Optical Fiber Communications

Chapter 3

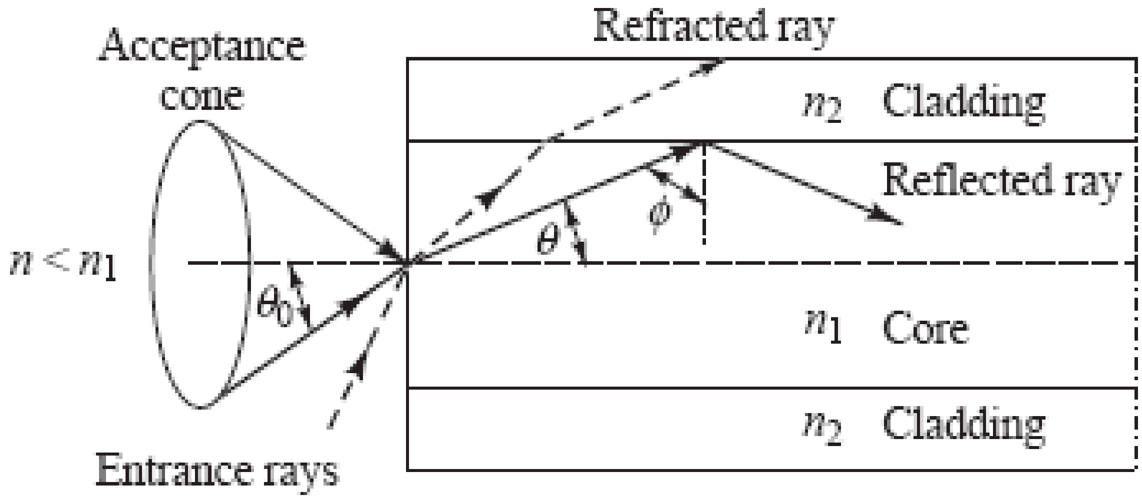
Fiber Attenuation

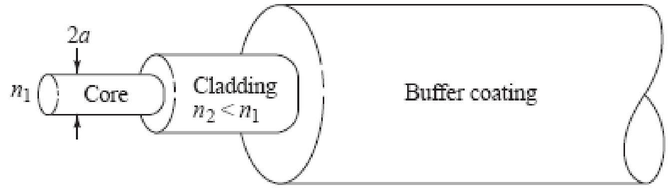
Attenuations

Propagating Rays in Fibers

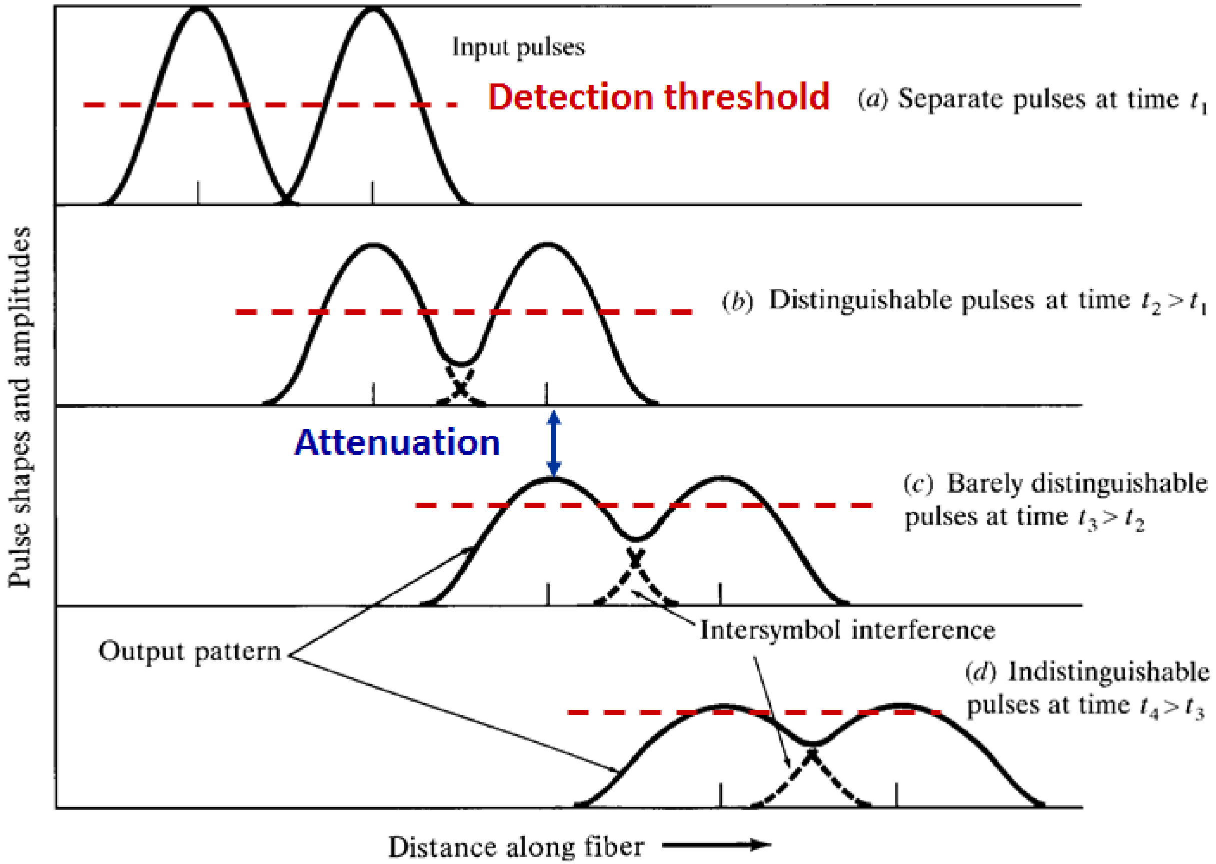
Propagation mechanism in an ideal step-index waveguide

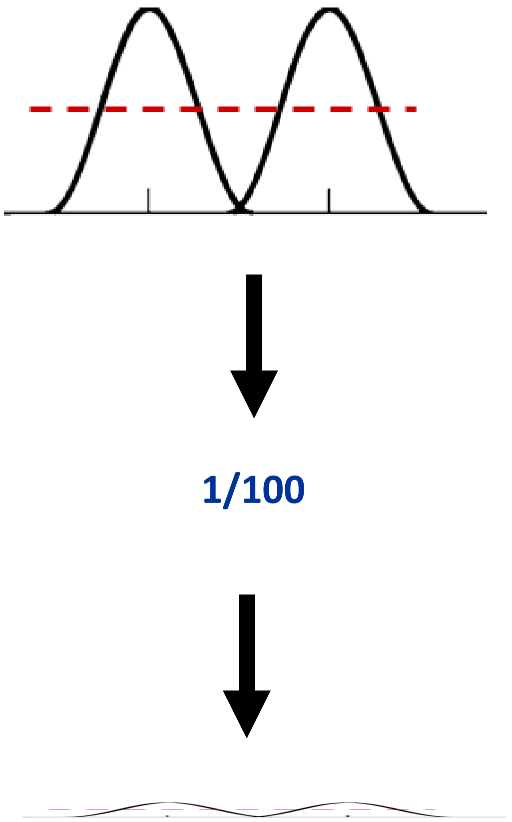
- Light enters the core at an angle θ_0 from a medium of index n
- Propagating rays are totally internally reflected at core/clad interface
- Meridional rays follow a zig-zag path along the fiber core
- These rays pass through the fiber axis after each reflection
- Snell's law determines the minimum angle for total internal reflection





Attenuation Effects (1)





(Q) How far can the light propagate?

