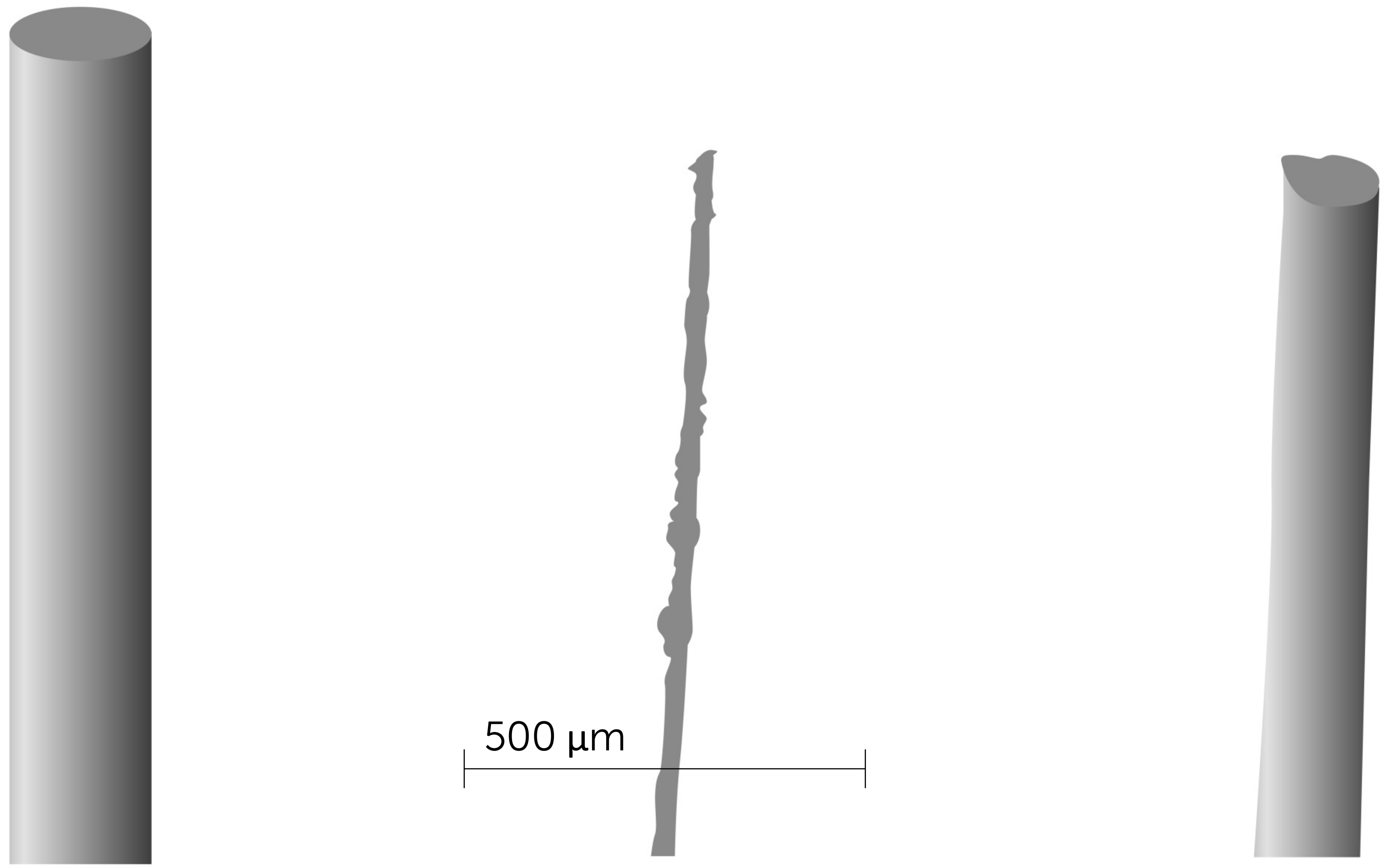
Typical attenuation limits:

- 1550nm $\leq$ 0.17dB/km
- 1625nm $\leq$ 0.19dB/km

An example of this fiber type is Corning® TXF™

In closing, just for fun!

Relative size of optical fiber



Optical fiber
(glass only)

Fiberglass from ceiling tile

Human hair

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