TE 357: Optical Communications

Lecture 3: Optical Fibers

Lecture Objectives

1. To gain insight into the propagation of light along an optical fiber
2. To explain some phenomena that light goes through

Lecture Objective 1

- To gain insight into the propagation of light along an optical fiber
- Thus
  - To determine
    - the conditions needed to transmit light through an optical fiber
      - and resolve how these conditions can be implemented in a practical manner

Lecture Objective 2

- To explain some phenomena that light goes through
- Thus
    - Attenuation
        - Definition
        - Mechanisms
        - Loss calculation

Lecture Objective 2

- Thus
  - Dispersion
    - definition
    - Concept of modes
    - Calculation of number of modes
    - Modal (intermodal) dispersion
      - Pulse spread calculation

Introduction

- What is an optical fiber?

Introduction

- What is an optical fiber?
  - It is a thin, transparent, flexible strand
  - It is a dielectric waveguide that operates at optical frequencies

Introduction

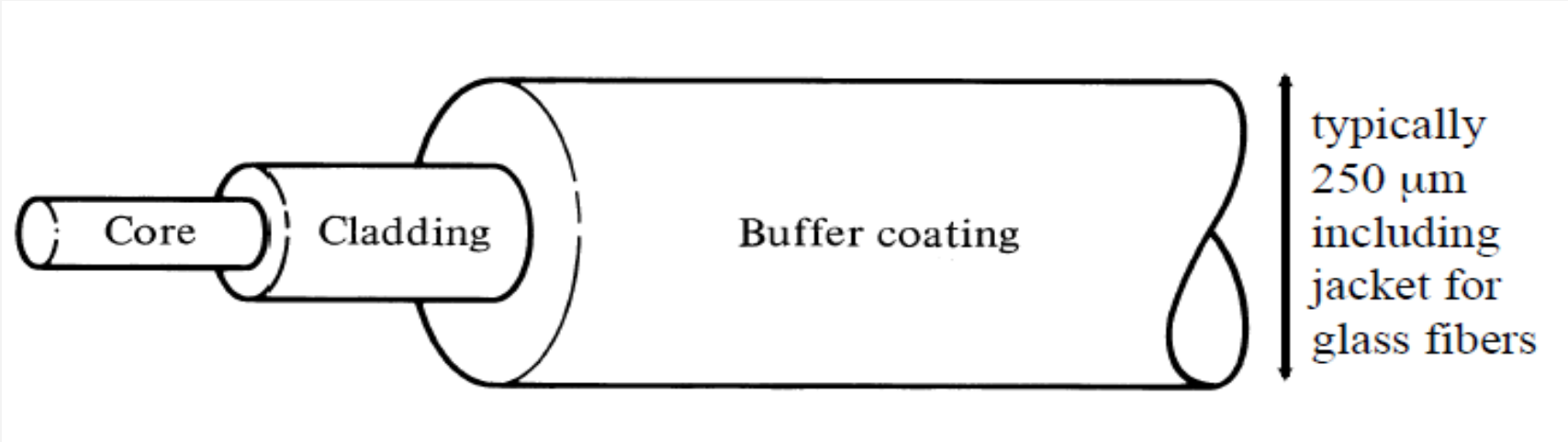
- What is an optical fiber?
  - It is normally cylindrical in form and confines electromagnetic energy in the form of light to within its surfaces.
    - It guides the light in a direction parallel to its axis

Introduction

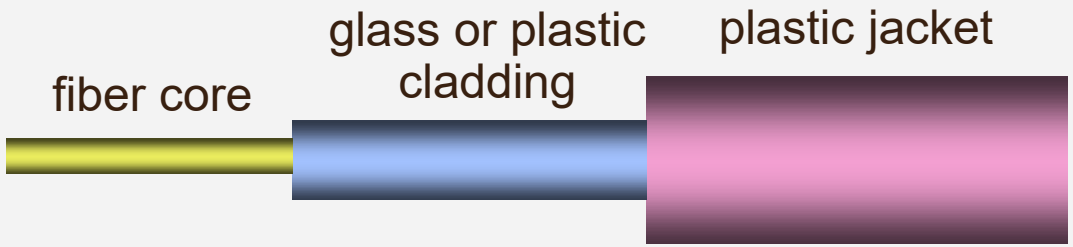
- Some questions that arise concerning optical fibers are:
  1. What is the structure of an optical fiber?
  2. Of what materials are fibers made?
  3. How does light propagate along a fiber?
  4. What is the signal loss or attenuation mechanism in a fiber?
  5. Why and to what degree does a signal get distorted as it travels along a fiber?

Optical Fiber- Basic structure

- Optical fiber structure
  - Core and cladding made from the same material (e.g. silica)
    - differ only in their refractive indexes (why?)