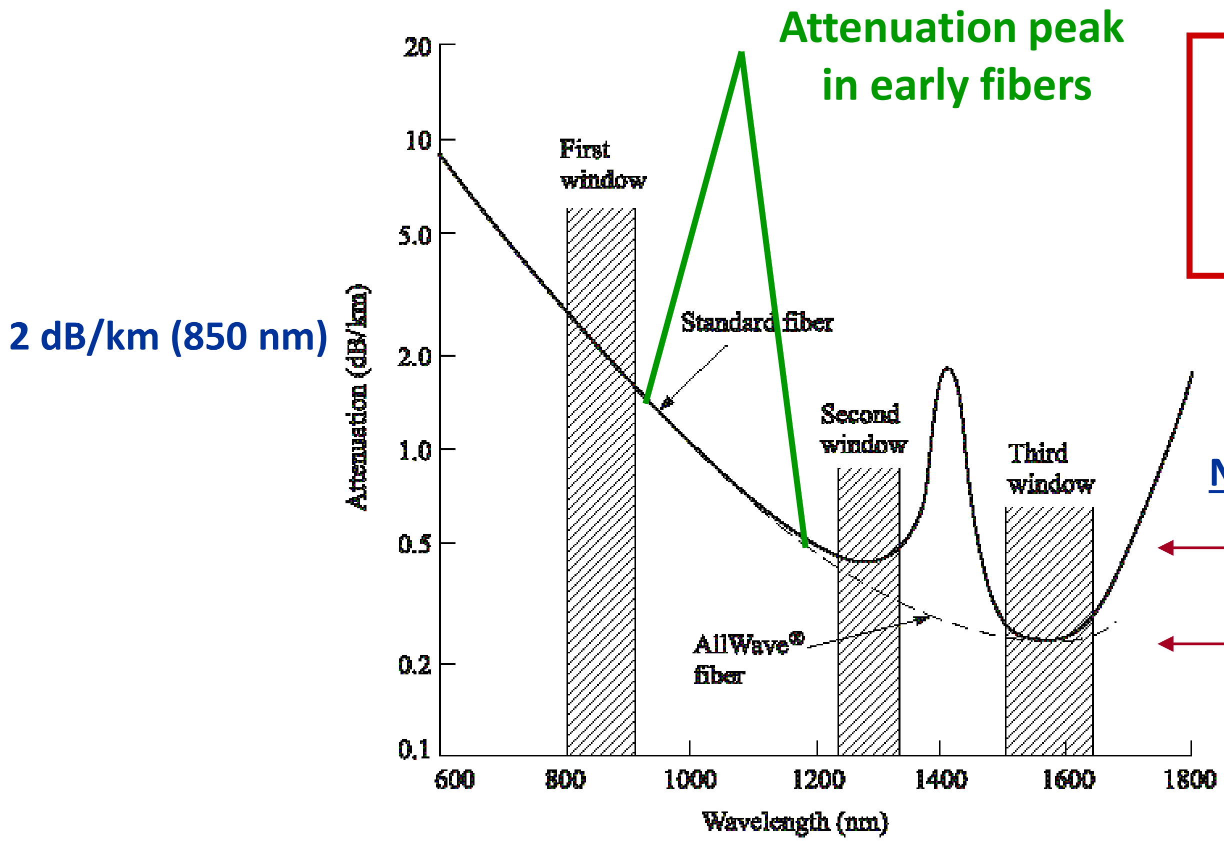
Depends on the optical source and optical receiver sensitivity

Optical source (typical LD) : 0dBm

Optical receiver (typical pin PD) : -20dBm

20 dB → 1/100

Optical Fiber Attenuation



$P(x) = P_0 e^{-ax}$

$\alpha = (10/x) \log P_0/P(x)$

Nominal attenuations:

0.5 dB/km (1310 nm)

0.2 dB/km (1550 nm)

OFS AllWave fiber: example of a "low-water-peak" or "full spectrum" fiber.
Prior to 2000 the fiber transmission bands were referred to as "windows."

