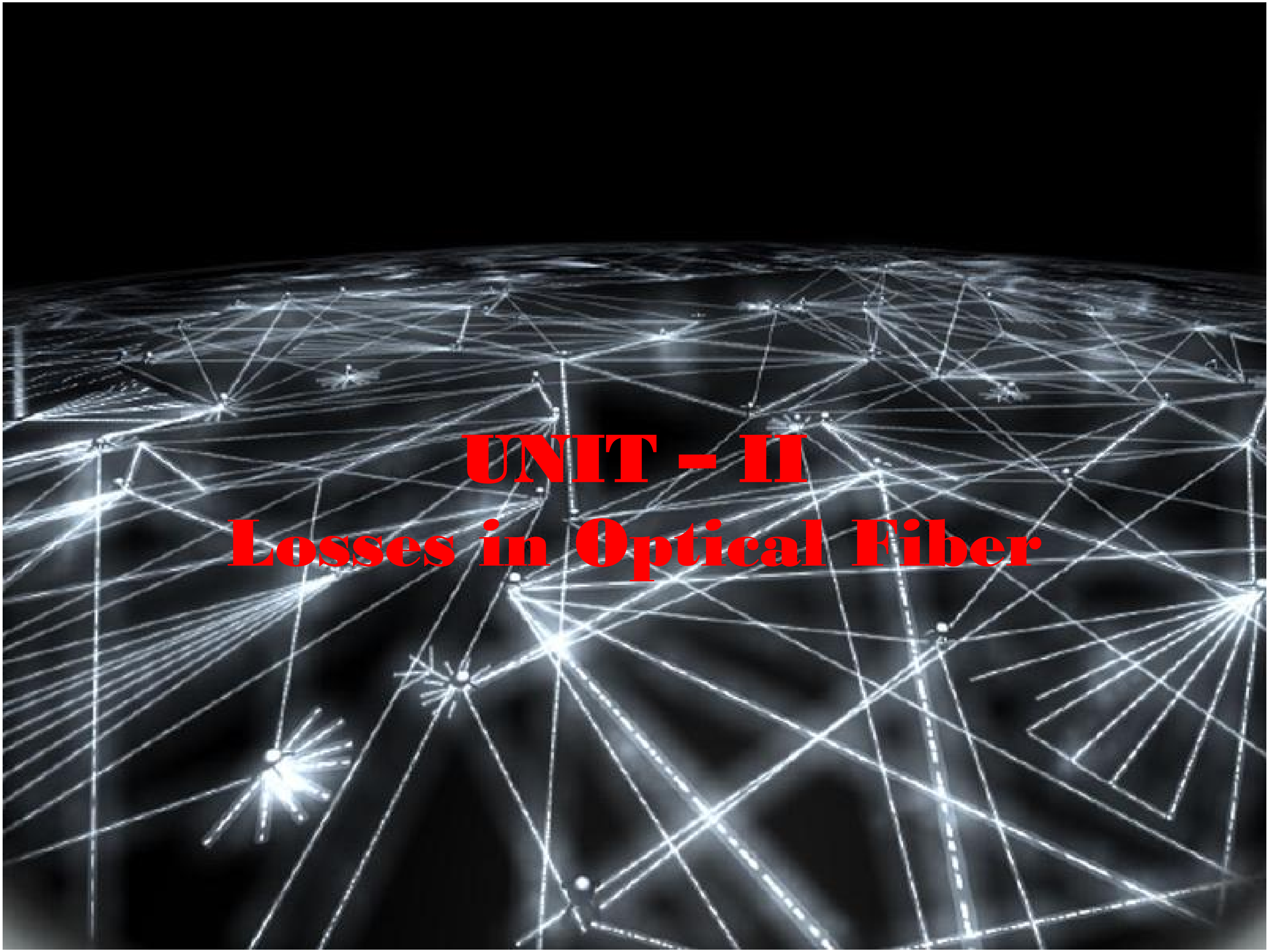
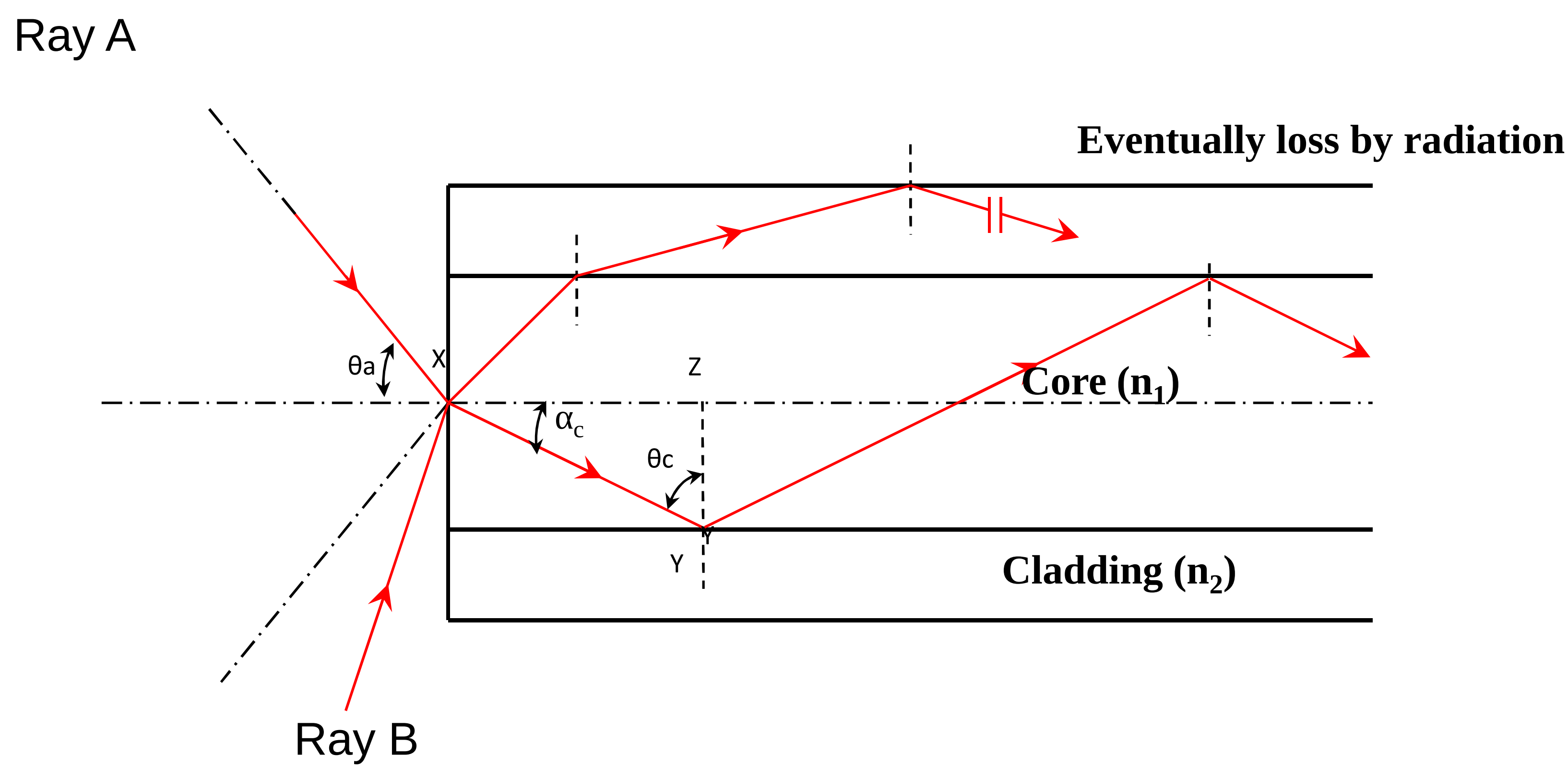


UNIT – II

Losses in Optical Fiber

Critical propagation angle or Emerging angle



$$\alpha_c = \sin^{-1}\left(\sqrt{1-\left(\frac{n_2}{n_1}\right)^2}\right)$$

Attenuation

- Glass contains impurities which lead to the absorption of light. Furthermore, non-uniformities in the manufacturing process and mechanical stress lead to scattering of the light inside of the fiber which limits the performance.
- Both the absorption of light by impurities and the scattering of light is wavelength dependent which complicates compensation and correction of these effects.
- The optical power that propagates through an optical fiber decreases exponentially with the distance as a result of absorption and scattering. Therefore an attenuation coefficient,

Where L is the length of the fiber in km. The power transmission ratio is defined as the ratio of the transmitted versus the incident optical power.

$$\propto = \frac{1}{L} 10 \log\left(\frac{P_o}{P_T}\right)$$

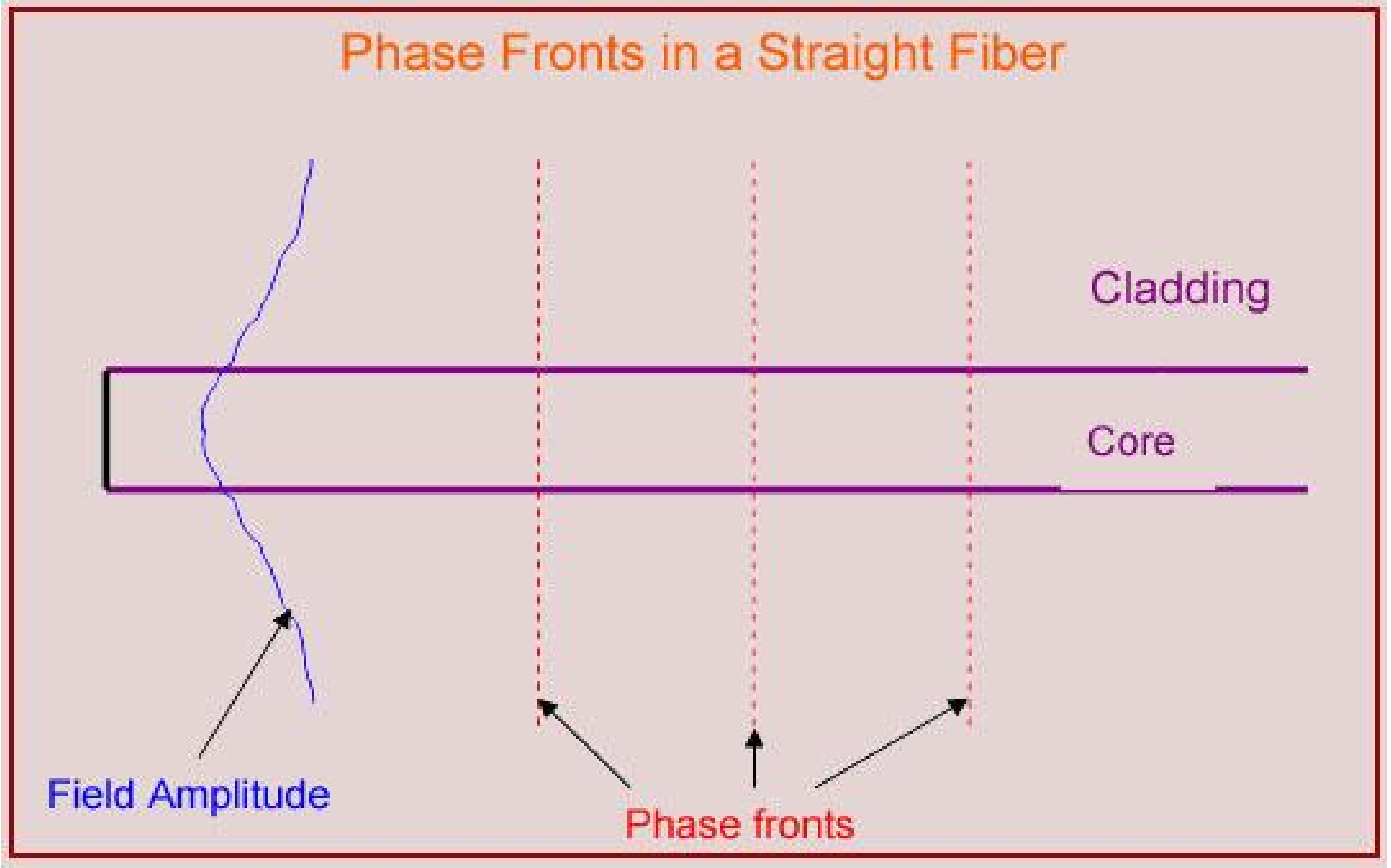
Absorption Loss

- Any impurities that remain in the fiber after manufacture will block some of the light energy. The worst culprits are hydroxyl ions and traces of metals.
- The hydroxyl ions are actually the form of water which caused the large losses at 1380 nm in optical fiber.
- In a similar way, metallic traces can cause absorption of energy at their own particular wavelengths.
- In both cases, the answer is to ensure that the glass is not contaminated at the time of manufacture and the impurities are reduced as far as possible.

