Fiber Optics

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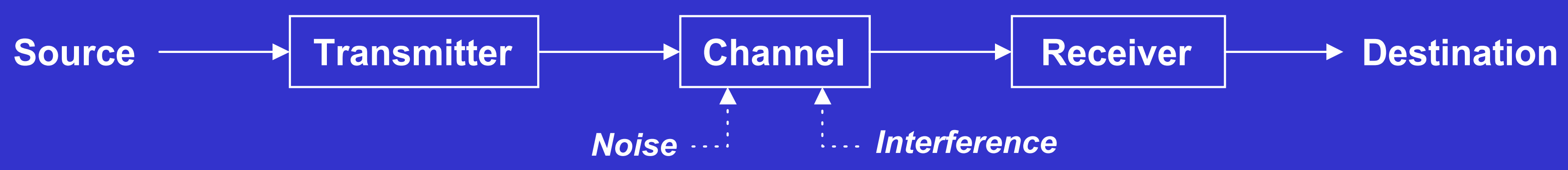
Outline

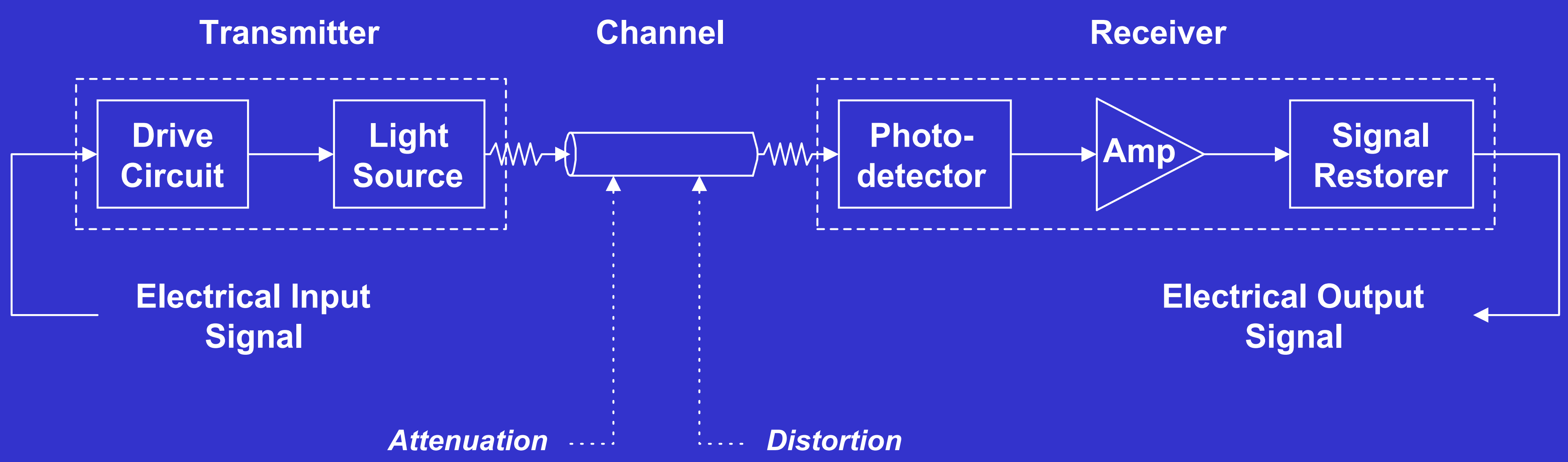
- Part 1: Fiber Basics
- Part 2: Fiber Optic Networks for Traffic and Transportation Systems
- Part 3: Troubleshooting (Problems, Test & Measurement)