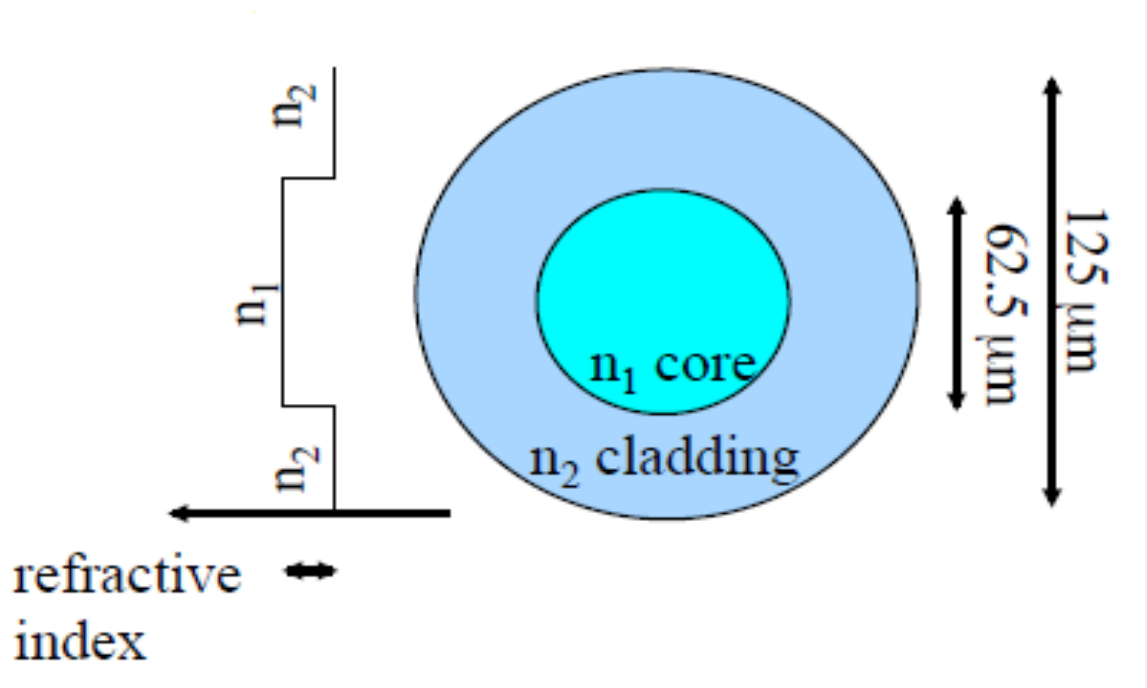


Optical Fiber-Basic structure



Optical Fiber

- Optical fiber structure



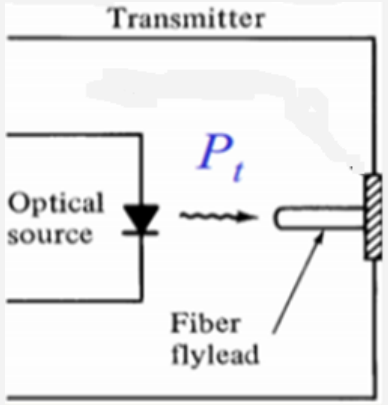
- Step index fiber

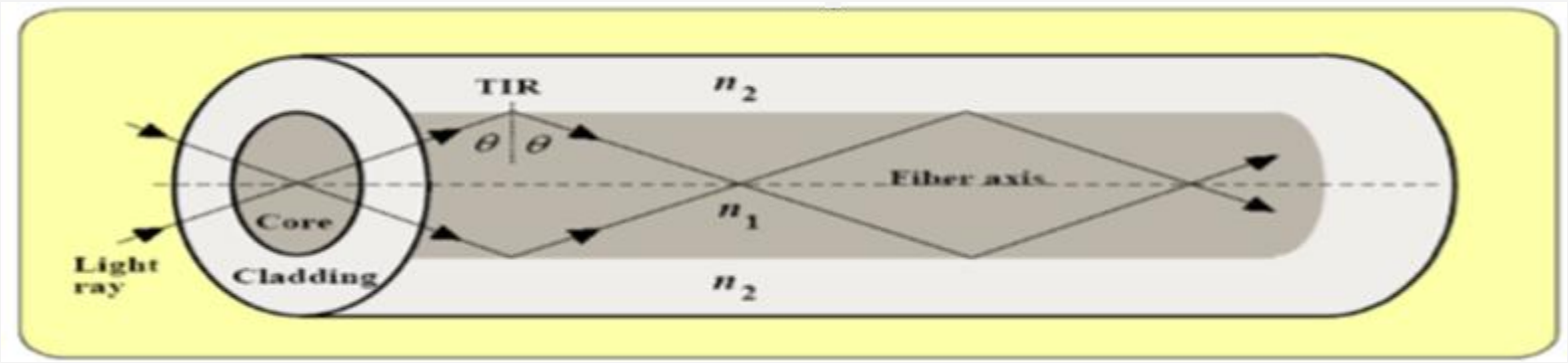
Light ray guiding condition

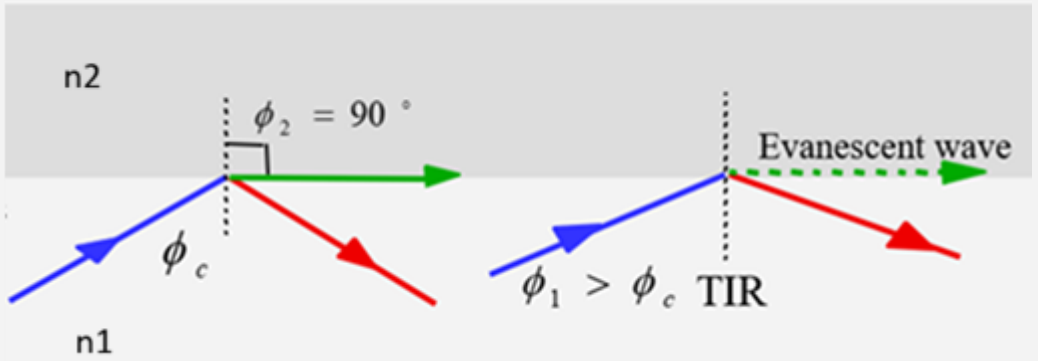
- To save light
  - inside a strand of fiber, what needs to happen?