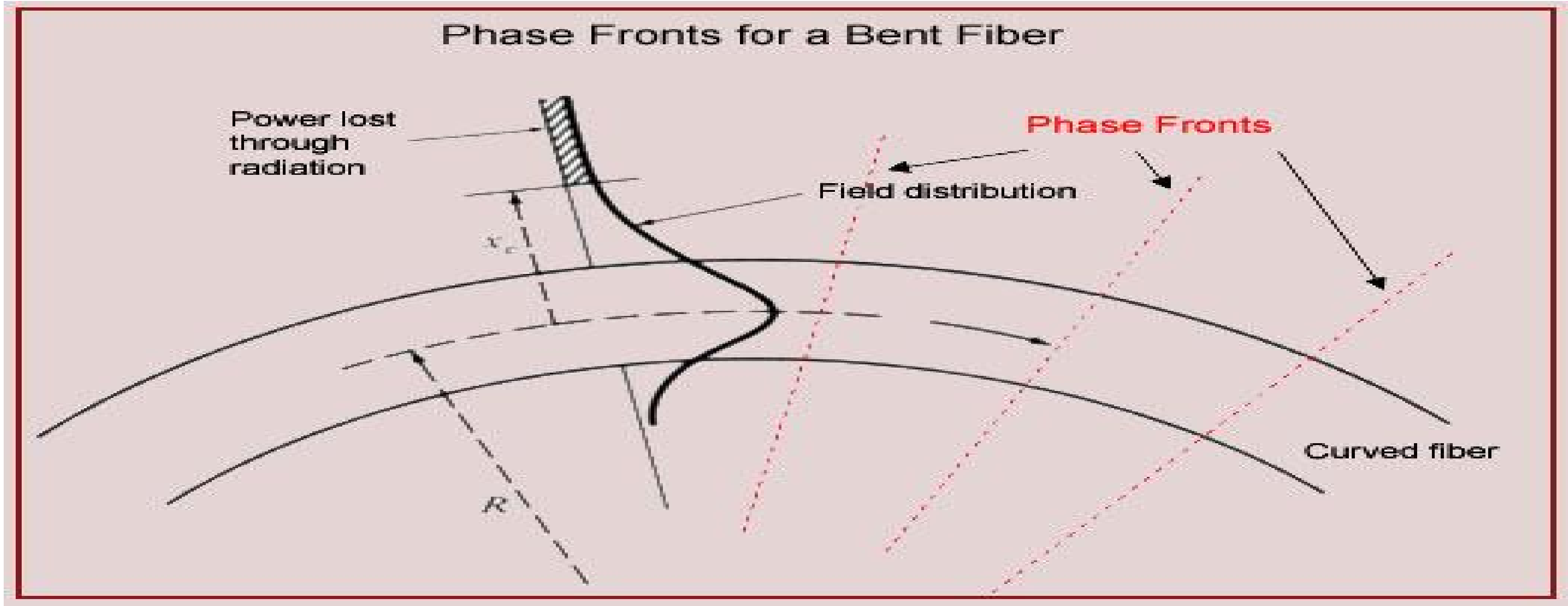
Continued……..

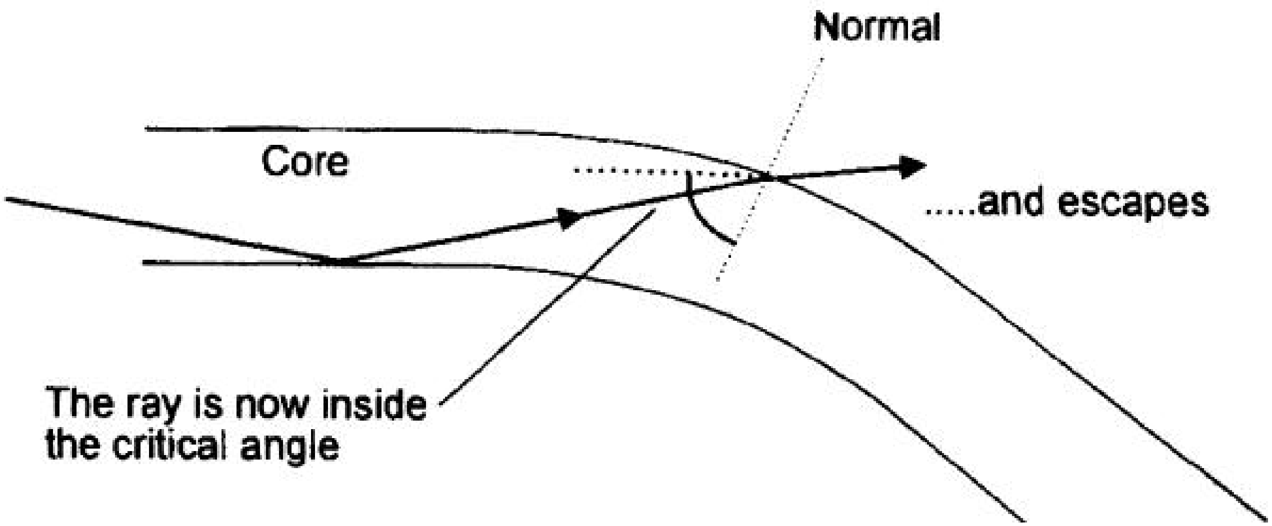
- We are aiming at maximum levels of 1 part in 109 for water and 1 part in 1010 for the metallic traces.
- The absorption is caused basically by three different ways,
  - The absorption by the atomic defects in a glass composition viz. missing molecules, high density cluster of atom groups or oxygen defects in glass structure .
  - Intrinsic absorption caused by the basic constituent's atoms of the fiber material.
  - Extrinsic absorption because of the impurity atoms in a glass material like transition metal ions (iron, chromium, cobalt, copper) and OH (water) ions.

