Engineering Optics

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by

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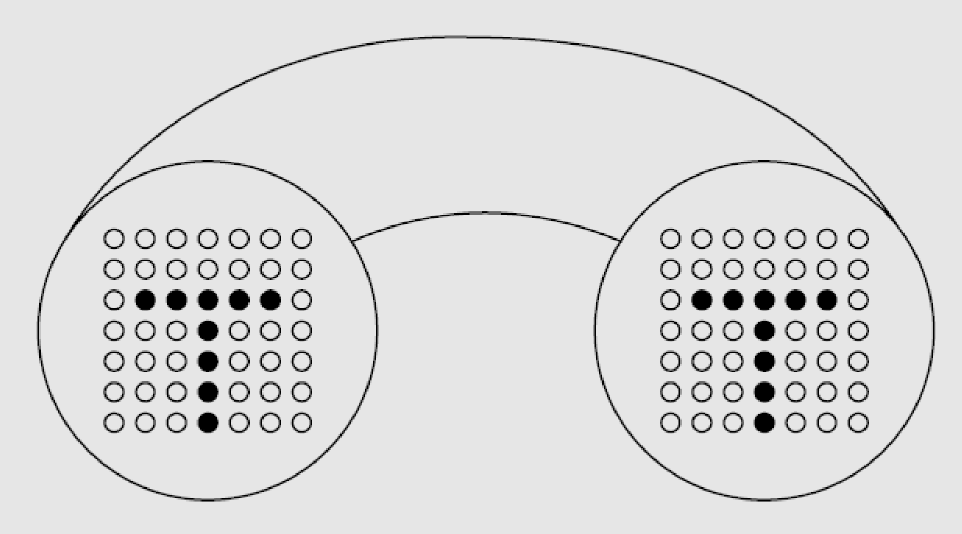
The coherent bundle

- If a large number of fibers are put together, it forms what is known as a *bundle*.
- If the fibers are not aligned, i.e., they are all jumbled up, the bundle is said to form an ***incoherent bundle***.
- However, if the fibers are aligned properly, i.e., if the relative positions of the fibers in the input and output ends are the same, the bundle is said to form a ***coherent bundle***.
- Usage: endoscope→ inserted through throat for detecting illnesses inside their stomach.
- At the top end →eyepiece and a lamp. The lamp shines its light down one part of the cable into the patient's stomach. When the light reaches the stomach, it reflects off the stomach walls into a lens at the bottom of the cable. Then it travels back up another part of the cable into the doctor's eyepiece.



A bundle of aligned fibers. A bright (or dark) spot at the input end of the fiber produces a bright (or dark) spot at the output end. Thus an image will be transmitted (in the form of bright and dark spots) through a bundle of aligned fibers.

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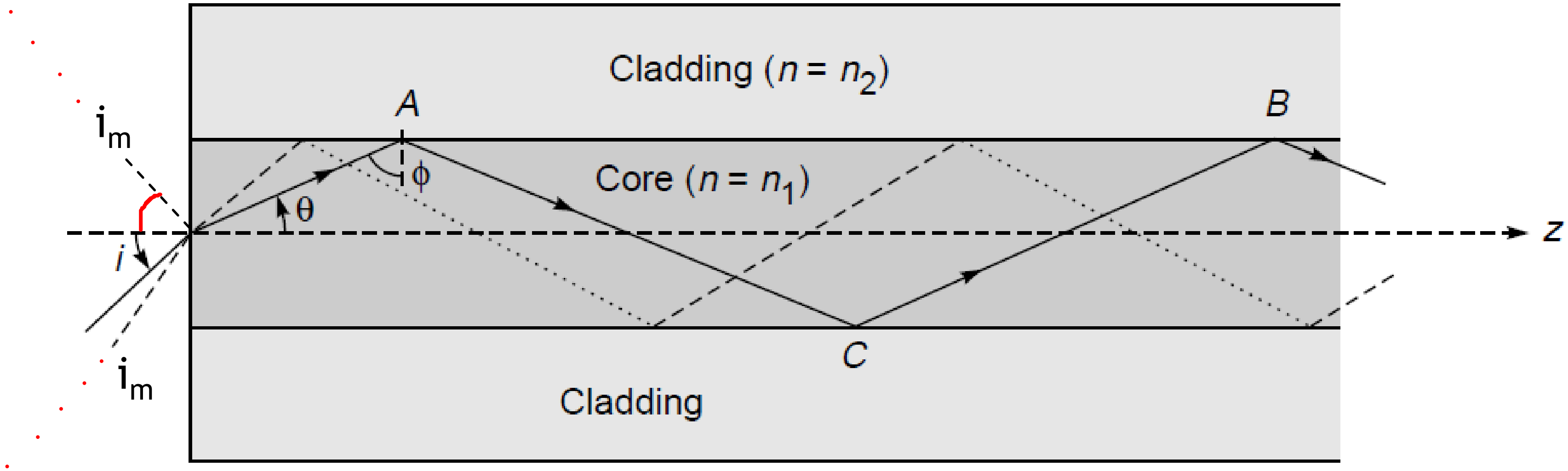
Incoherent bundle