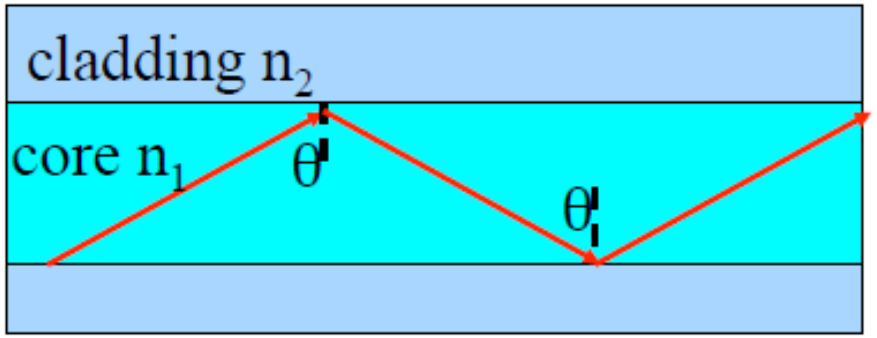
Light ray guiding condition

- Framework



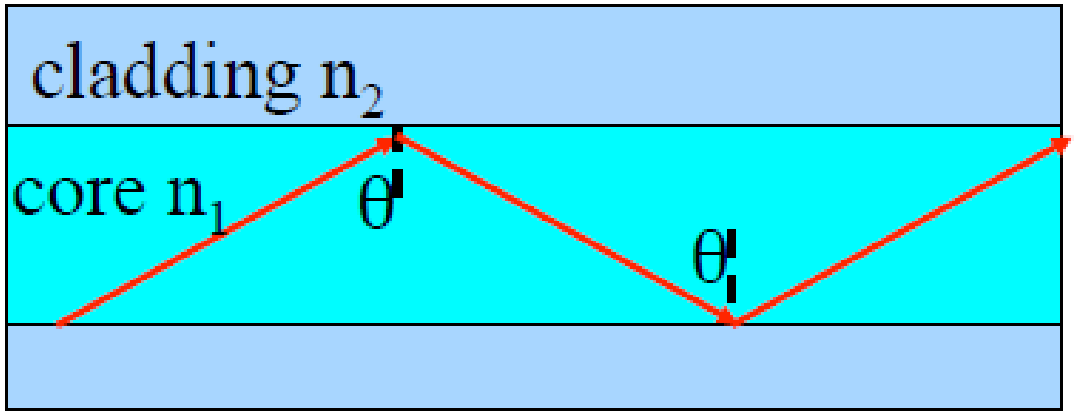






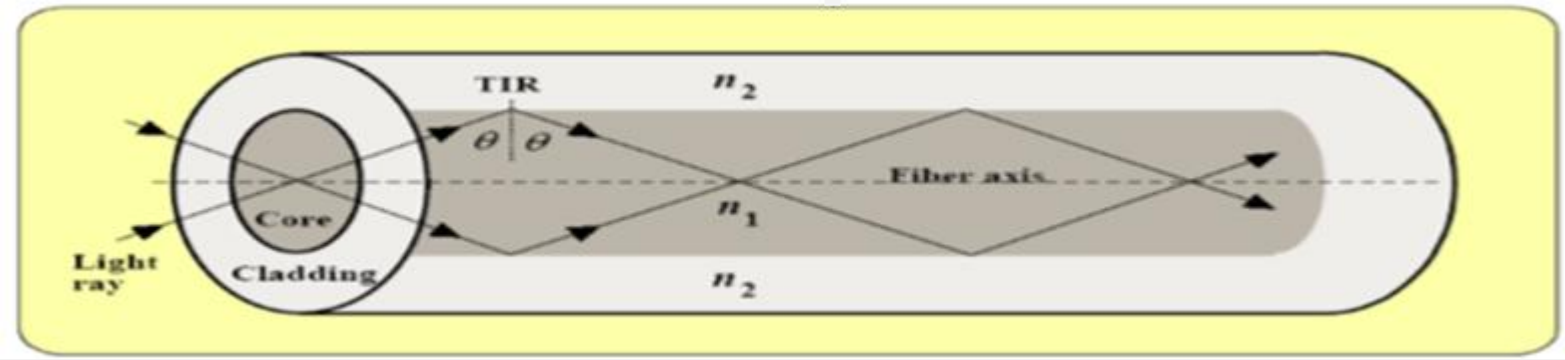
Light ray guiding condition

- To save light
  - inside a strand of fiber, we need to have it strike the
    - core-cladding boundary at an angle above the critical incident angle, θ_c, in order to provide total reflection of this light



Light ray guiding condition

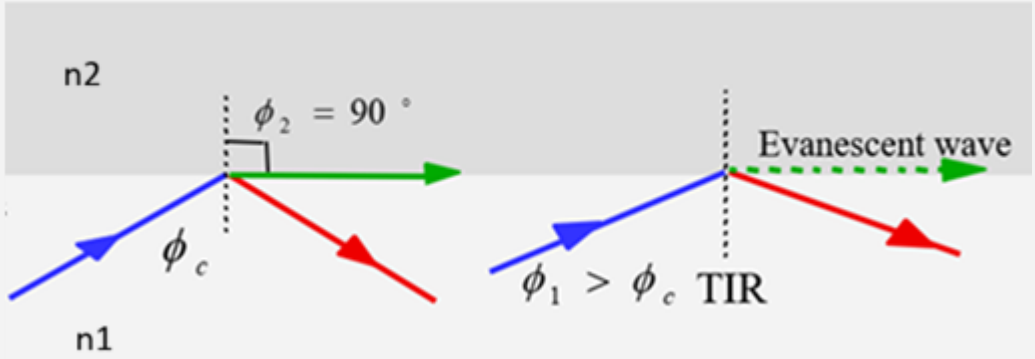
- Light ray that satisfies
  - total internal reflection condition at the Interface/boundary of the CORE and the CLADDING can be guided along an optical fiber