Part 1: Fiber Basics

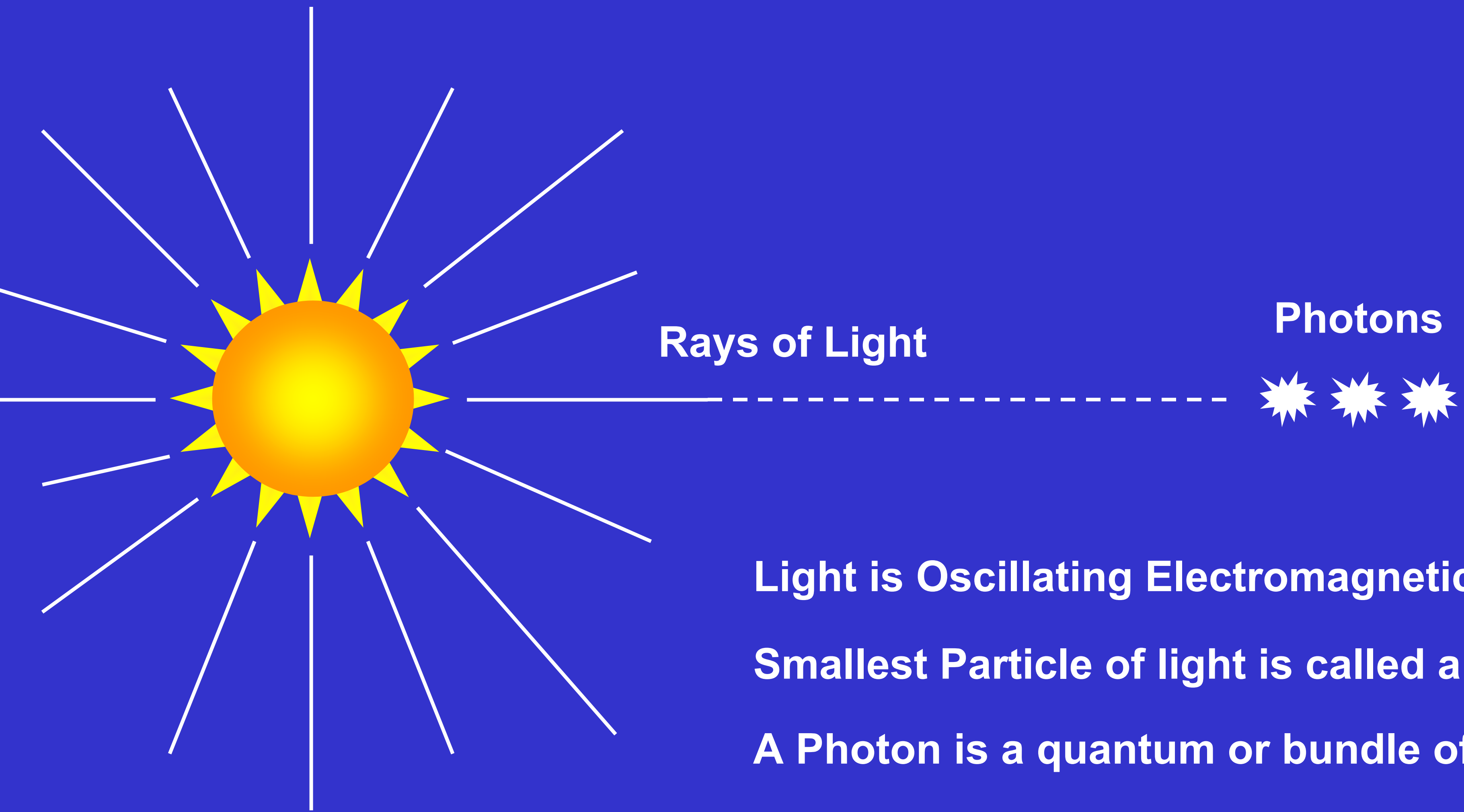
Basic Communications Link



Basic Fiber Transmission Link



Electromagnetic Energy



Light is Oscillating Electromagnetic Energy

Smallest Particle of light is called a Photon

A Photon is a quantum or bundle of energy