Optical Fiber Attenuation

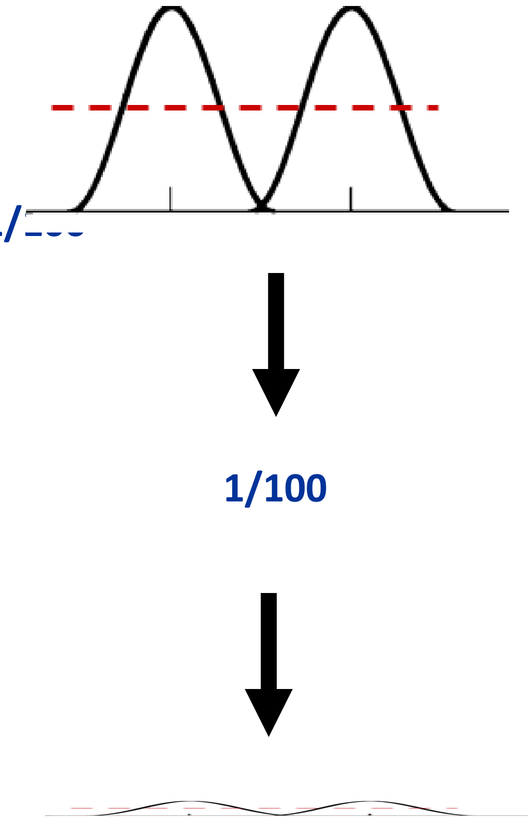
(Q) How far does "20 dB" translate into?

Depends on the optical source and optical receiver sensitivity

Optical source (typical LD) : 0dBm

Optical receiver (typical pin PD) : -20dBm

20 dB → 1/



2 dB/km (850 nm) →

0.5 dB/km (1310 nm) →

0.2 dB/km (1550 nm) →

(Q) Which wavelength would you use?

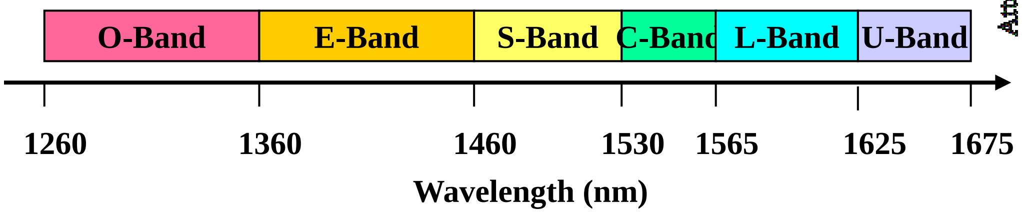
2 dB/km (850 nm) → Last Mile

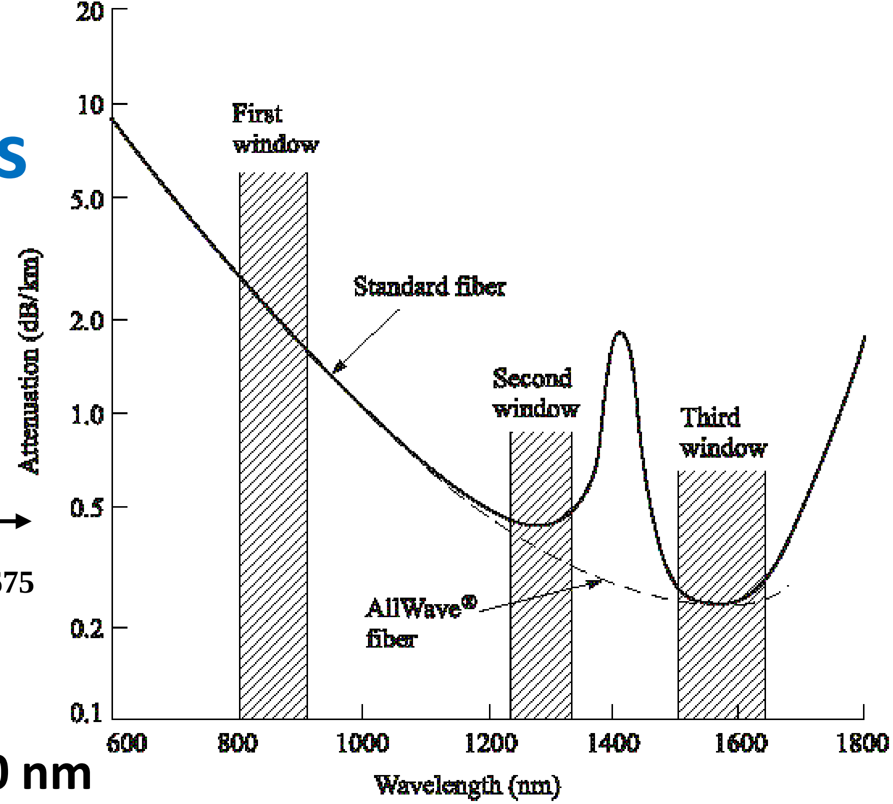
0.5 dB/km (1310 nm) → Access Network

0.2 dB/km (1550 nm) → Metro Area Network

1.2 Optical Spectral Bands

(Q) Why do we need more band?