- In an incoherent bundle the output image will be scrambled. Because of this property, an incoherent bundle can be used as a coder; the transmitted image can be decoded by using a similar bundle at the output end.

- In a bundle, since there can be hundreds of thousands of fibers, decoding without the original bundle configuration should be extremely difficult.

Numerical aperture



if light is incident on one end of the fiber, it will be guided through it provided i <i_m.

The quantity **sini_m is known as the numerical aperture (NA)** of the fiber and is a measure of the light-gathering power of the fiber.

In almost all practical situations, $n_1^2 < n_2^2 + 1$

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

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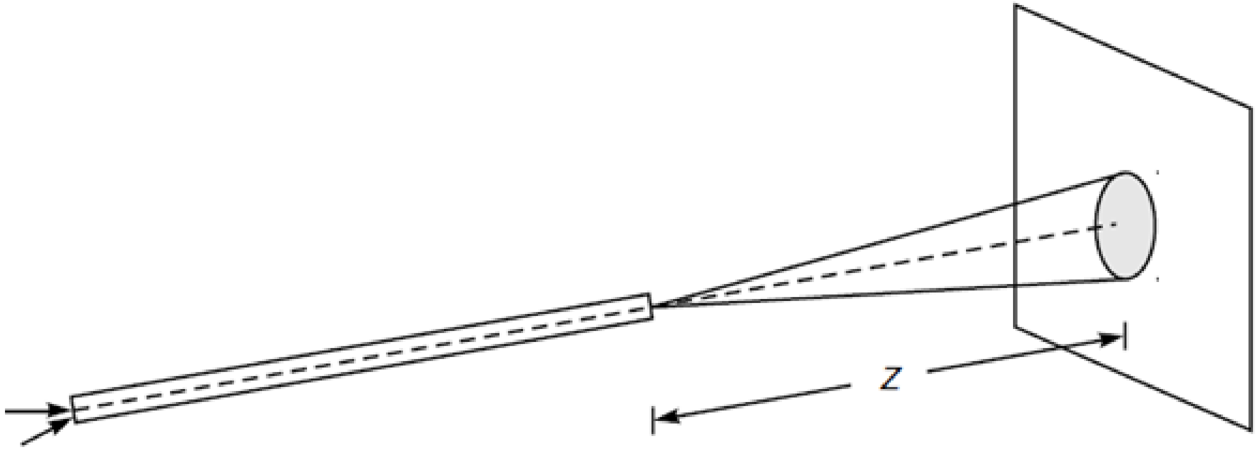
Calculation of N.A.

Now, in a short length of an optical fiber, if all rays between $i = 0$ and i_m are launched, then, the light coming out of the fiber will also appear as a cone of semiangle i_m emanating from the fiber end.



Q: NA =?