Only exists if the particle is in motion

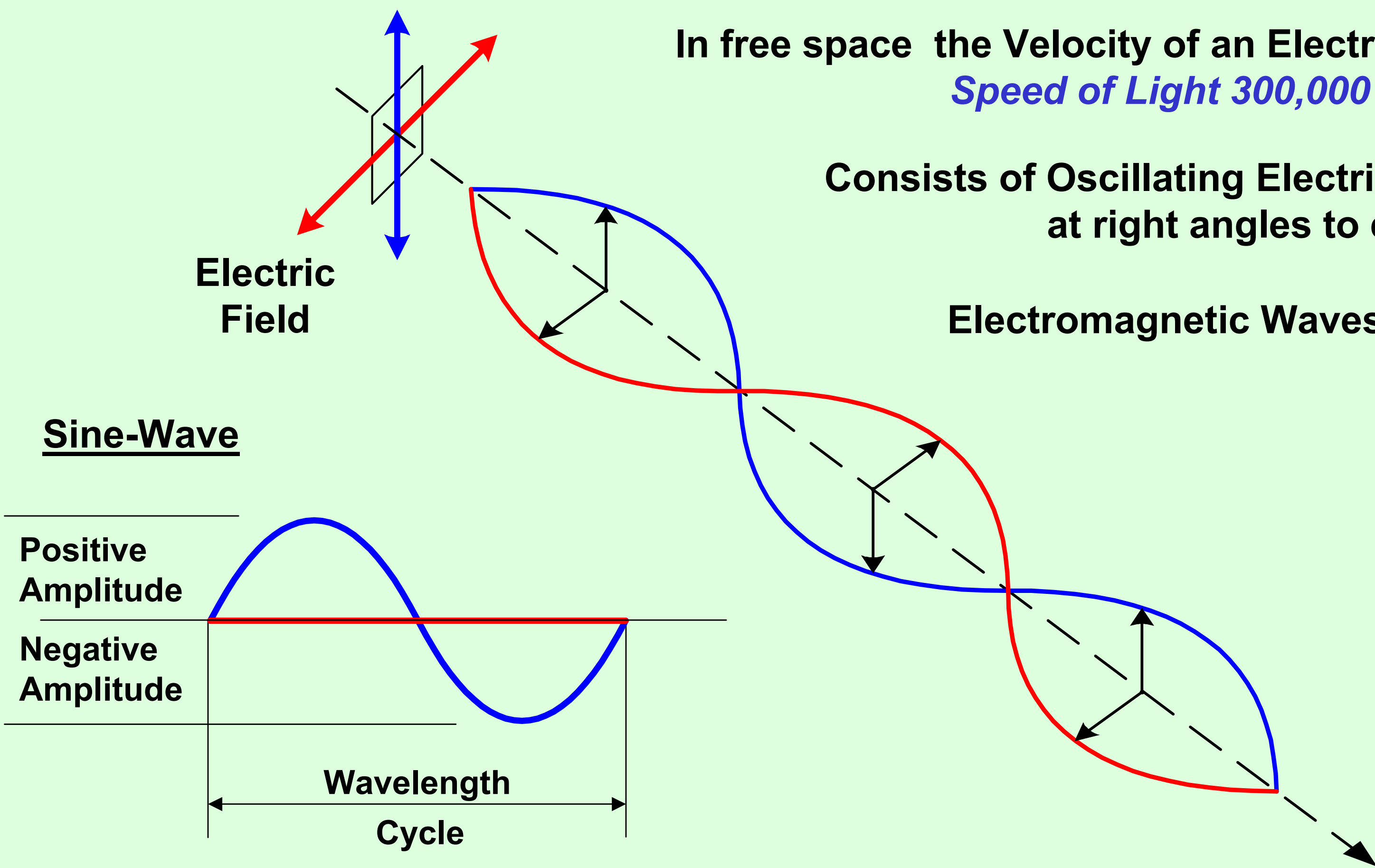
Electromagnetic Energy

Travels through free space @ 300,000 Km/sec or 186,000 Miles/sec

In free space the Velocity of an Electromagnetic Wave is the *Speed of Light 300,000 Km/sec*