- **Original band (O-band):** **1260 to 1360 nm**
  - Region originally used for first single-mode fibers
- **Extended band (E-band):** **1360 to 1460 nm**
  - Operation extends into the high-loss water-peak region
- **Short band (S-band):** **1460 to 1530 nm (shorter than C-band)**
- **Conventional band (C-band):** **1530 to 1565 nm (EDFA region, Optical Amp)**
- **Long band (L-band):** **1565 to 1625 nm (longer than C-band)**
- **Ultra-long band (U-band):** **1625 to 1675 nm**

Optical Fiber Attenuation

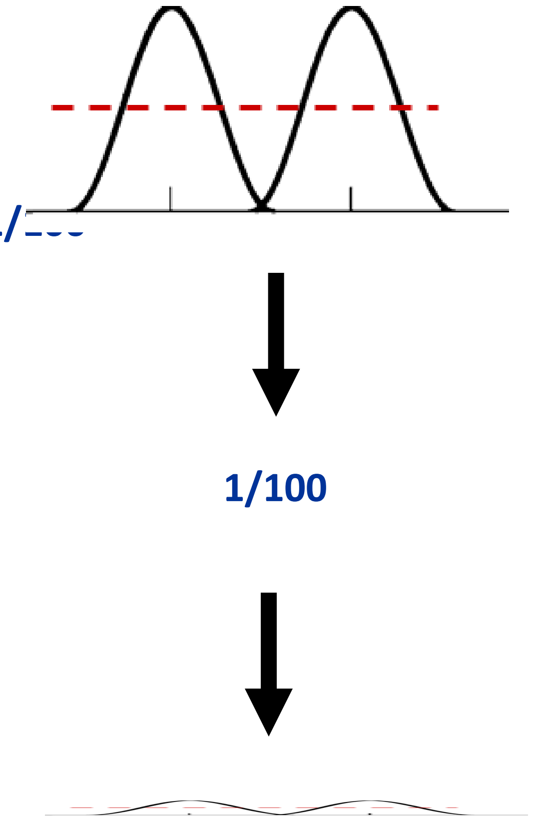
(Q) How far does "20 dB" translate into?

Depends on the optical source and optical receiver sensitivity

Optical source (typical LD) : 0dBm

Optical receiver (typical pin PD) : -20dBm

20 dB → 1/



2 dB/km (850 nm) → Last Mile

0.5 dB/km (1310 nm) → Access Network

0.2 dB/km (1550 nm) → Metro Area Network

Wide Area Network

Fiber Optic System Design Aspect

Sources of Losses in System

(Q) Why do we need to minimize the sources of losses?

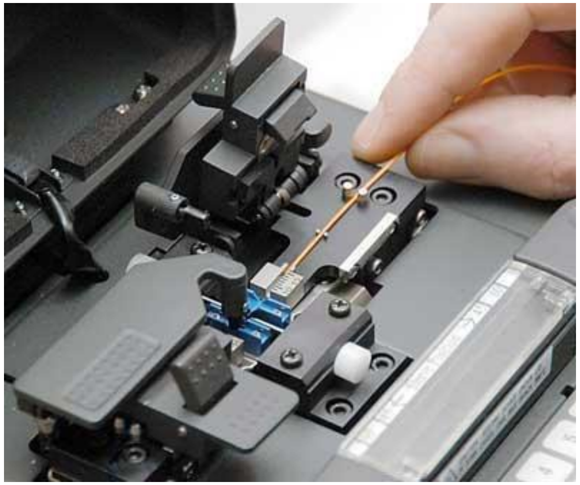
- Sources of Losses (Attenuations) in a Fiber Communication System
  - Fiber Attenuation
  - Use of Connectors
  - Splicing
  - Bending Loss