Light ray guiding condition

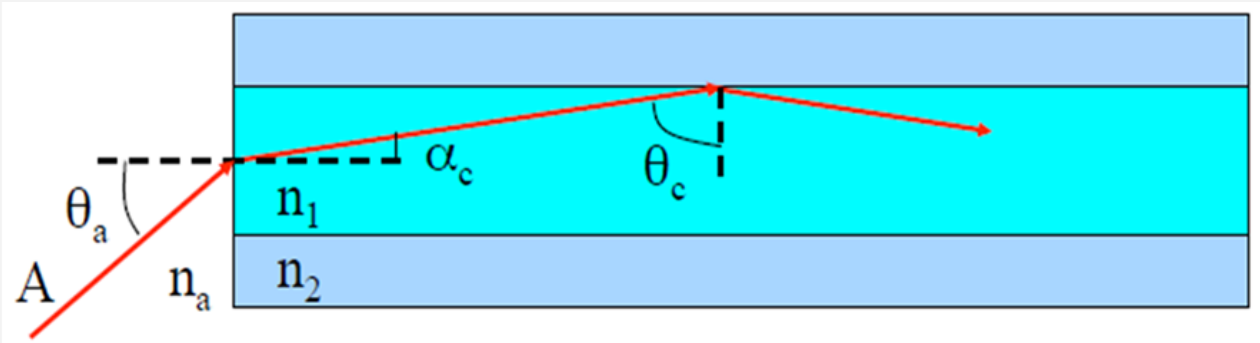
- Under what condition will light be trapped inside the fiber core?
  - i. $n_1 = 1.48$ and $n_2 = 1.46$ (silica)
  - ii. $n_1 = 1.495$ and $n_2 = 1.402$ (Plastic)

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



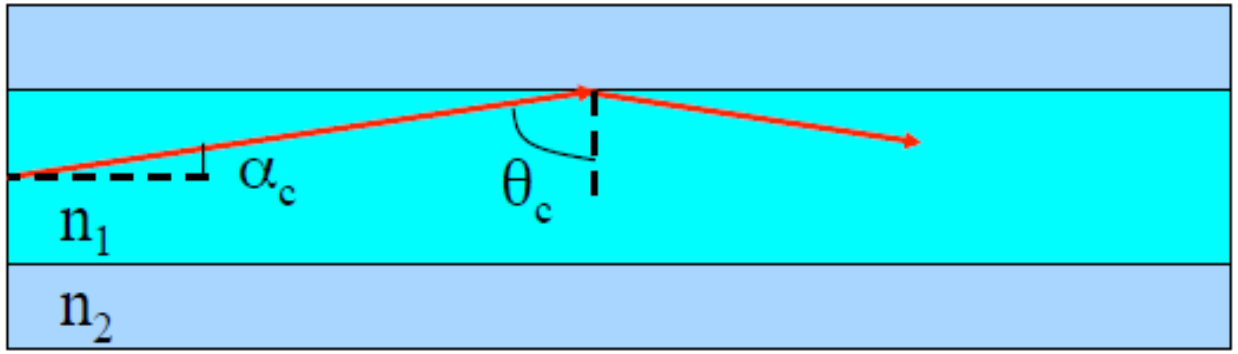
Light ray guiding condition

- Total Internal Reflection (TIR)
  - Critical incident angle
  - Critical propagation angle
- Launching of light
  - Acceptance angle
  - Numerical aperture



Critical- Incident & Propagation angles

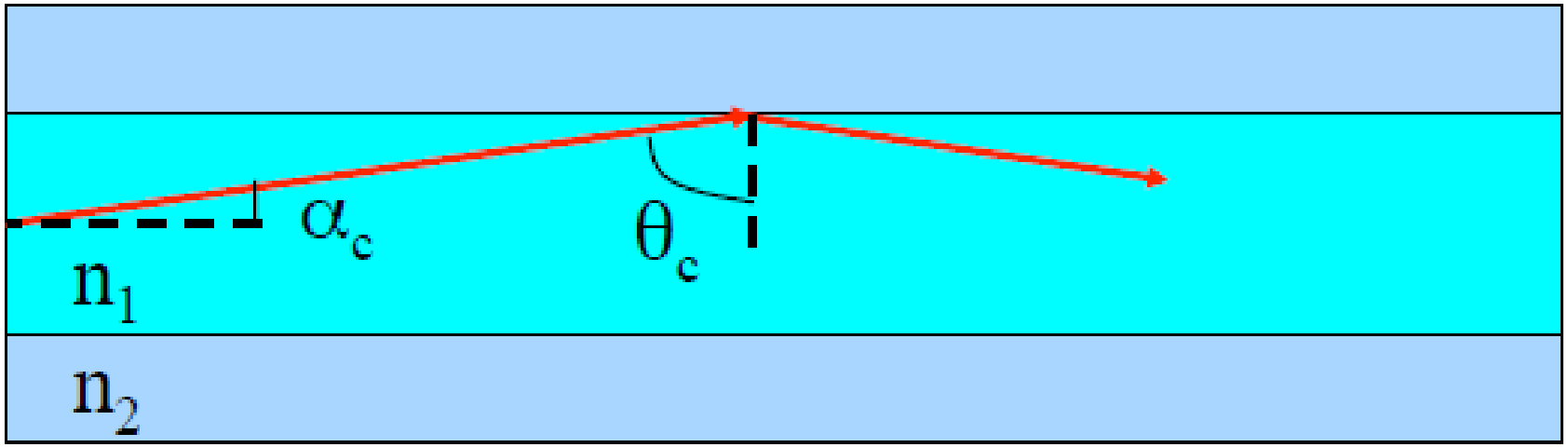
- Two key terms
  - i. Critical incident angle, θ_c
    - Is the angle the beam makes with the line perpendicular to the boundary between the core and the cladding
  - ii. Critical propagation angle, α_c
    - Is the angle the beam makes with the centerline of the optical fiber