Situation when fiber is straight

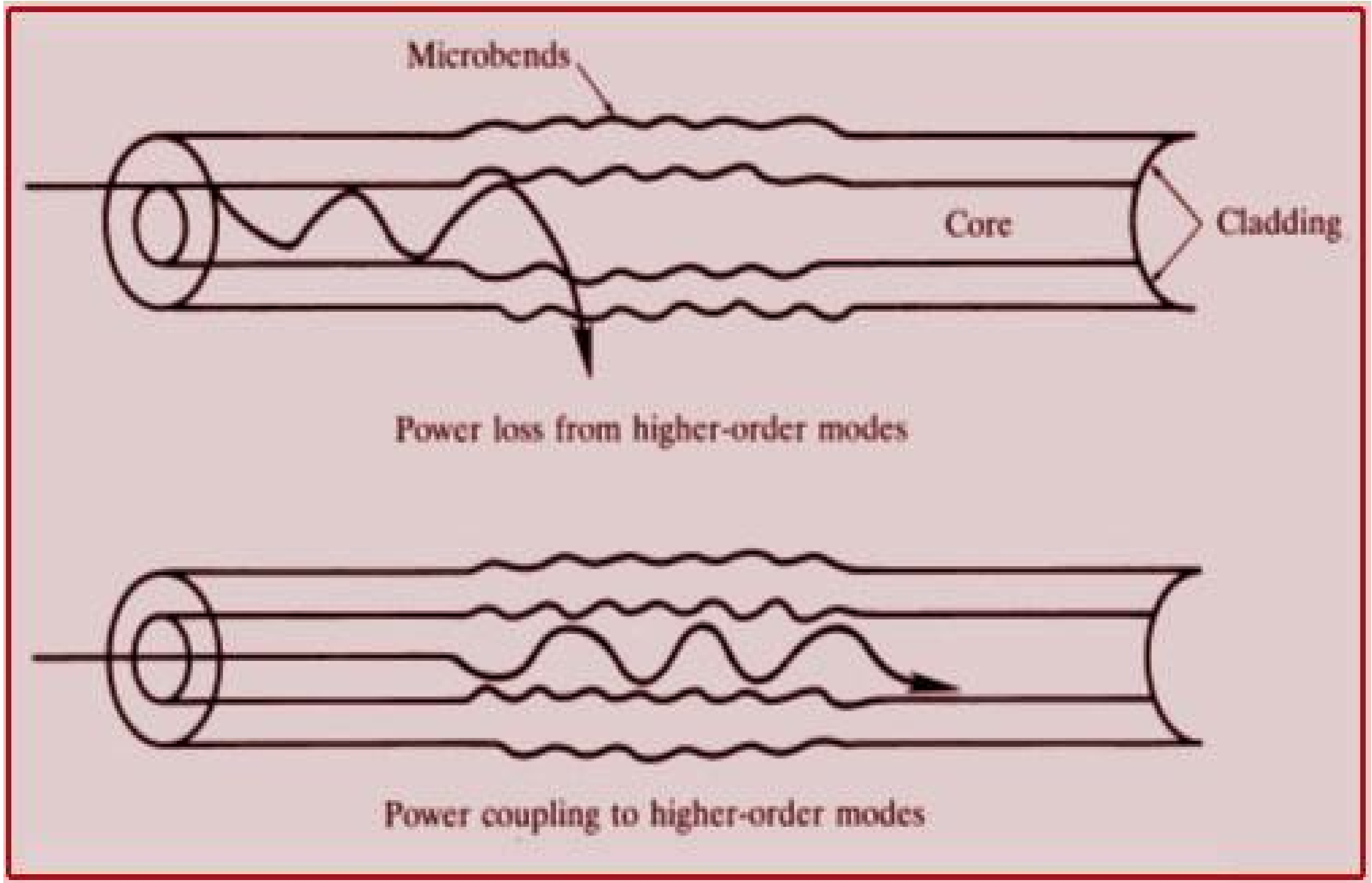


Macro bending Loss

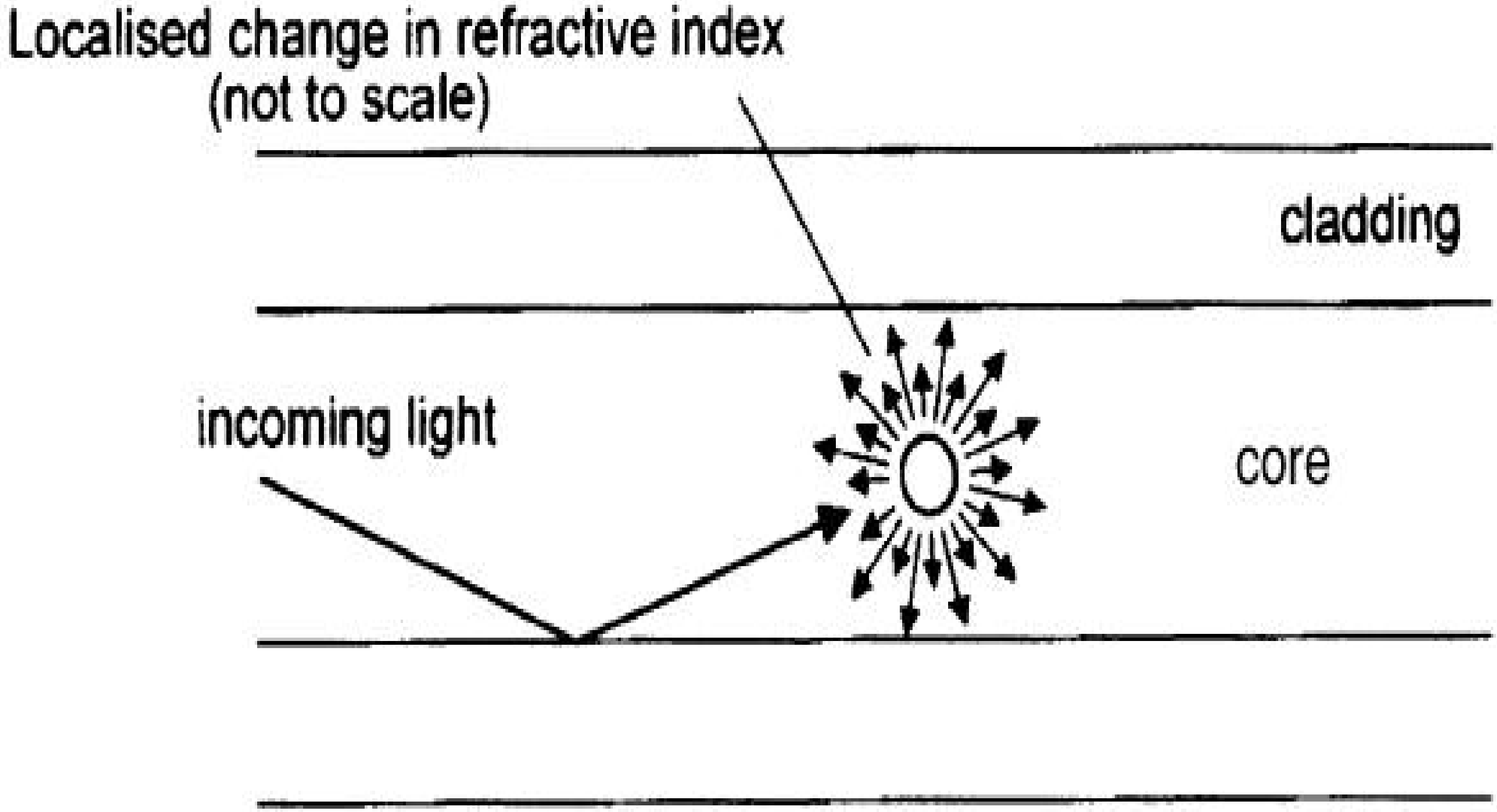




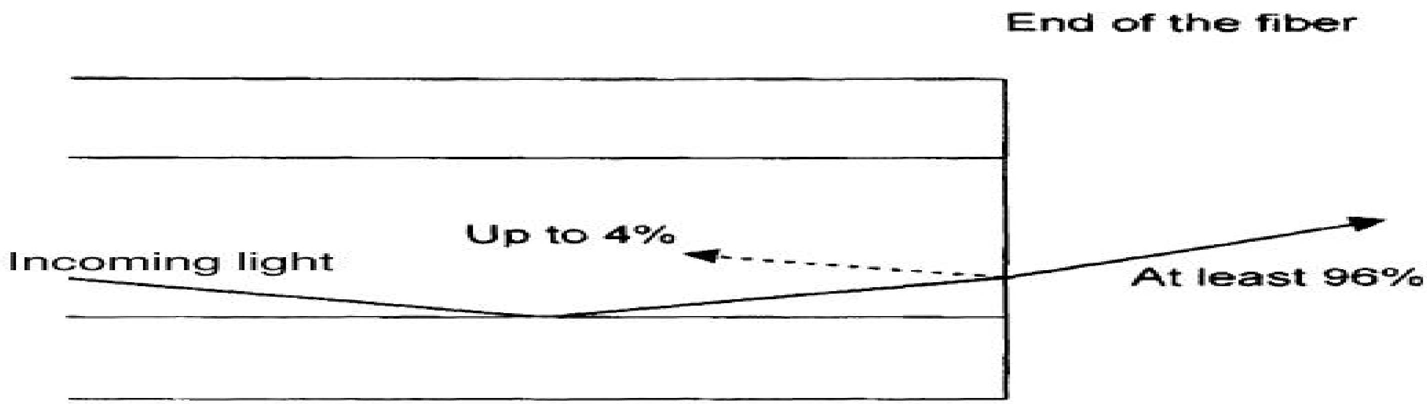
Micro bending Loss

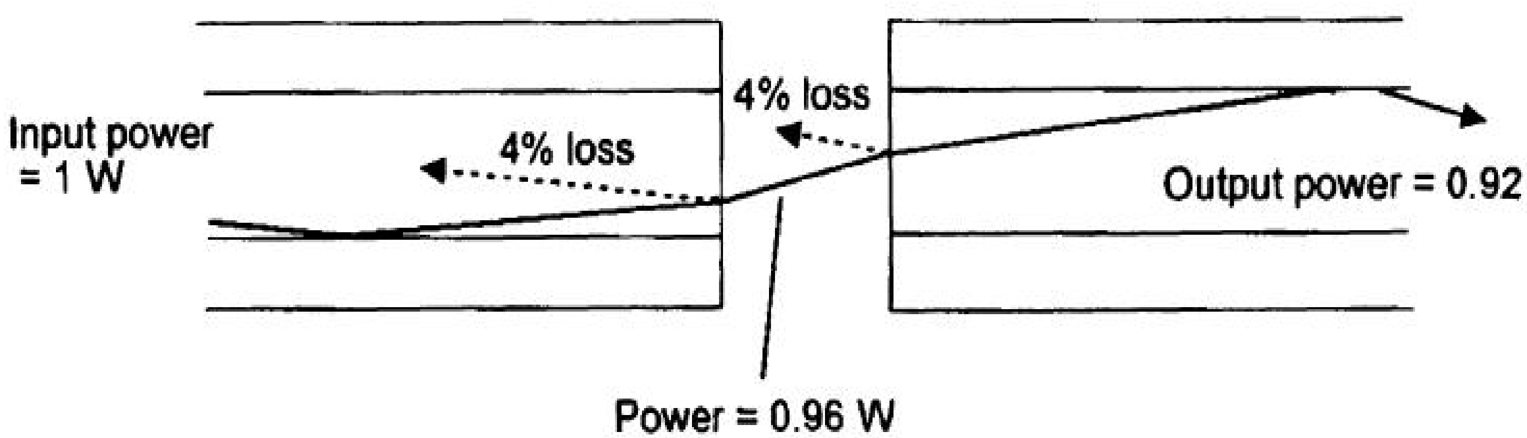


Rayleigh scattering loss



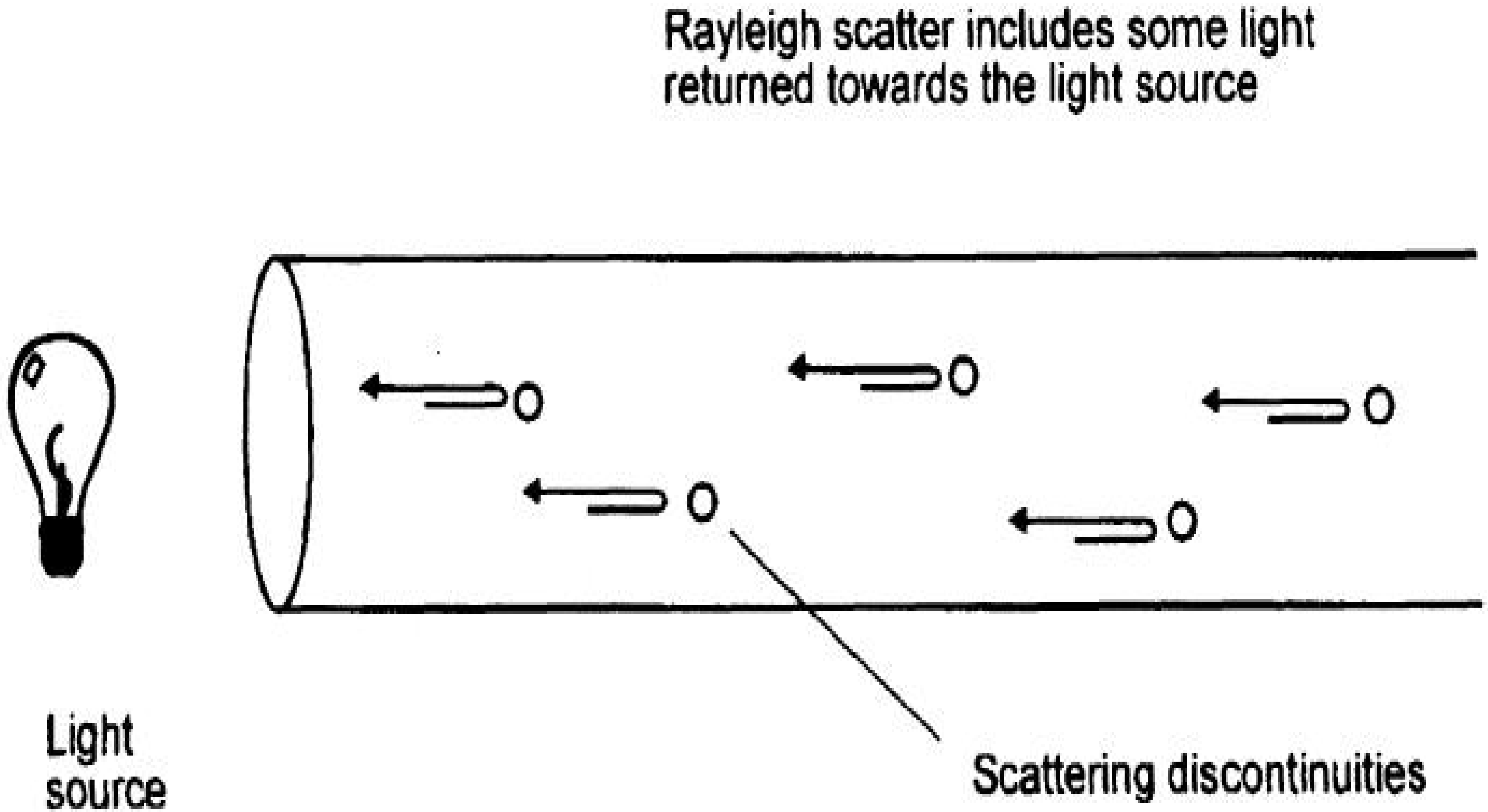
Fresnel reflection & A Fresnel reflection from each surface