Consists of Oscillating Electric and Magnetic Waves at right angles to each other

Electromagnetic Waves are Sinusoidal in shape



<u>Wavelength</u>* (Meters)** = ***The distance between the same points on consecutive waves

<u>Frequency</u>* (Hertz's)** = ***The number of Cycles/sec

Electromagnetic Energy

Magnetic

Travels through free space @ 300,000 Km/sec or 186,000 Miles/sec

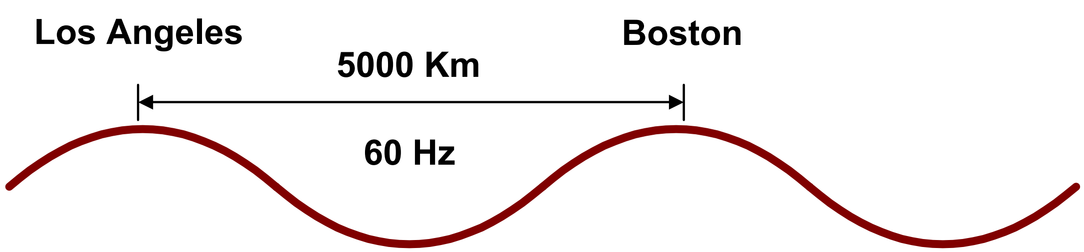
$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

Wavelength	=	Meters
Velocity	=	300,000Km/Sec.
Frequency	=	Hertz

Question

What is the wavelength of 60 Hz ?

$$\text{Wavelength} = \frac{300{,}000\text{ Km}}{60\text{ Hz}} = \underline{5000\text{Km}}$$



Sine-Wave

Positive Amplitude

Negative Amplitude

Wavelength (Meters) = The distance between the same points on consecutive waves

Frequency (Hertz's) = The number of Cycles/sec

Direction of Propagation

Electromagnetic Energy

Magnetic

Travels through free space @ 300,000 Km/sec or 186,000 Miles/sec

Wavelength = Velocity / Frequency

Wavelength	=	Meters
Velocity	=	300,000Km/Sec.
Frequency	=	Hertz

Question

What is the wavelength of 2.4 GHz ?

$$\text{Wavelength} = \frac{300{,}000\ \text{Km}}{2.4\ \text{GHz}} = \underline{125\ \text{microns}}$$

Approximately the same diameter as a strand of human hair!