Critical- Incident & Propagation angles

- Two key terms
  - Critical incident angle, θ_c
  - Critical propagation angle, α_c

$$\alpha_c = 90 - \theta_c$$



Critical- Incident & Propagation angles

- We know that

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

$$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$$

- Since

$$\alpha_c = 90 - \theta_c$$

- It implies

$$\cos\alpha_c = \sin\theta_c$$

Critical- Incident & Propagation angles

- thus

$$\sin^2 x + \cos^2 x = 1$$

$$\cos\alpha_c = \frac{n_2}{n_1}$$

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

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

Critical- Incident & Propagation angles

- The critical propagation angle α_c
  - represents the requirement of achieving total internal reflection
- What is the critical propagation angle α_c
  - For $n_1 = 1.48$ and $n_2 = 1.46$
- State the requirement
  - of achieving total internal reflection in terms of critical propagation angle α_c

Critical- Incident & Propagation angles

- For $n_1 = 1.48$ and $n_2 = 1.46$

$$\alpha_c = \sin^{-1}\sqrt{\left(1-\left(\frac{1.46}{1.48}\right)^2\right)} = 9.43°$$

- What happens
  - when a beam travels at a propagation angle of 10 degrees?

Critical- Incident & Propagation angles

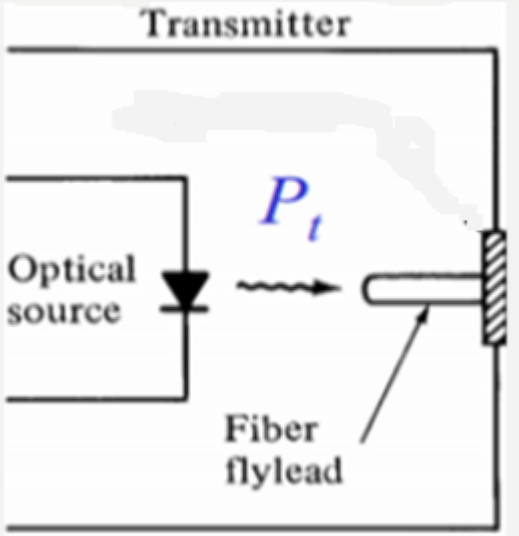
- In conclusion,
  - To save light
    - inside a strand of fiber, we need to have it strike the
      - core-cladding boundary at an angle above the critical incident angle, θ_c, in order to provide total reflection of this light
        - To make light fall above that angle, we have to direct it so that it is below the critical propagation angle, α_c , with respect to the centerline of the fiber

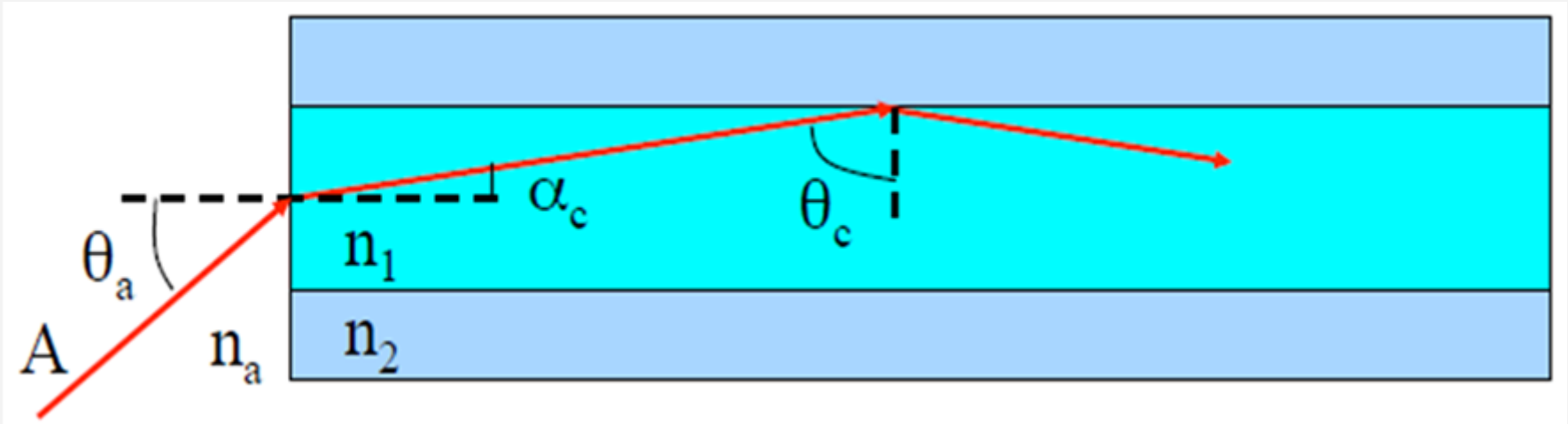
Acceptance Angle

- The next question that arises is
  - How can we direct this beam so that
    - it does indeed fall below the critical propagation angle?