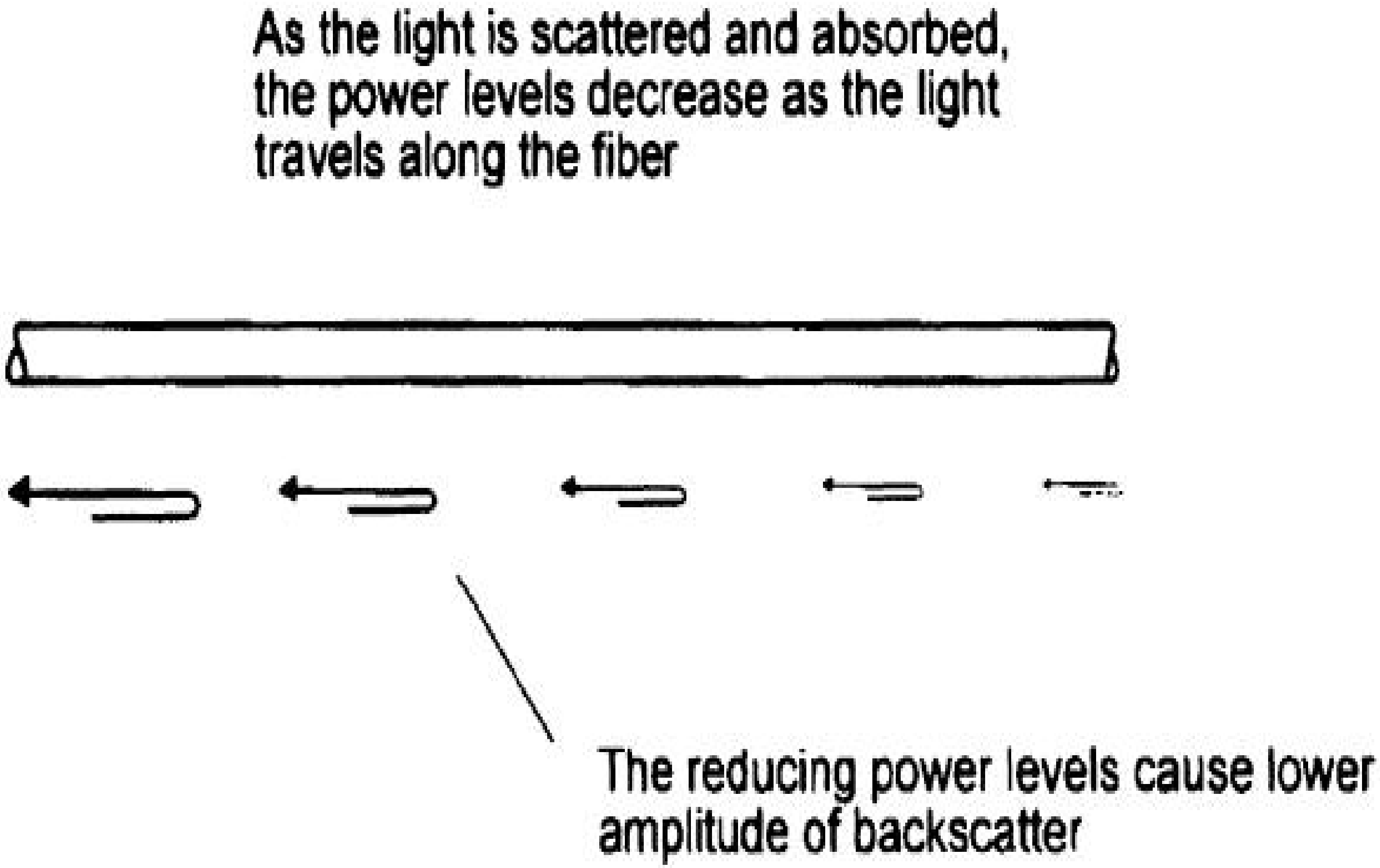


$$\textbf{Reflected power} = \left(\frac{(n_1 - n_2)}{(n_1 + n_2)}\right)^2$$

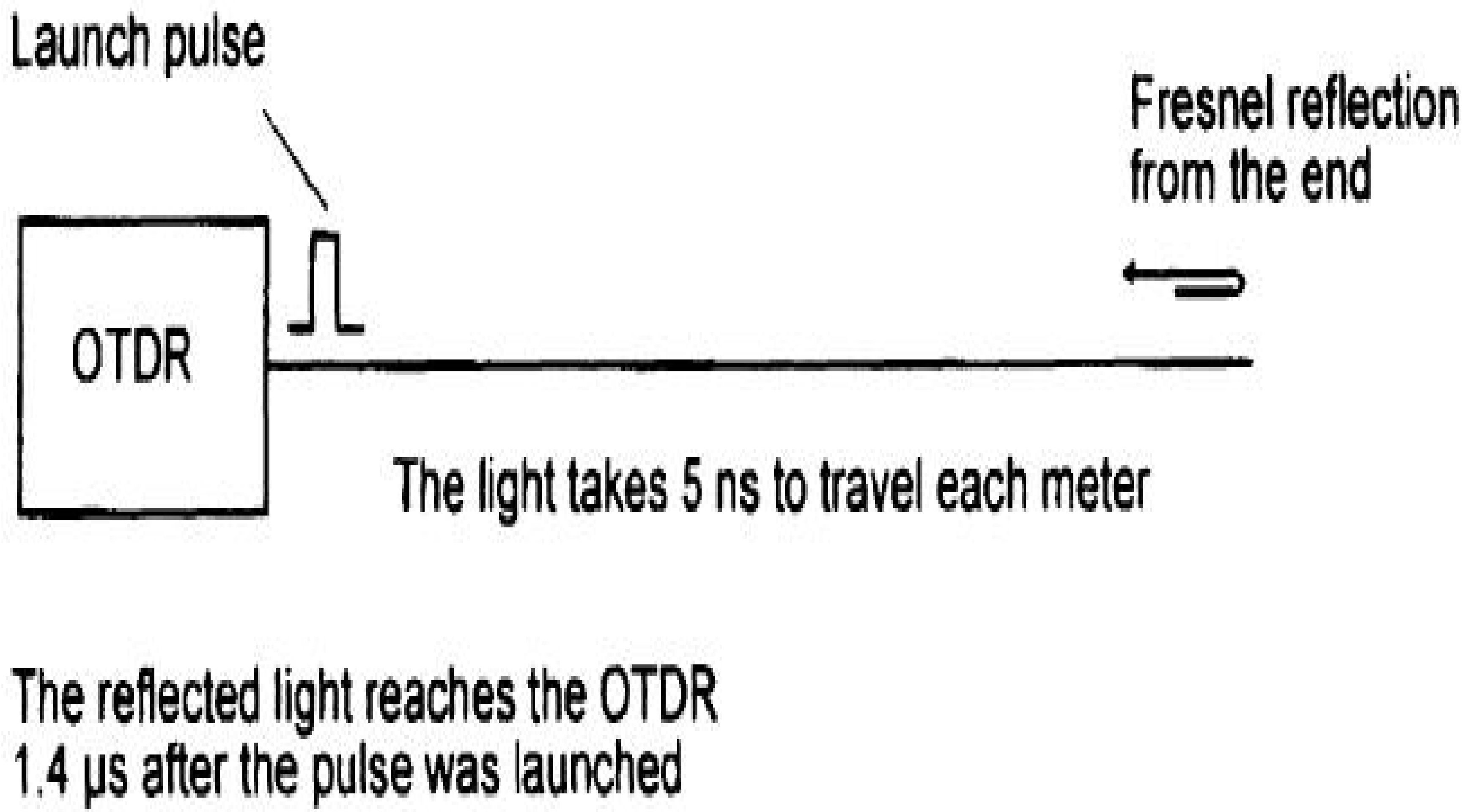
Backscatter



The backscatter becomes weaker



How long is the fiber?



Continued……..

Assuming the refractive index of the core is 1.5, the infrared light travels at a speed of:

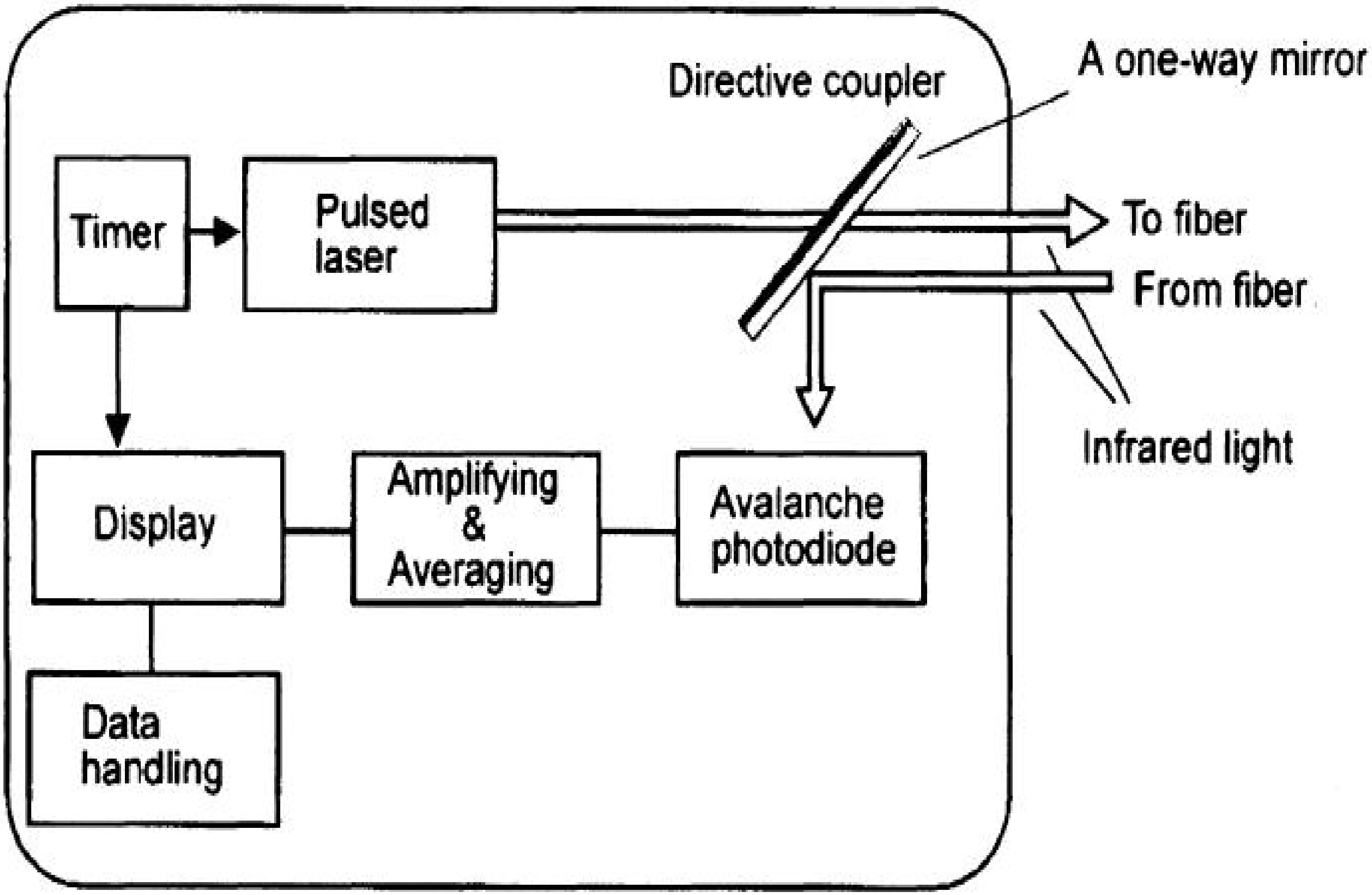
$$\frac{Speed\,of\,light\,in\,free\,space}{\mathrm{Re}\,fractive\,index\,of\,the\,core} = \frac{3\times10^{8}}{1.5} = 2\times10^{8}\,ms^{-1}$$

This is a useful figure to remember, If the OTDR measures a time delay of 1.4 μs, then the distance traveled by the light is:

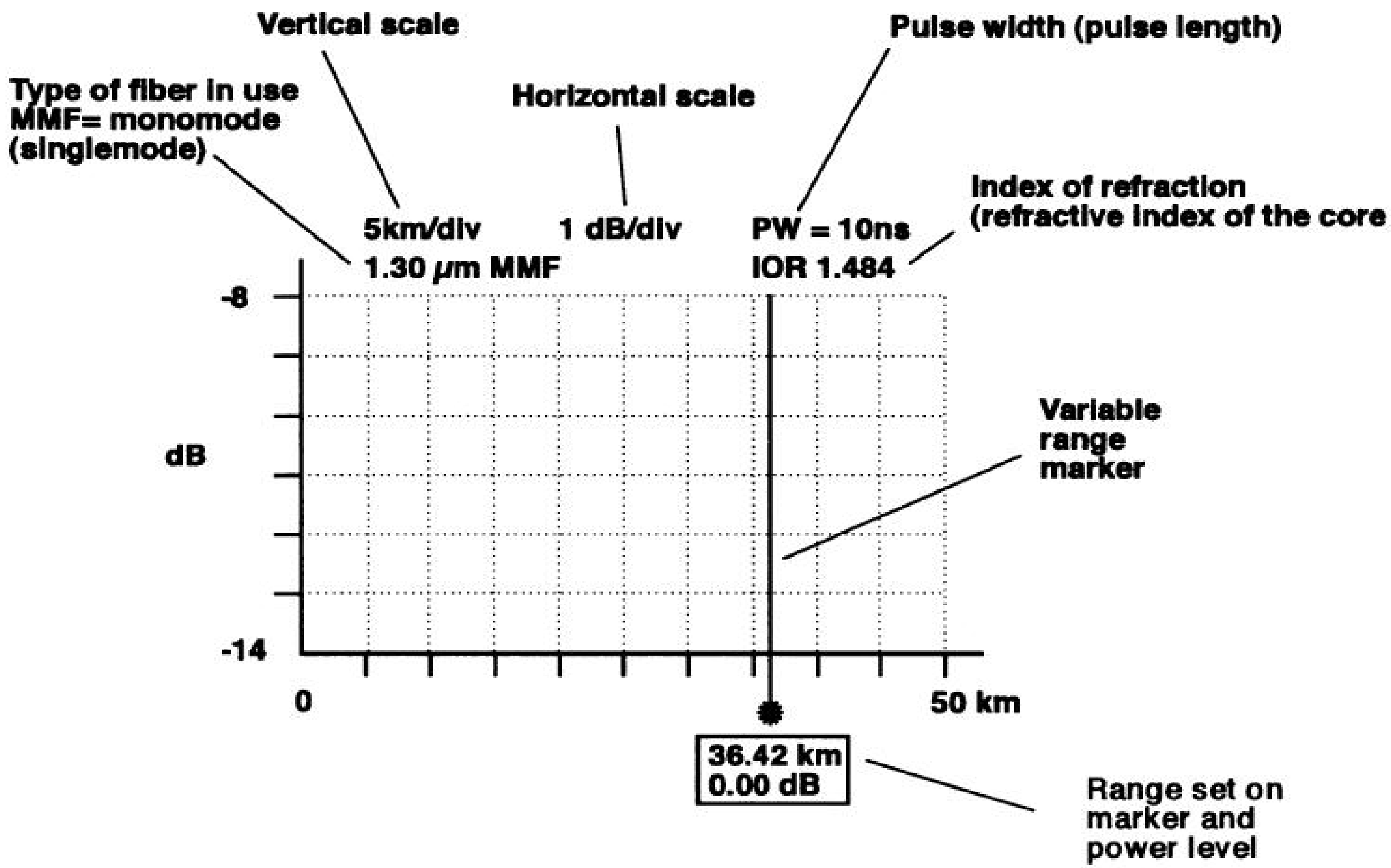
$$2\times10^{8}\times1.4\times10^{-6} = 280\ m$$