Sine-Wave

Positive Amplitude

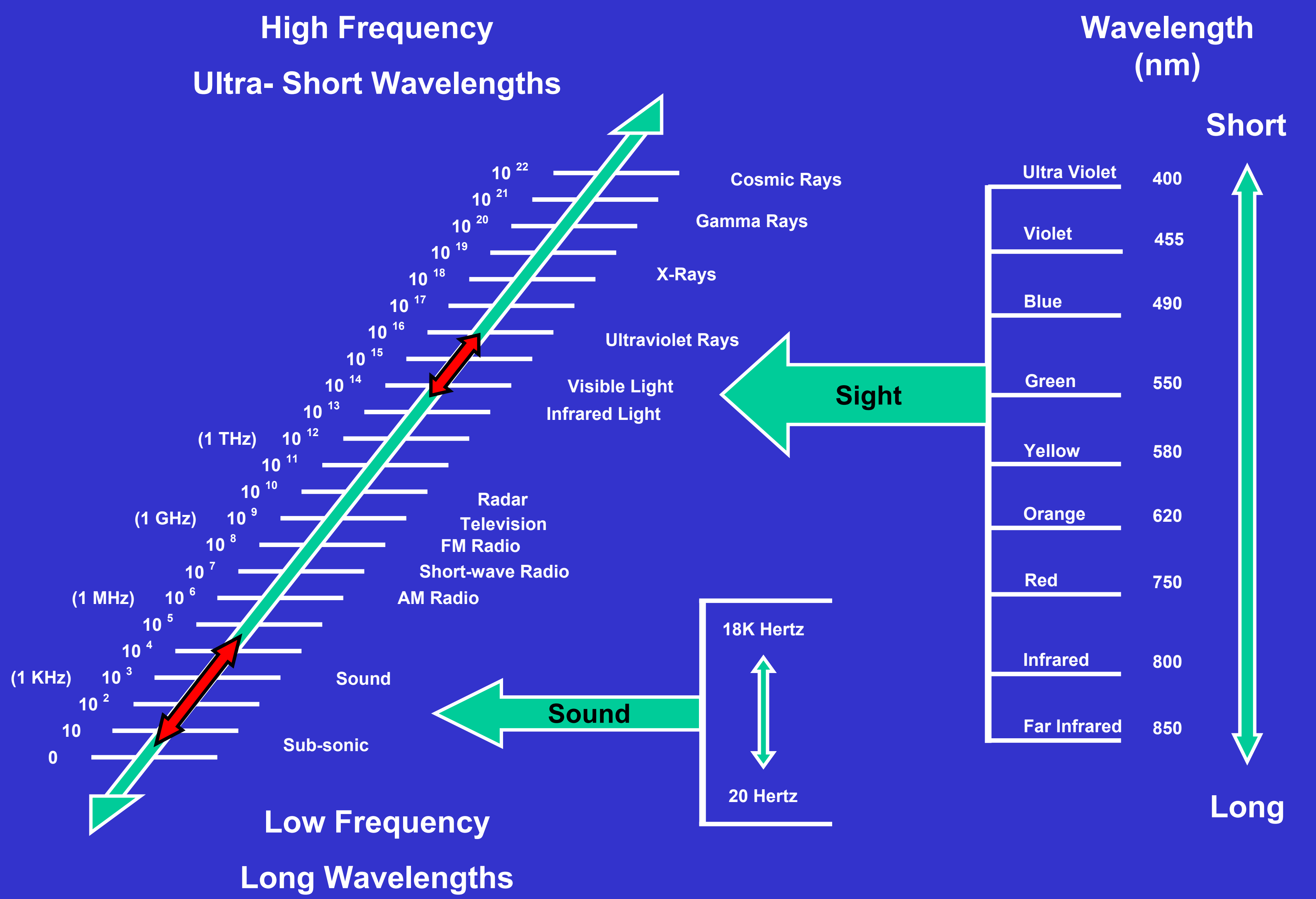
Negative Amplitude

Wavelength (Meters) = *The distance between the same points on consecutive waves*