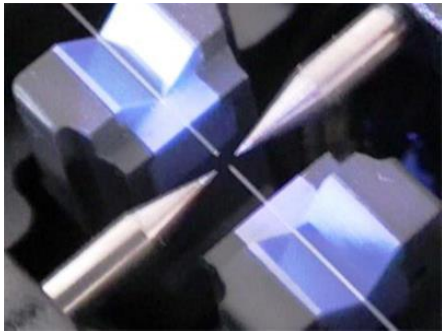
Connectors

- **Used to connect fiber with fiber network elements or fiber components**
- **Connected via free space**
- **Finite "connection losses (attenuation)" exists per connections**
- **Strong "light reflections" exists at connections**

Splicing (Fiber Fusion Splicing)

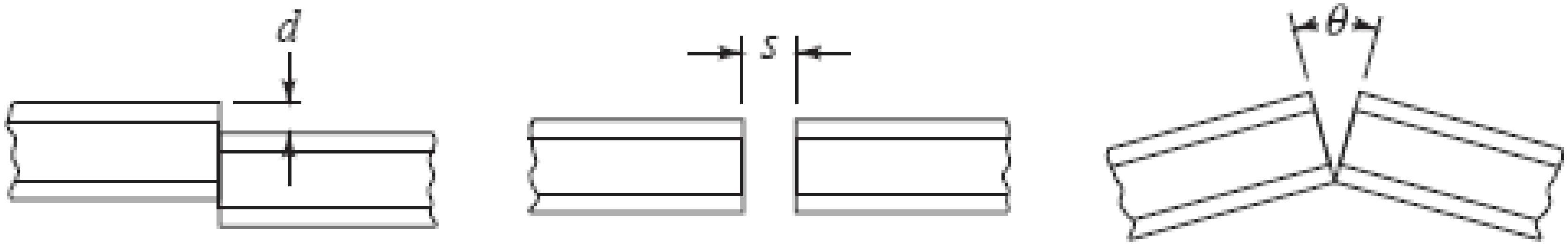
- **Used to "permanently" connect fibers, fiber components, and/or fiber network element**
- **Finite "splicing losses (attenuation)" exists per splice**





Splicing - Mechanical Misalignment

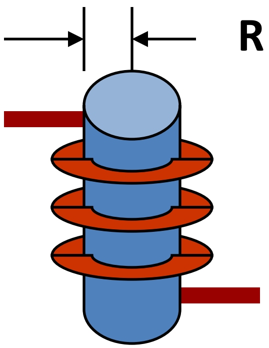
- **Splicing losses occur when there is non-perfect splicing**
- **For a receiving fiber to accept all the optical power emitted by the first fiber, there must be perfect mechanical alignment between the two fibers, and their geometric and waveguide characteristics must match precisely.**
- **Mechanical alignment is a major problem in joining fibers.**



(a) Lateral (axial) (b) Longitudinal (end separation) (c) Angular

Bending Losses in Fibers (1)

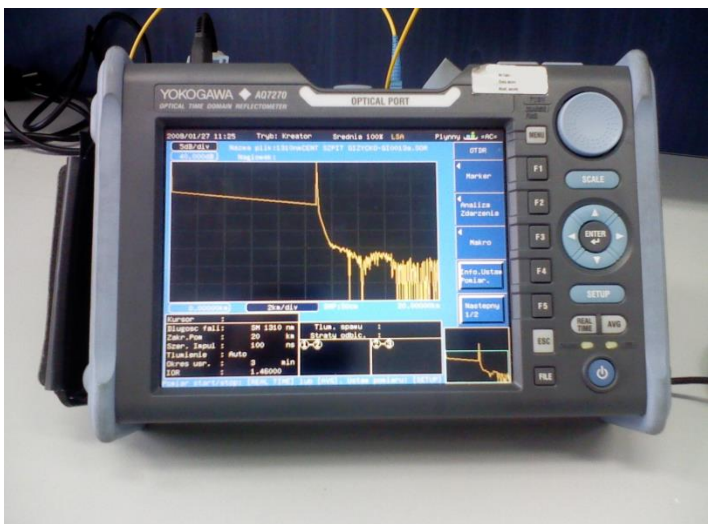
- Optical power escapes from tightly bent fibers
- Bending loss increases at longer wavelengths
  - Typical losses in 3 loops of standard 9-μm single-mode fiber (from: *Lightwave*; Feb 2001; p. 156):
  - 2.6 dB at 1310 nm and 23.6 dB at 1550 nm for R = 1.15 cm
  - 0.1 dB at 1310 nm and 2.60 dB at 1550 nm for R = 1.80 cm
- Progressively tighter bends produce higher losses
- Bend-loss insensitive fibers have been developed and now are recommended
- Improper routing of fibers and incorrect storage of slack fiber can result in violations of bend radius rules