The 280 meters is the total distance traveled by the light and is the ‘there and back’ distance. The length of the fiber is therefore only 140 m. This adjustment is performed automatically by the OTDR — it just displays the final result of 140 m.

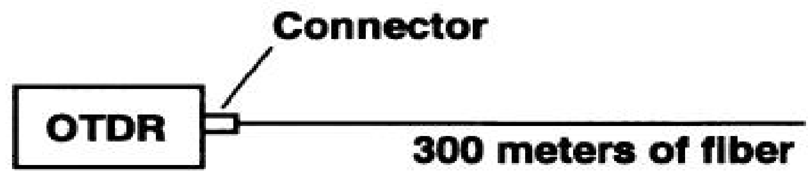
A block diagram of an OTDR

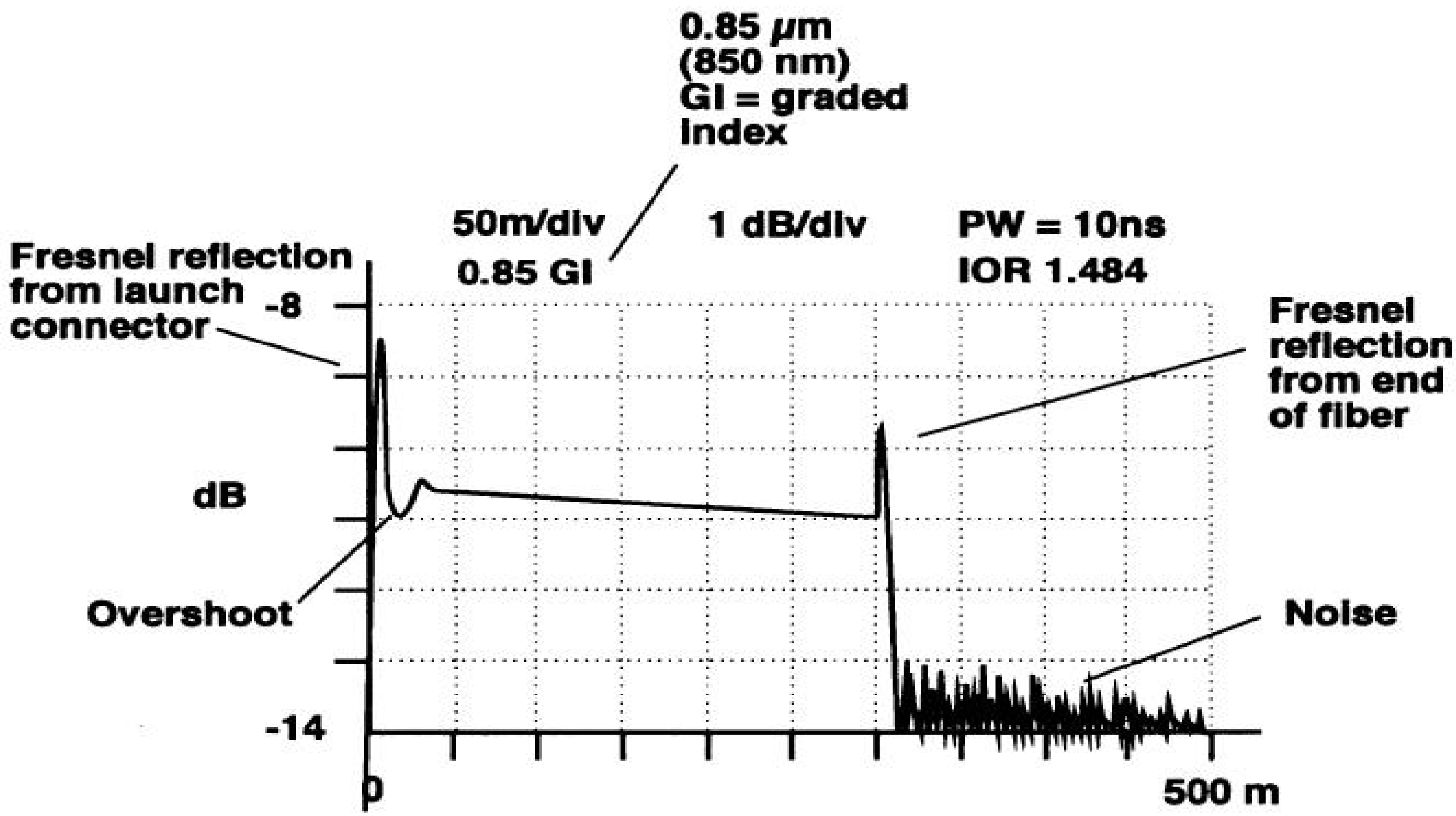


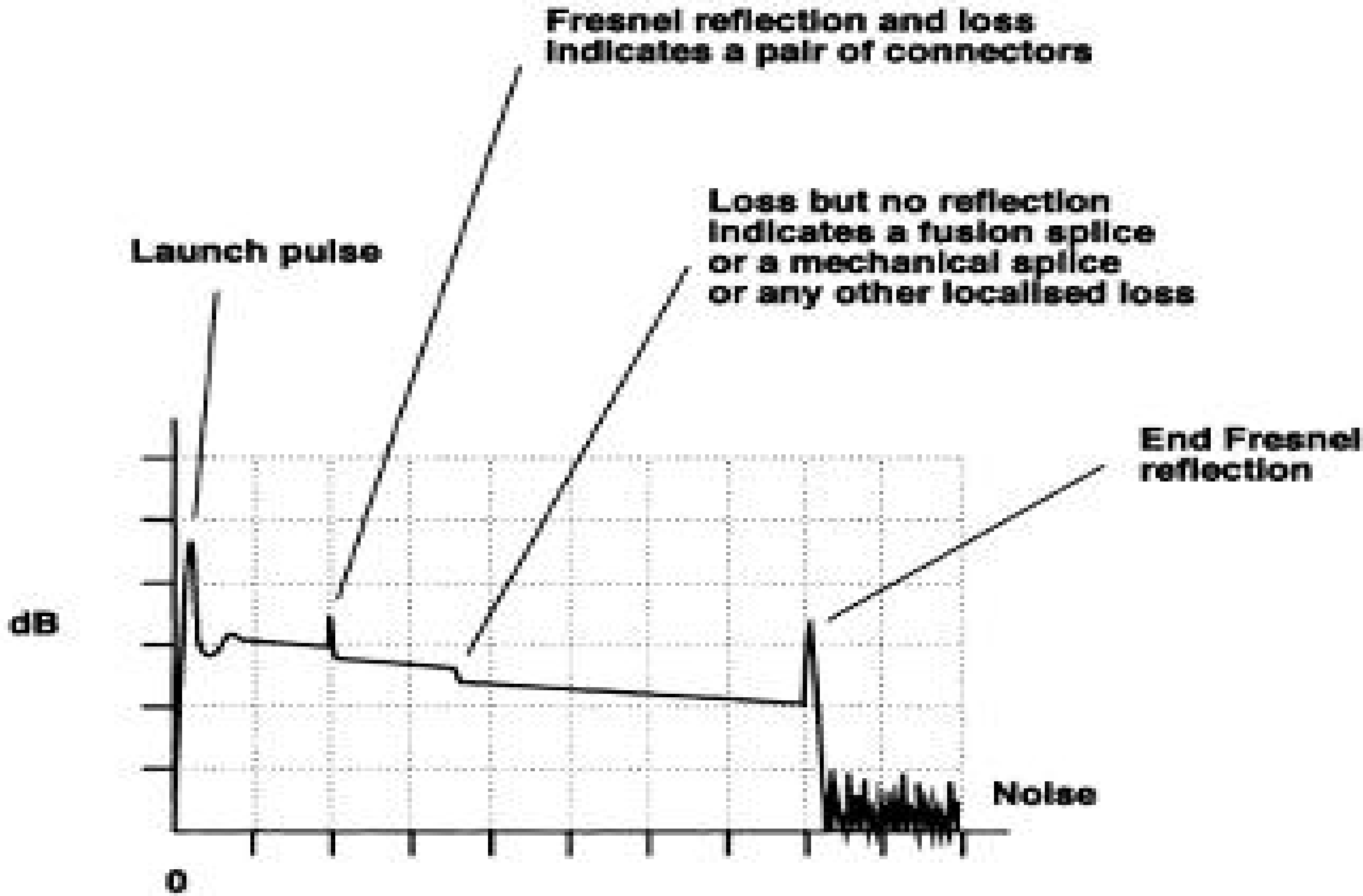
An OTDR display — no signal



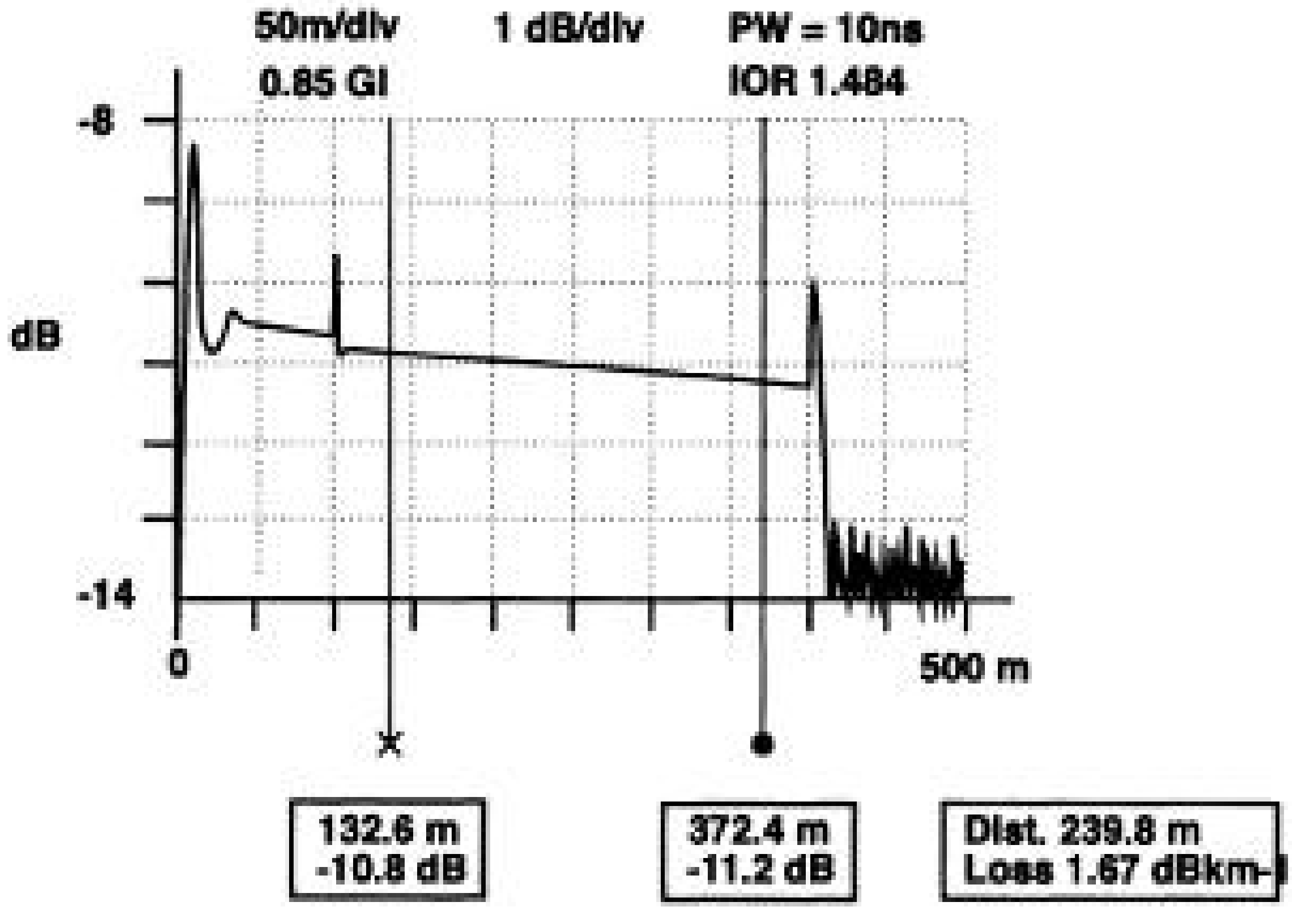
A simple fiber measurement






Fresnel reflection and loss
indicates a pair of connectors
Loss but no reflection
indicates a fusion splice
or a mechanical splice
or any other localised loss
Launch pulse
End Fresnel
reflection
dB
Noise
0

Attenuation measurement



Continued……..

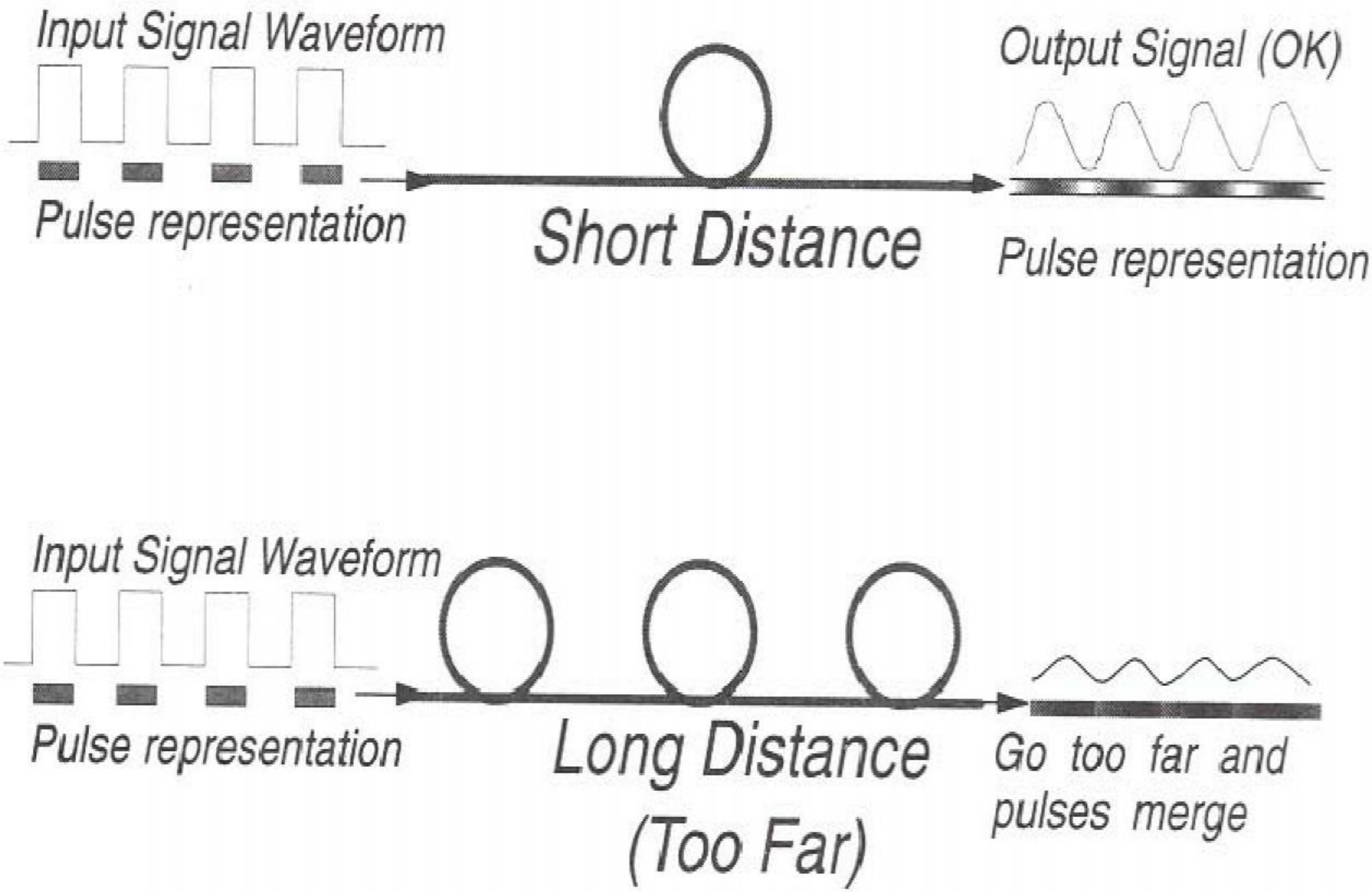
The end of the fiber appears to be at 400 m on the horizontal scale but we must deduct 100 m to account for our patch cord. This gives an actual length of 300 m for the fiber being tested.