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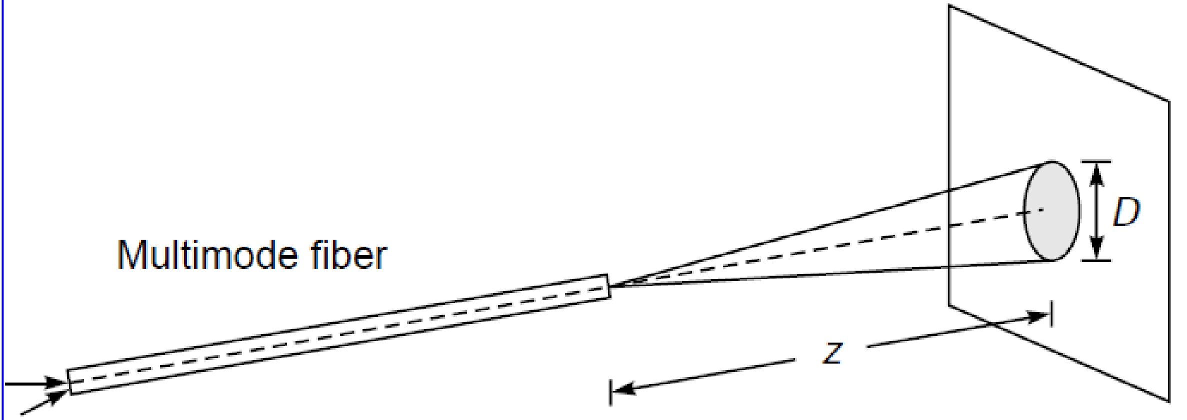
Calculation of N.A.

Now, in a short length of an optical fiber, if all rays between $i = 0$ and i_m are launched, then, the light coming out of the fiber will also appear as a cone of semiangle i_m emanating from the fiber end. If we now allow this beam to fall normally on a white paper (see Fig. 27.11) and measure its diameter, we can easily calculate the NA of the fiber. This allows us to estimate the NA of the optical fiber by a very simple experiment.



Measurement of the diameter D of the spot on a screen placed at a far-field distance z from the output end of a multimode fiber can be used to measure the NA of the fiber.

$$\boxed{\mathrm{NA} = \sin i_m = \sin\left[\tan^{-1}\left(\frac{D}{2z}\right)\right]}$$

Q: NA will then change with D and z ?

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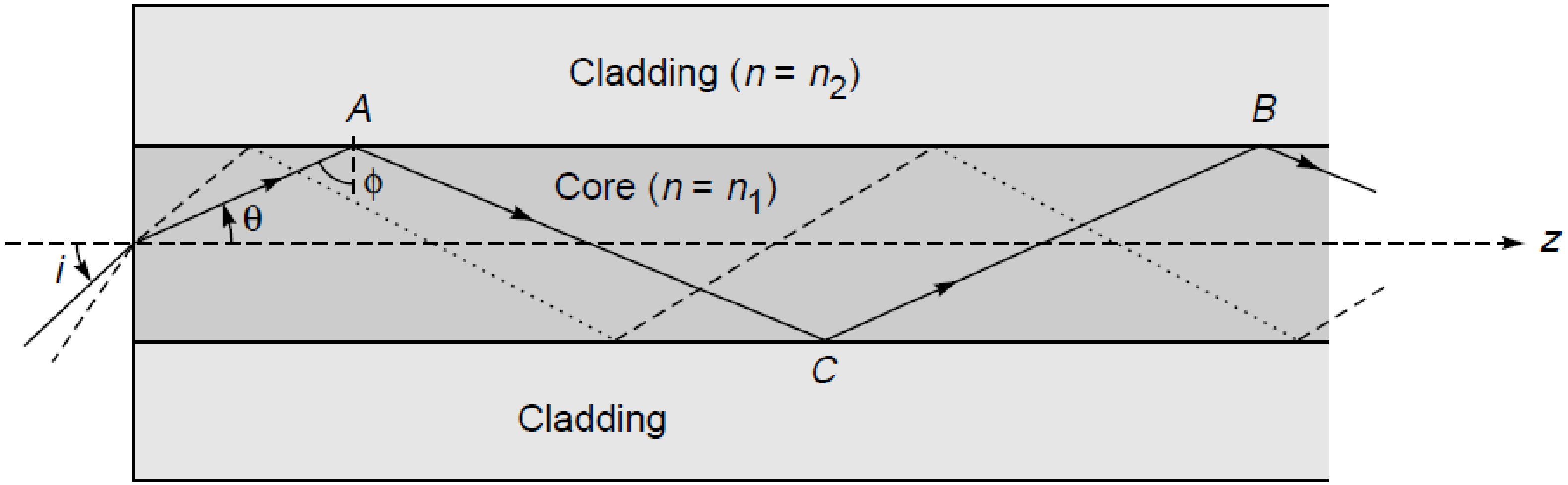
Problem-1

- For an optical fiber with n_1=1.45 and Δ=0.01, calculate the NA.



Hint: if n_1 and Δ are given what is n_2 ?