Acceptance Angle

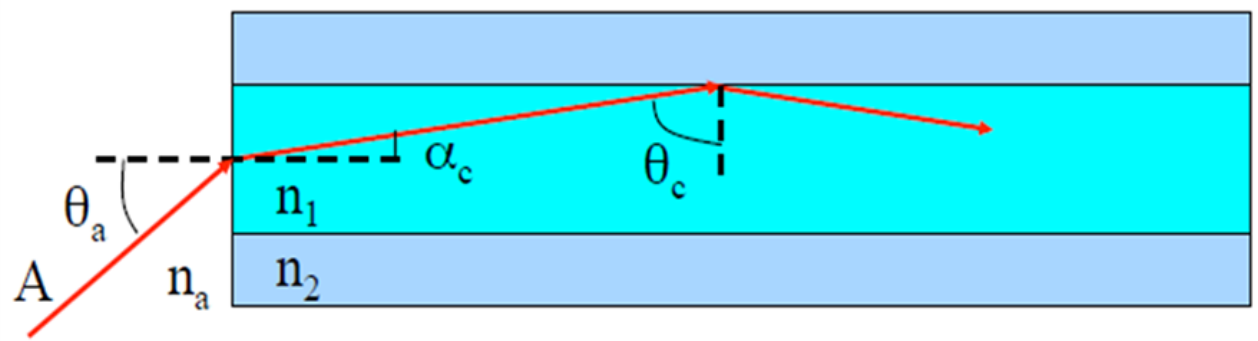
- The light
  - of course, must come from a source that is outside the fiber and therefore have to be directed into the fiber





Acceptance Angle

- Launching light into an optical fiber
  - at the gap-fiber interface, the beam at angle θ_a is the incident beam and the beam at angle α_c is the launched one

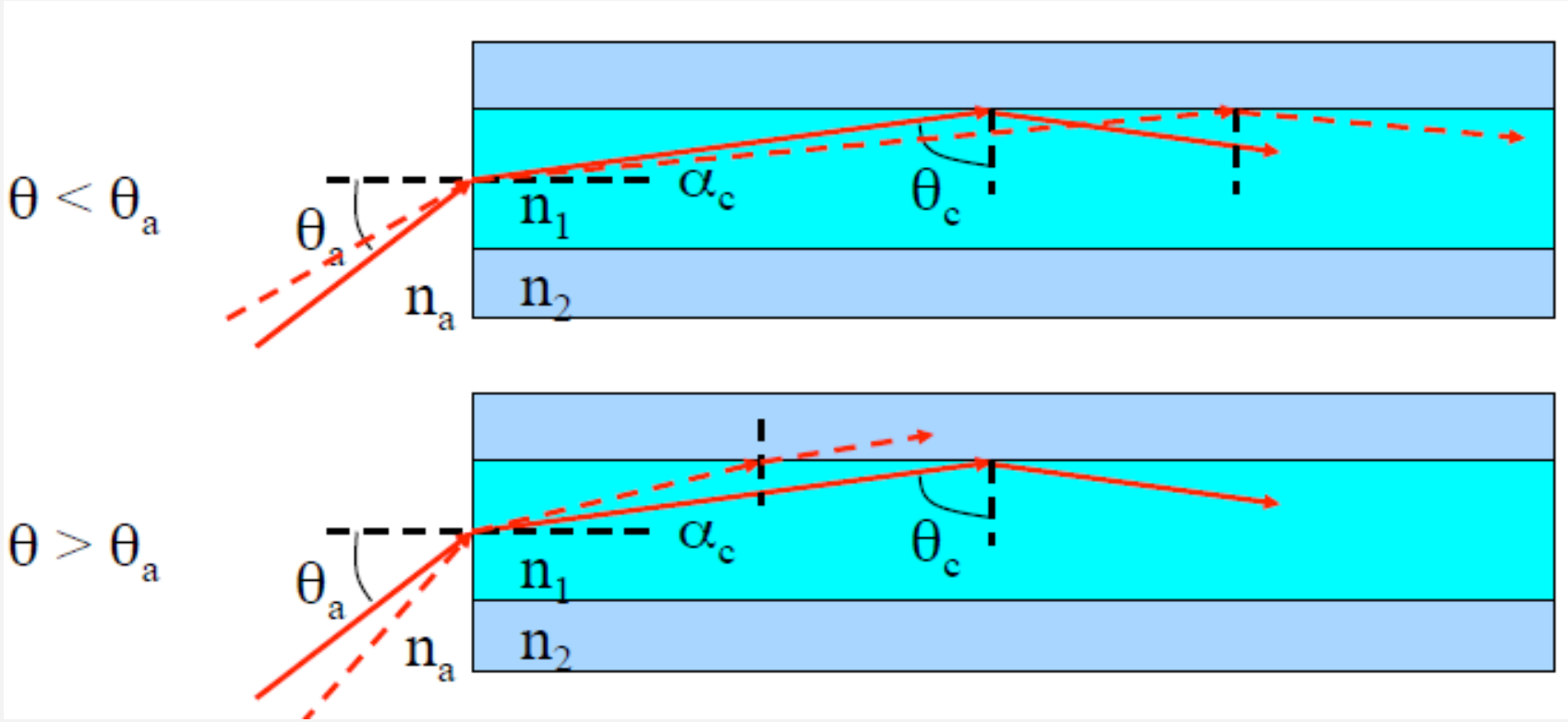


- The relationship between
  - θ_a and α_c can be derived using Snell's law

$$n_a \sin\theta_a = n_1 \sin\alpha_c$$

Acceptance Angle

- What happens when the incidence beam, θ is less than θ_a ?
- What happens when the incidence beam, θ is greater than θ_a ?