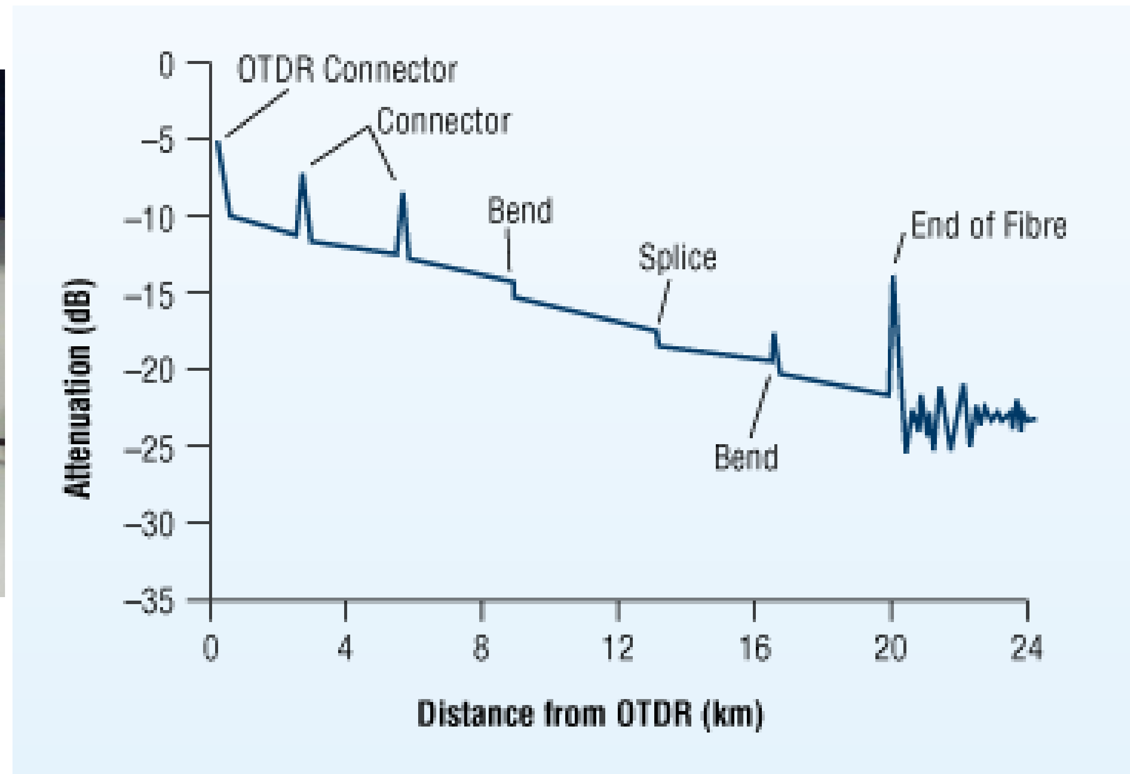


Test setup for checking bend loss: N fiber loops on a rod of radius R

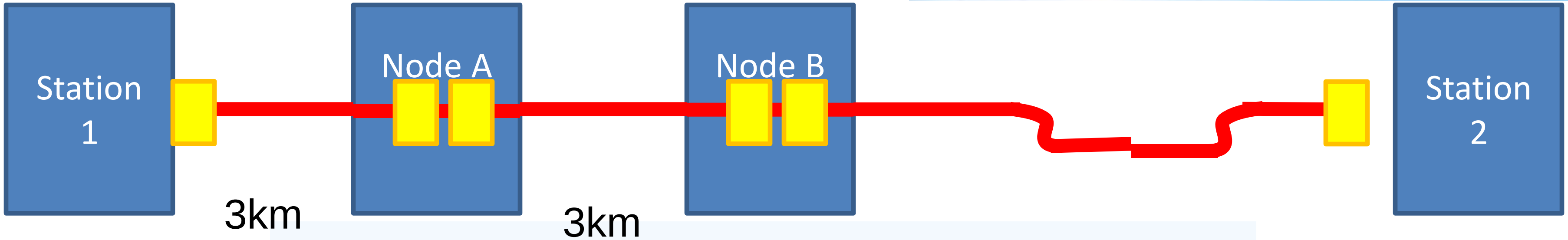
OTDR Trace

- Optical Time Domain Reflectometer
  - Measures losses (attenuations) along the fiber