Frequency (Hertz's) = *The number of Cycles/sec*

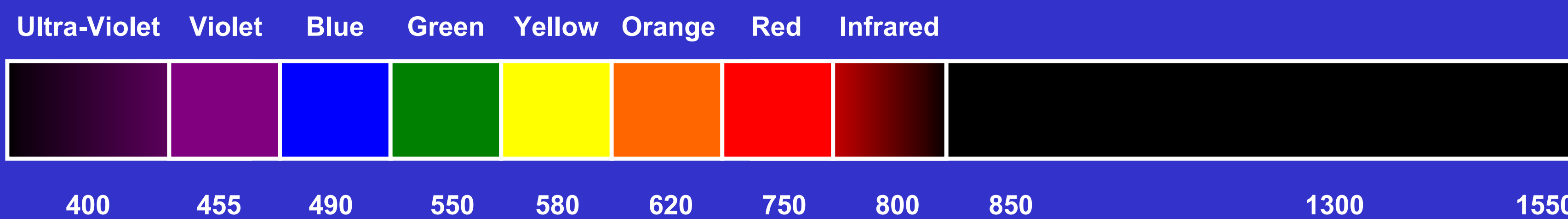
Direction of Propagation

Electromagnetic Spectrum



Electromagnetic Spectrum

Visible Light | **Invisible Light**