Immediately after the patch cord Fresnel reflection the power level shown on the vertical scale is about –10.8 dB and at the end of the 300 m run, the power has fallen to about –11.3 dB. A reduction in power level of 0.5 dB in 300 meters indicates a fiber attenuation of:

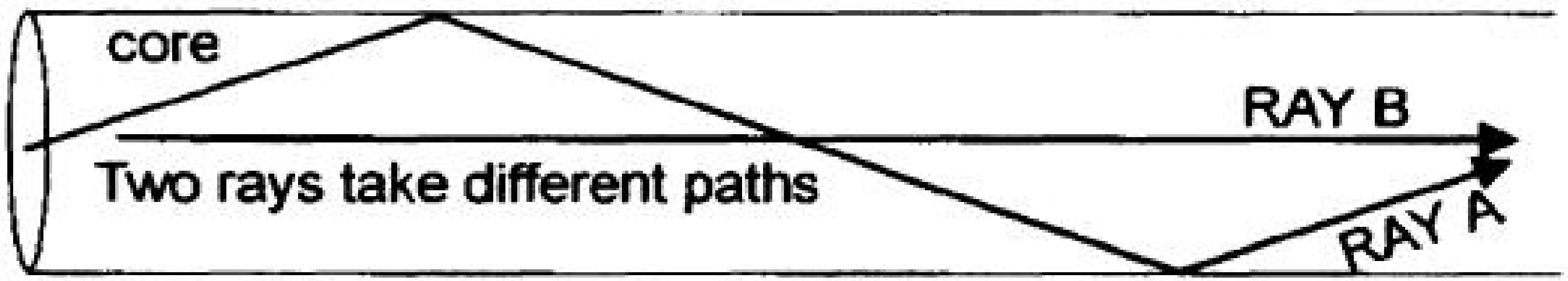
$$\frac{attenuation}{length\ in\ km} = \frac{0.5}{0.3} = 1.66\ dBkm^{-1}$$

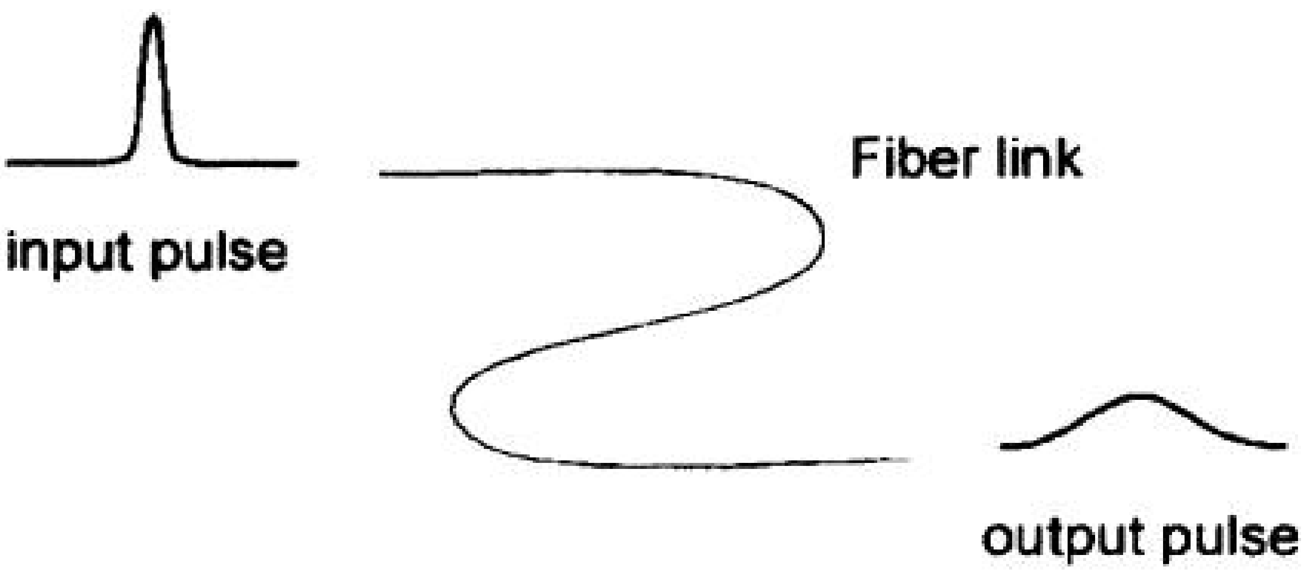
Most OTDRs provide a loss measuring system using two markers. The two markers are switched on and positioned on a length of fiber which does not include any other events like connectors or whatever as shown in Figure.

Dispersion


Input Signal Waveform
Pulse representation
Short Distance
Output Signal (OK)
Pulse representation
Input Signal Waveform
Pulse representation
Long Distance
(Too Far)
Go too far and
pulses merge

The Ray will travel first



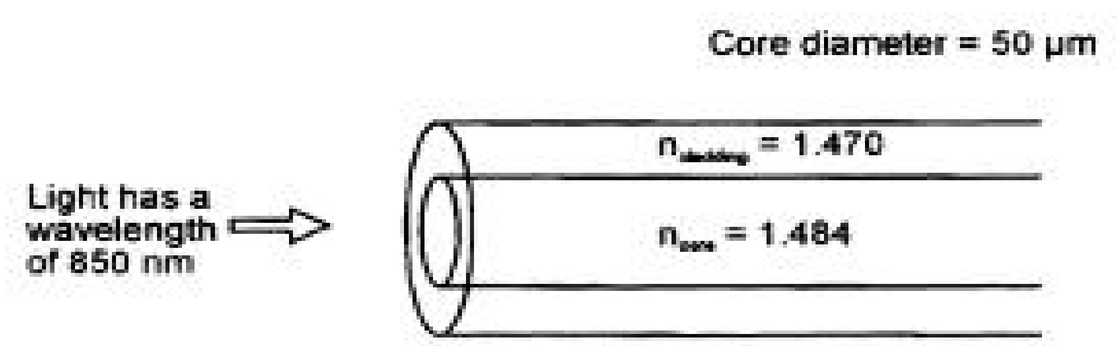


How many modes are there?