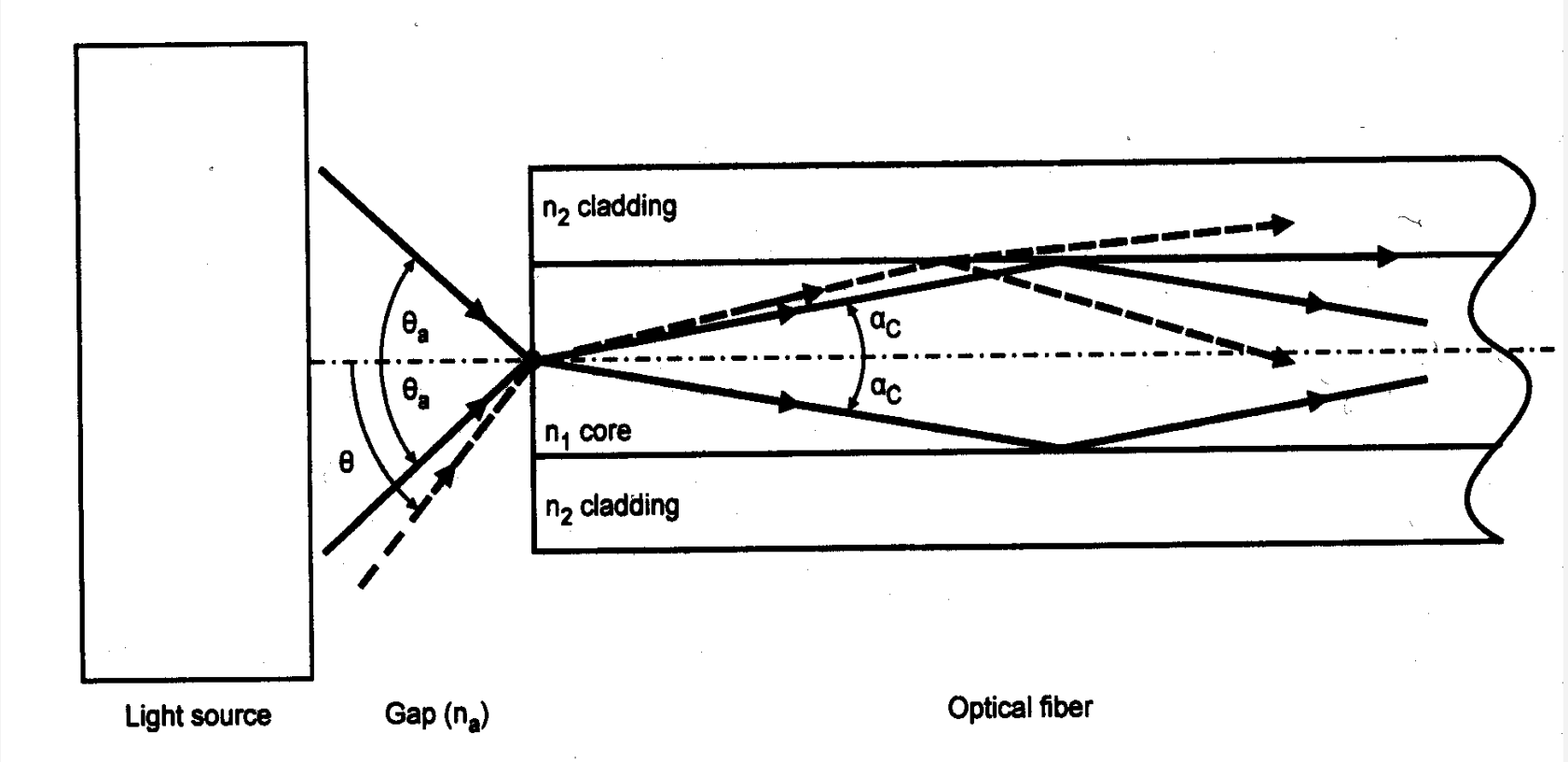


Acceptance Angle

- Any ray which is incident into the fiber core at
  - an angle greater than θ_a will have a propagation angle greater than α_c and therefore incident angle less than θ_c at the core-cladding interface and will NOT be totally internal reflected