Solution

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

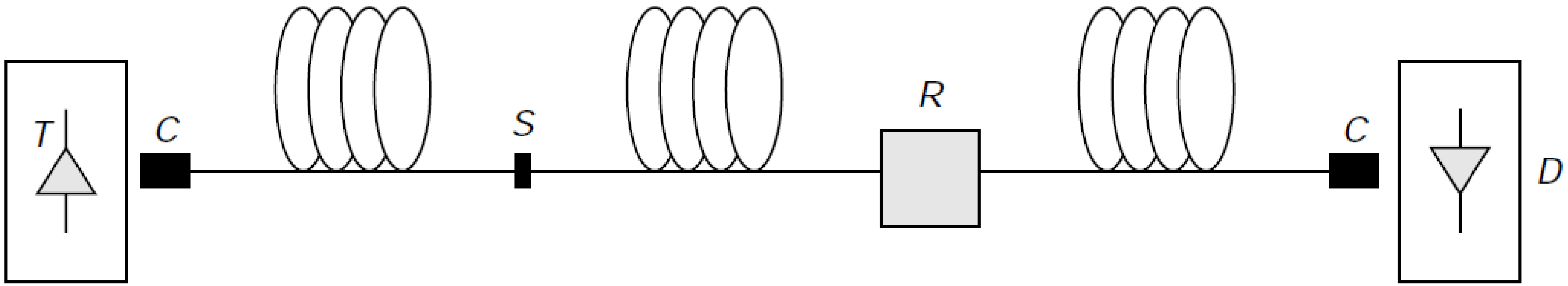
$\Delta = 0.01$ and $n_1 = 1.45$

$\Delta = (n_1 - n_2)/n_1$

$n_2 = 1.4355$

NA = 0.2045

Attenuation (loss)



- Attenuation → information-carrying capacity of a fiber-optic communication system. measured in *decibels (dB)*
- Obviously, the lower the attenuation→ the greater the required *repeater* spacing and therefore the lower will be the cost of the communication system.
- If an input power P_1 results in an output power P_2, then the loss in decibels is given by

$$\boxed{\alpha = 10 \log \left(\frac{P_{\text{input}}}{P_{\text{output}}} \right)}$$

Attenuation (loss)

$$\alpha = 10 \log \left(\frac{P_{\text{input}}}{P_{\text{output}}} \right)$$

- **Problems:**

2. If the output power is the same as the input power, then the loss in dB is = ?
3. If the output power is one-tenth of the input power, then the loss is = ?
4. If the output power is one-hundredth of the input power, then the loss is = ?
5. If the output power is one-thousandth of the input power, then the loss is = ?

Answers

$$\boxed{\alpha = 10 \log \left(\frac{P_{\text{input}}}{P_{\text{output}}} \right)}$$

2. If the output power is the same as the input power, then the loss is = 0 dB.
3. If the output power is one-tenth of the input power, then the loss is = 10 dB.
4. If the output power is one-hundredth of the input power, then the loss is = 20 dB
5. If the output power is one-thousandth of the input power, then the loss is = 30 dB

Problem-6

(a) A 40 km fiber link has a loss of 0.4 dB per km. Each of the three connectors in its path has a loss of 1.8 dB, calculate the total loss.

(b) Another 40 km fiber link has a loss of 0.2 dB per km. Each of the three connectors in its path has a loss of 1.5 dB, calculate the total loss.

(c) Suppose for case (a) the distance between successive repeaters is d_1 and for (b) it is d_2. Which one is true and why? (i) $d_1 = d_2$ (ii) $d_1 > d_2$ and (iii) $d_1 < d_2$

Answers

a) Total loss = (0.4 x 40) + (3 x 1.8) dB = 21.4 dB

b) Total loss = (0.2 x 40) + (3 x 1.5) dB = 12.5 dB

c) (iii)

Problem-7

- If the power of a 5 mW laser beam decreases to 1 mW after traversing through 60 km of an optical fiber, what is the attenuation of the fiber per km?

- (example 27.4 Ghatak's book → typo)

Answer

- Attenuation (loss) = $\boxed{\alpha = 10 \log \left(\frac{P_{\text{input}}}{P_{\text{output}}} \right)}$
- Here P_{in} = 5 mW
- P_{out} = 1 mW
- Attenuation (total) = α = 10 log (5) = 6.989 dB
- Attenuation/km = α /60 ~ 0.1164 dB/km

Thank You