The number of modes is given (reasonably accurately) by the formula:

$$Number\ of\ modes = \frac{\left(Diameter\ of\ core \times NA \times \frac{\Pi}{a}\right)^2}{2}$$

where NA is numerical aperture of the fiber and λ is the wavelength of the light source.

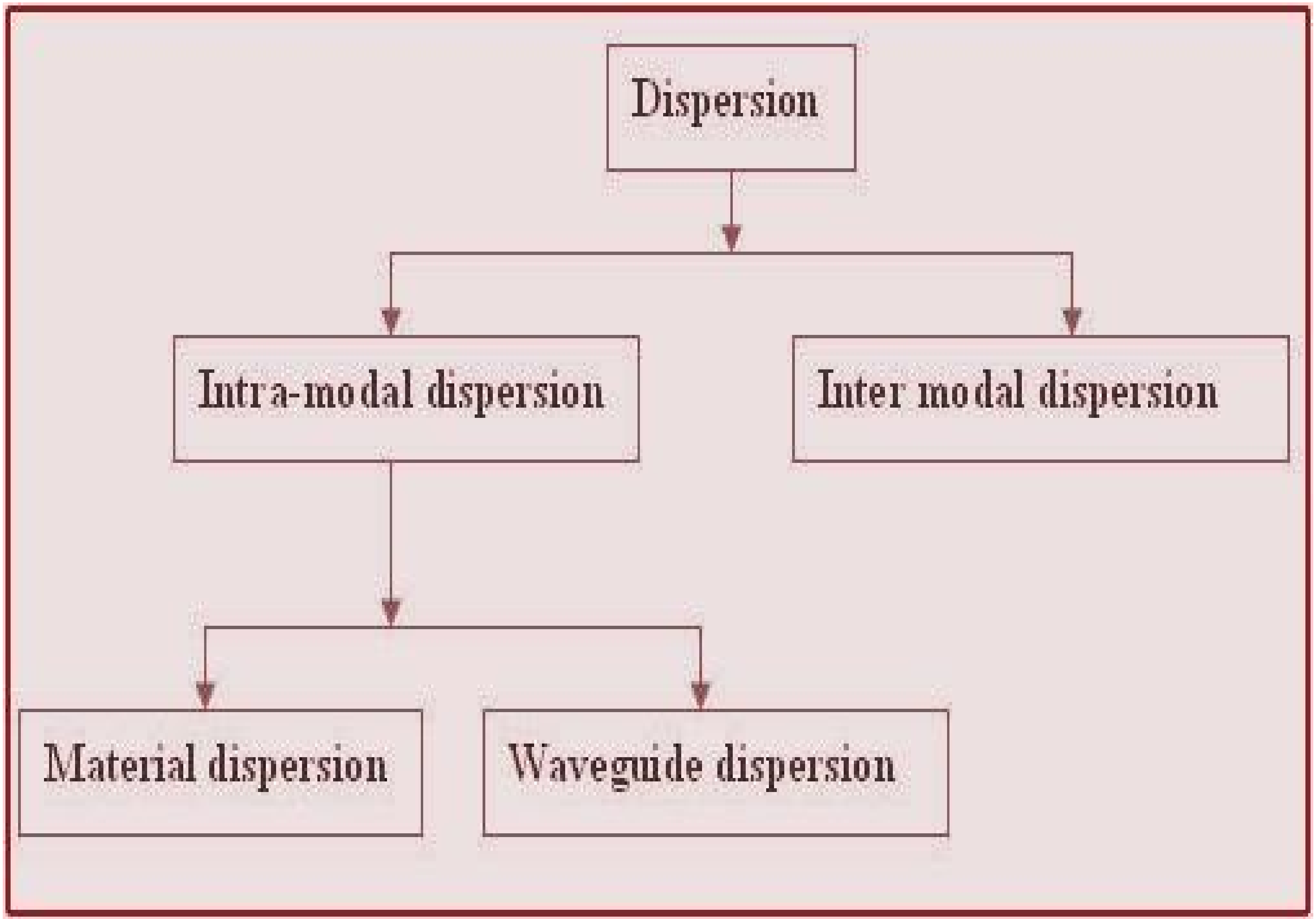


$\boxed{\text{number of modes} = 703.66 \approx 703;\ \text{Note: Always round down}}$

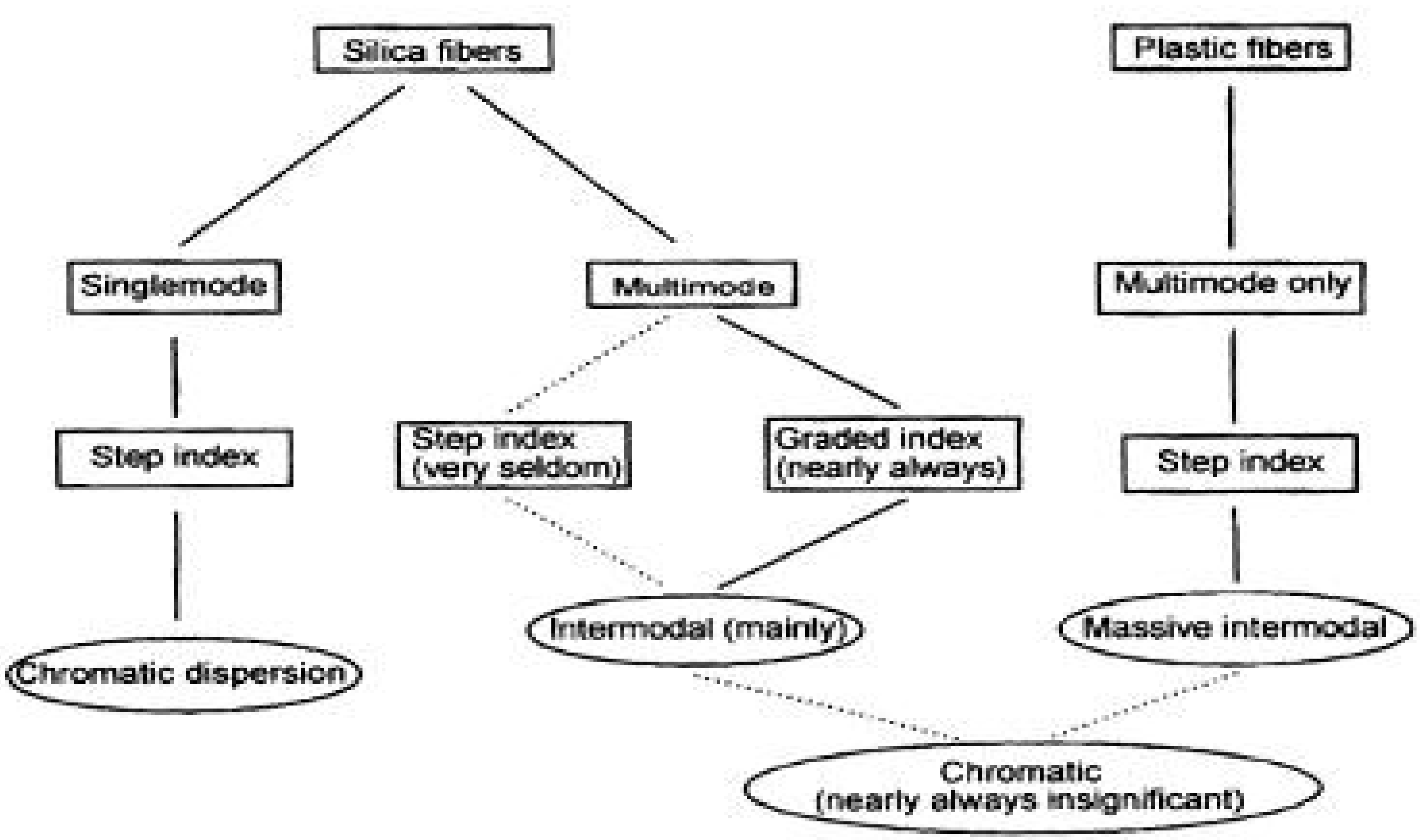
How to get one mode and solve the problem

Intermodal dispersion is the result of different modes (rays) traveling at different speeds. The easy way to avoid this is to have only one mode.

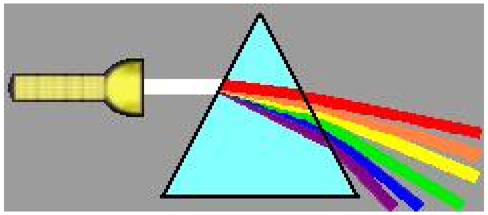
- We can see that we could decrease the number of modes by increasing the wavelength of the light. However this alone cannot result in reducing the number of modes to 1. Changing from the 850 nm window to the 1550 nm window will only reduce the number of modes by a factor of 3 or 4 which is not enough on its own.
- Similarly, a change in the numerical aperture can help but it only makes a marginal improvement.
- We are left with the core diameter. The smaller the core, the fewer the modes. When the core is reduced sufficiently the number of modes can be reduced to just one. The core size of this SM or single mode fiber is between 5 µm and 10 µm.


Dispersion
Intra-modal dispersion
Inter modal dispersion
Material dispersion
Waveguide dispersion