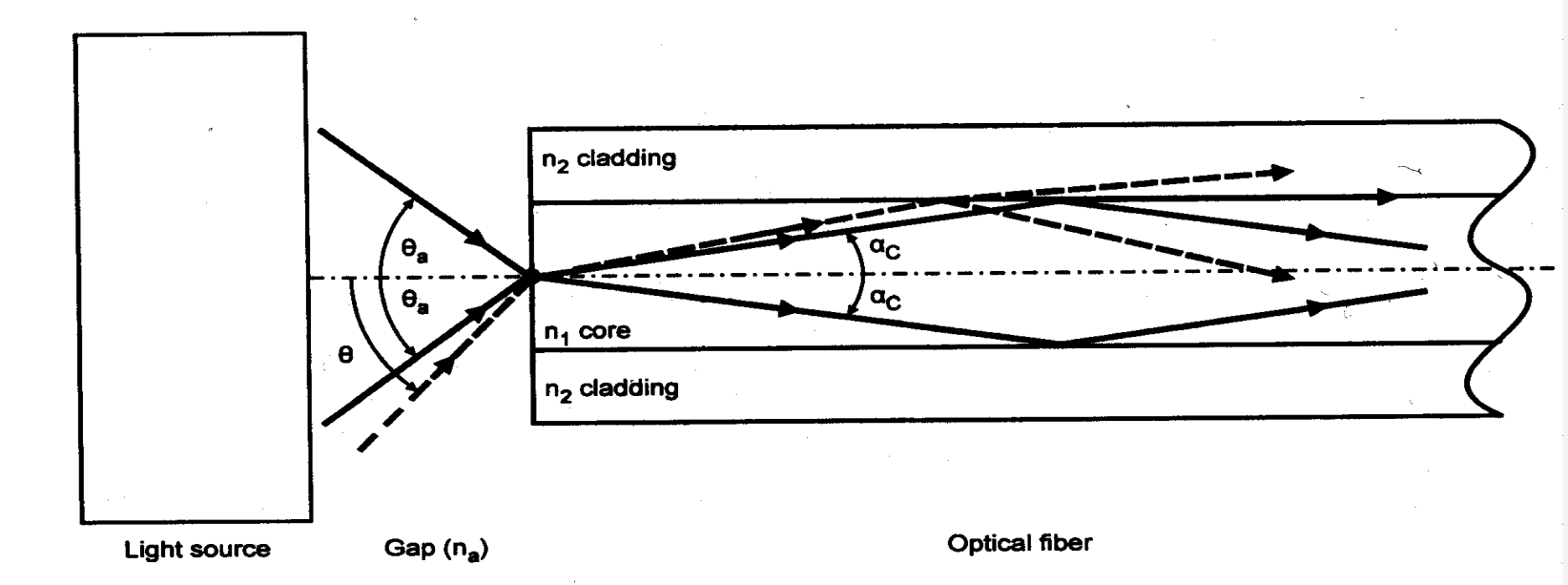
Acceptance Angle

- Thus θ_a defines
  - an acceptance cone for an optical fiber



Acceptance Angle

- Light will be
  - saved inside the fiber if it comes from a source bounded by the cone $2\theta_a$ (cone of light)



Acceptance Angle

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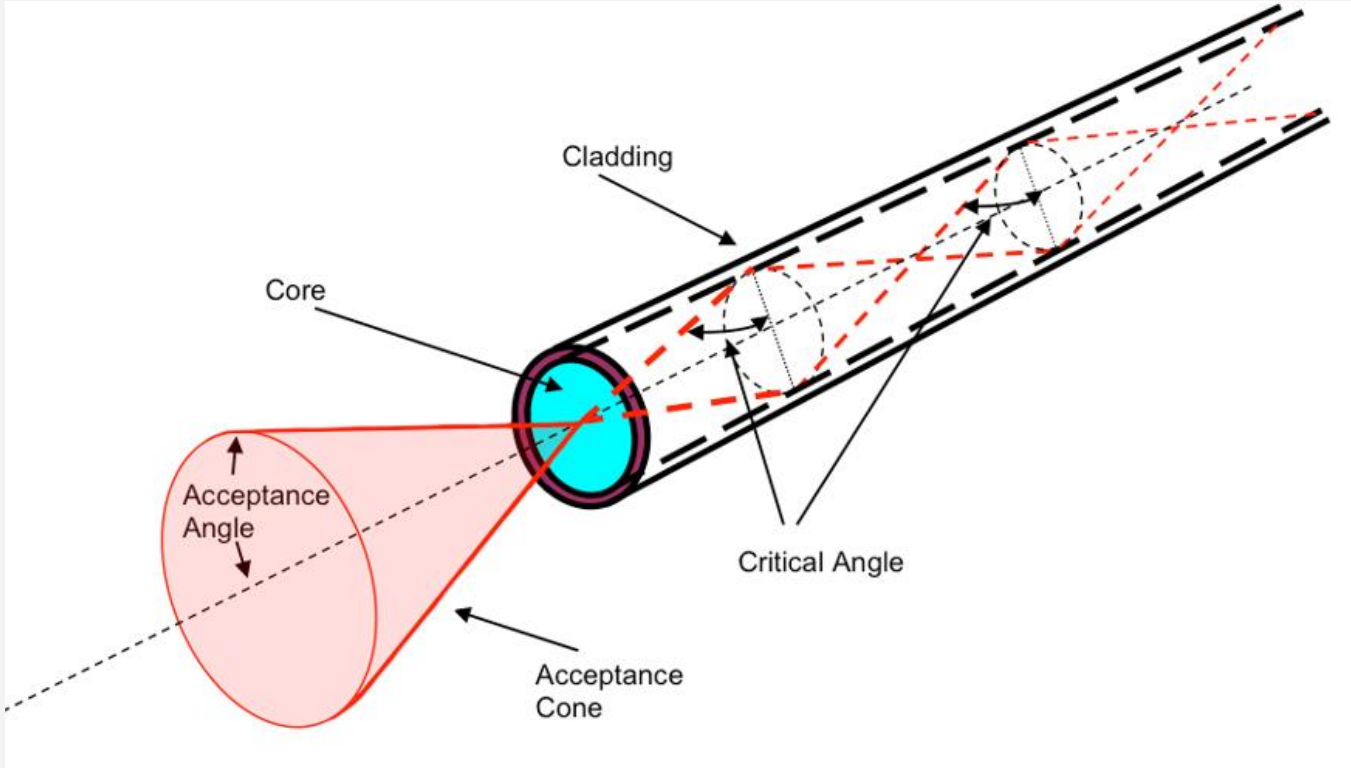

Acceptance Angle

- To save light
  - inside a fiber all rays must propagate at an angle less than the critical propagation angle α_c
    - In order for light to be maintained in the fiber at this angle, it must be directed from outside the fiber at angle θ_a or less

Acceptance Angle

- What
  - is the acceptance angle and cone of light for a fiber when $n_1 = 1.48$ and $n_2 = 1.46$

THANK YOU

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