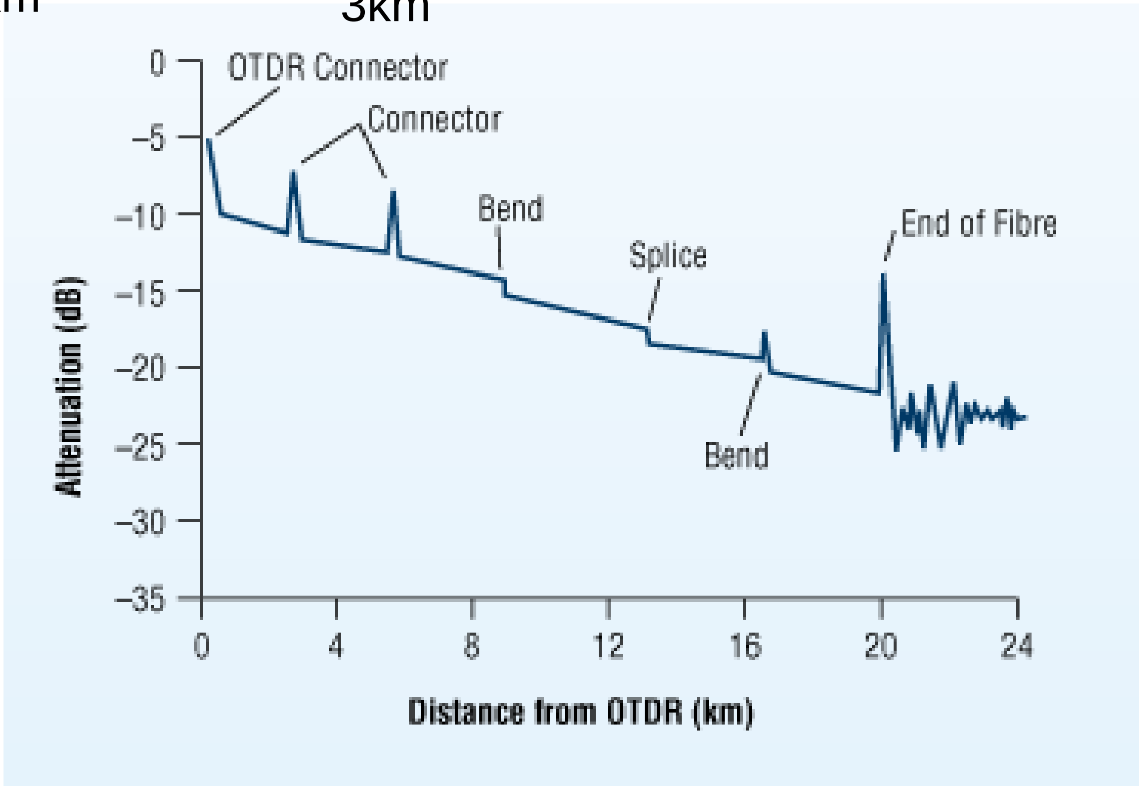




OTDR Trace



Station 1
Node A
Node B
Station 2
3km
3km



OTDR Connector
Connector
Bend
Splice
End of Fibre
Bend
Attenuation (dB)
0
−5
−10
−15
−20
−25
−30
−35
0
4
8
12
16
20
24
Distance from OTDR (km)