Dispersion — a summary

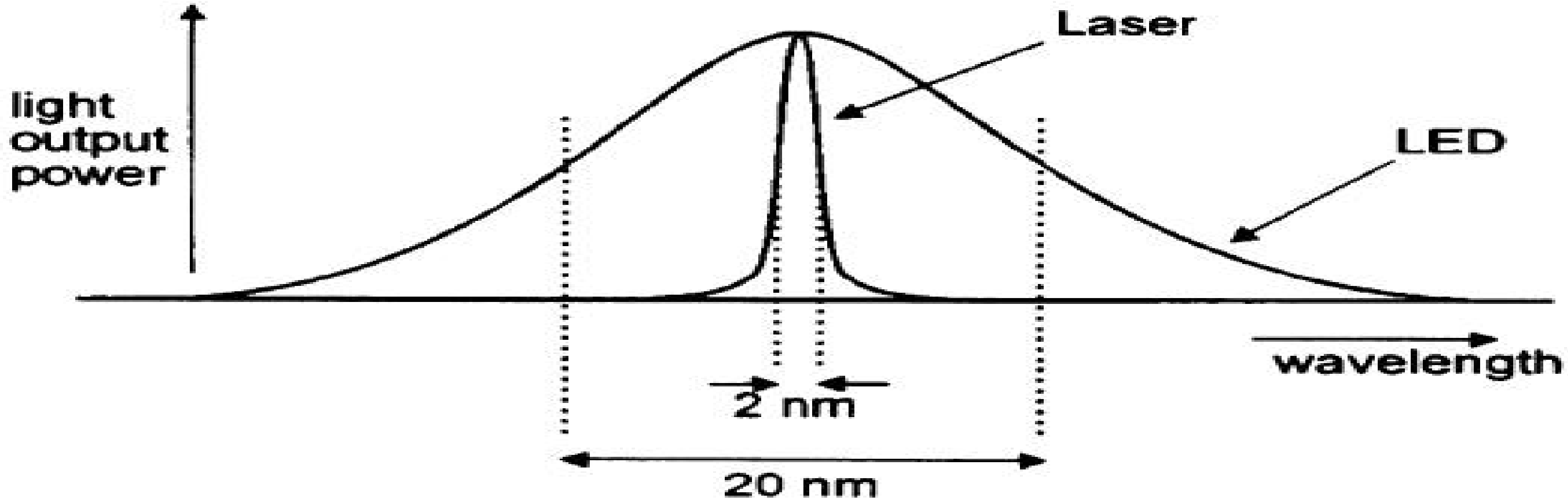


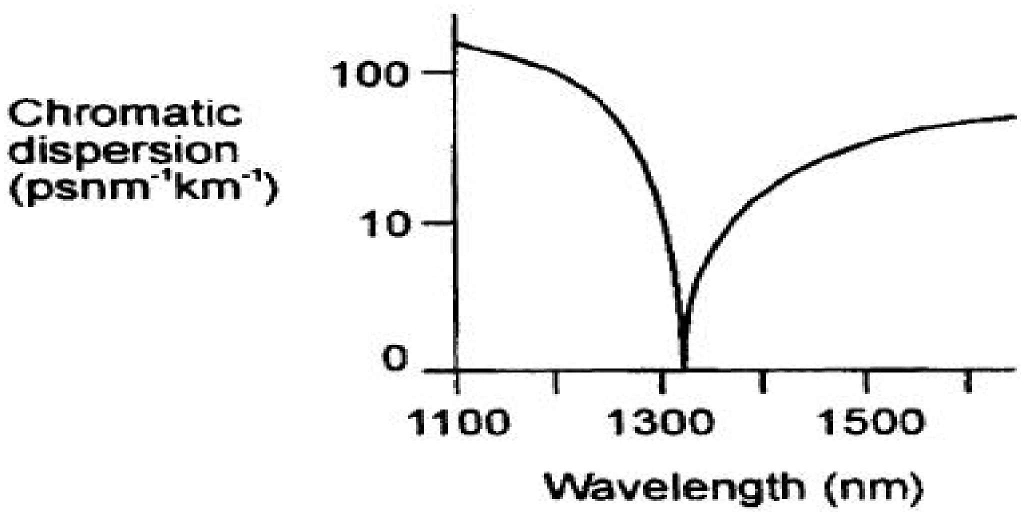
Modes in fiber



- Signals traveling through the fiber forms a pattern. These patterns are called *modes of transmission. Modes means* methods — hence methods of transmission.
- An optic fiber that carries more than one mode is called a *multimode fiber (MM)*. The number of modes is always a whole number.
- ***Inter means between. Intermodal — between modes***
- ***Intra means within. Intramodal — within a single mode***
- Intermodal dispersion is not the only cause of dispersion. We know that light of different wavelength is refracted by different amounts. It means the refractive index and hence the speed of light is determined to some extent by its wavelength.
- LASER produces a range of wavelengths but fewer than LED.
- This is unfortunate as each component wavelength travels at a slightly different speed in the fiber. This causes the light pulse to spread out as it travels along the fiber — and hence causes dispersion. The effect is called ***chromatic dispersion***. Actually, chromatic dispersion is the combined effect of two other dispersions — ***material dispersion*** and ***waveguide dispersion***. Both results in a change in transmission speed, the first is due to the atomic structure of the material and the second is due to the propagation characteristics of the fiber.

The laser has a narrow spectral width & The effect of wavelength





Material dispersion (Chromatic dispersion)

- A range of wavelengths (optical spectrum) is typically transmitted through an optical fiber.
- As a consequence of the wavelength dependent refractive index of the fiber the light will travel at different speed in the fiber, which leads to a spreading of the optical pulses.
- Even in the case of a laser which has a very narrow spectral width a spreading of the optical pulses is observed while traveling through a fiber.
- The problem gets obviously more severe if a LED or another light source is used which emits a broader spectrum.
- In DWDM (Dense-Wavelength-Division-Multiplex) communication systems the chromatic dispersion is therefore an inherent problem as different wavelength are used to transmit different channel.
- As a consequence dispersion management is absolutely essential for DWDM networks.

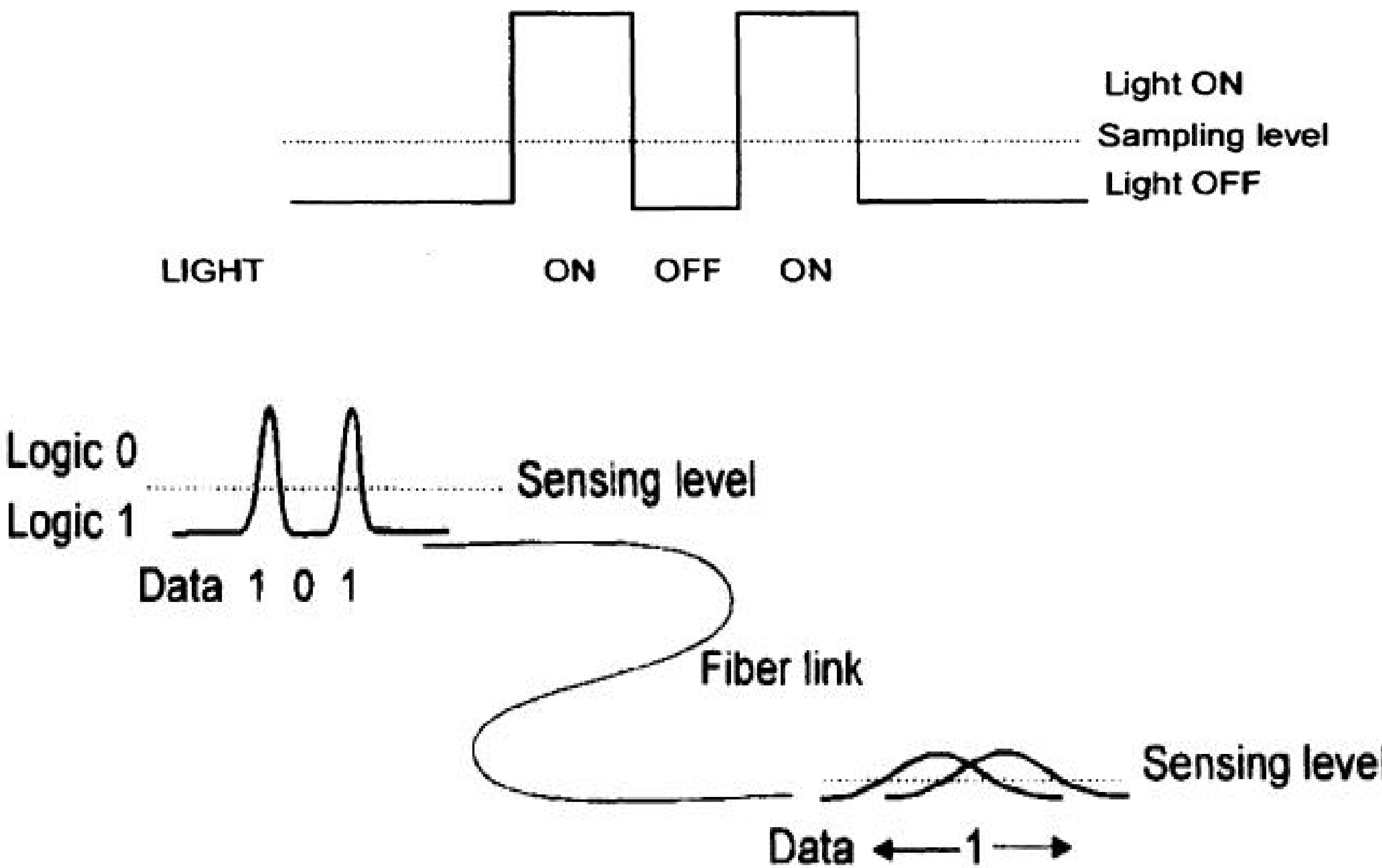
Waveguide dispersion

- Waveguide dispersion is due to the waveguide structure itself meaning the effect depends on the design of the fiber, the refractive index of the core and the cladding and the wavelength of the transmitted light.
- Depending on the design of the fiber and the mode propagating in the fiber a fraction of the light is propagated in the cladding of the fiber. This effect is due to the fact that the electric and the magnetic field at the interface of the core and the cladding have to be continuous so that the field extends into the cladding.
- In the case of a single mode fiber for example 20% of the light is transmitted in the cladding. As a consequence of the field distribution in the fiber (different refractive indices in the core and the cladding) the light propagates at different speed in the core and the cladding.
- Such kind of pulse spreading is called waveguide dispersion. Again, this effect is inherent to a waveguide structure, but the effect can be controlled by the shape and the profile of refractive index inside of the fiber.

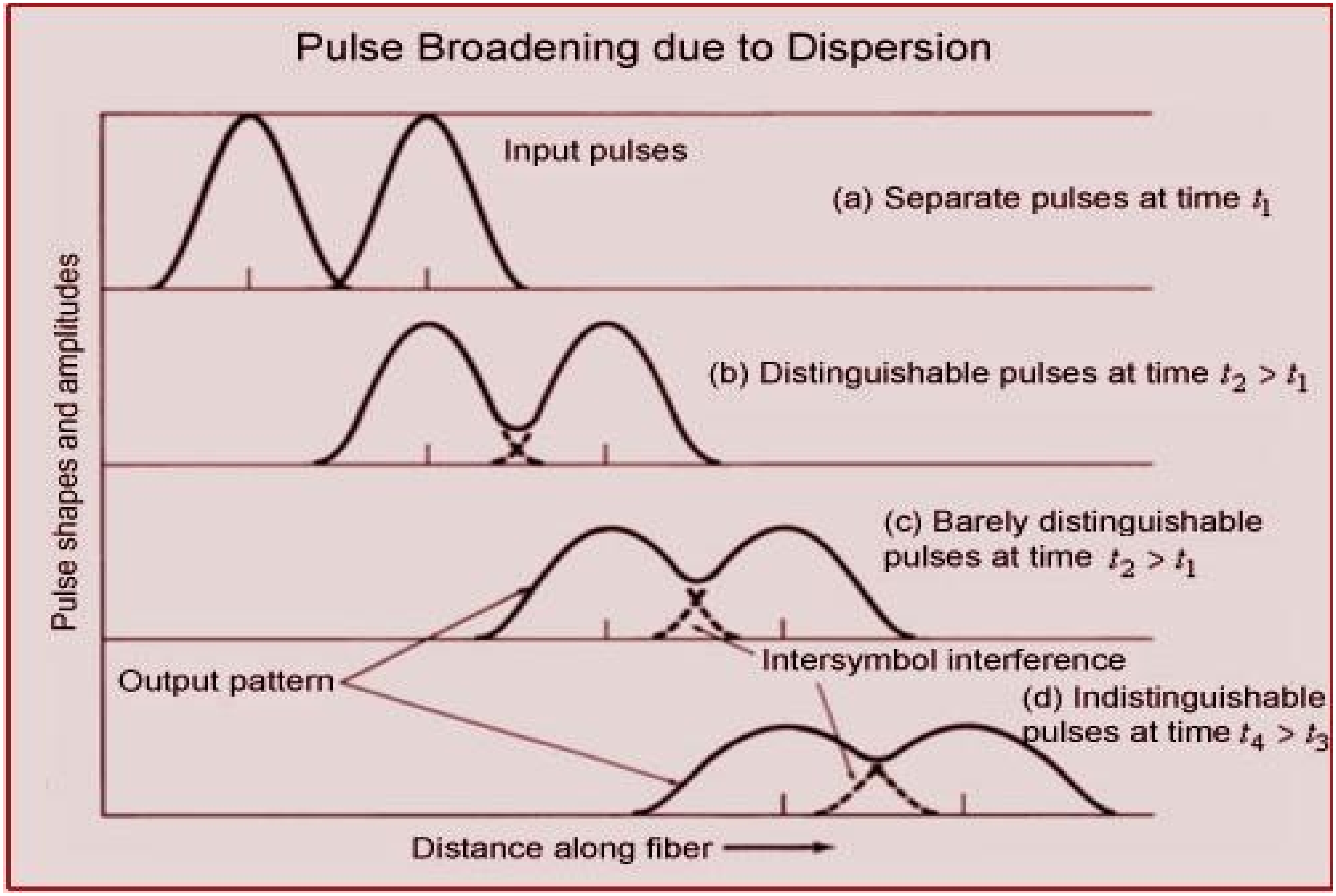
Inter Modal dispersion

- Modal dispersion is related to the difference in propagation speed caused by the propagation of different modes.
- This is of course only a problem for multimode fibers. The explanation is relatively simple. We already discussed that different modes can propagate in waveguides.
- Each mode is associated with a specific propagation angle and a specific effective refractive index.
- With increasing mode number the effective refractive index and the propagation angle are reduced.
- Again, this effect is inherent to the propagation of modes in a multi-mode fiber.
- Even though the difference in refractive index is very small between the core and the cladding of the fiber (therefore the difference in effective refractive index and the difference in the propagation angle is small) the effect cannot be avoided.

Electronic pulses controlling the light source & Dispersion has caused the pulses to merge



Pulse Broadening due to dispersion




Thank You