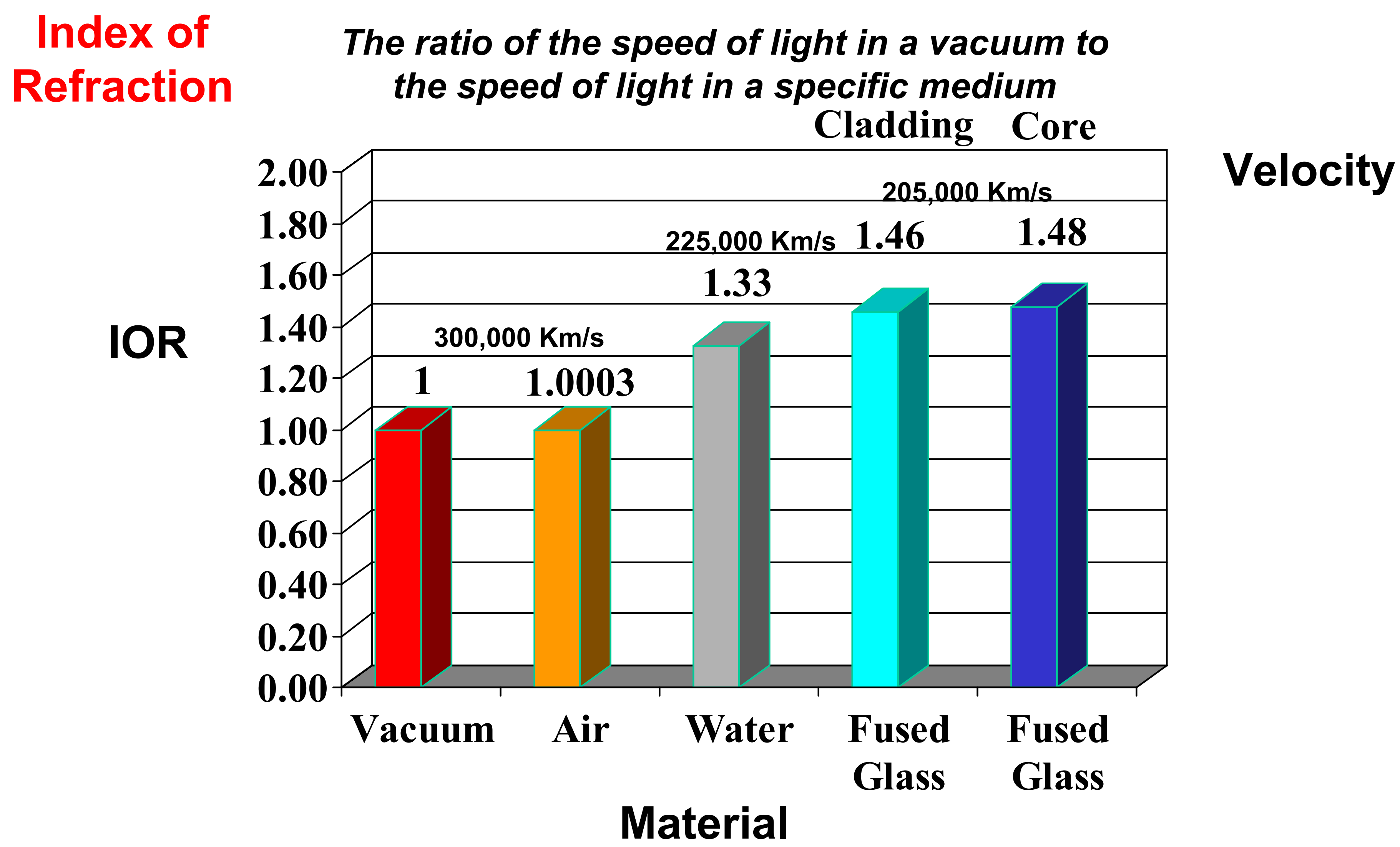


Wavelength (nm) | **Fiber Optics Transmission**

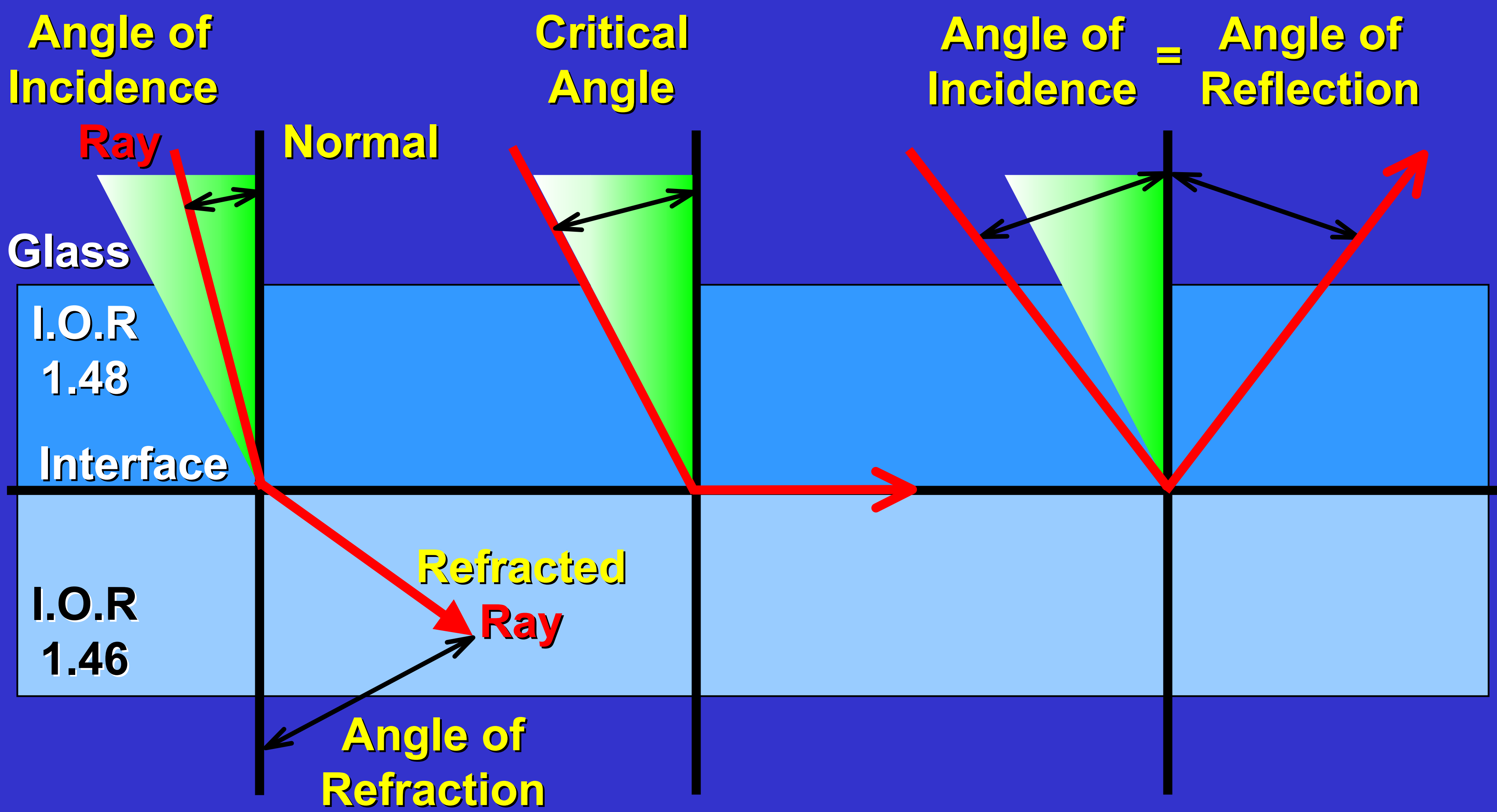
$1nm = 10^{-9} m$

$$\frac{1m}{1,000,000,000}$$

The Speed Of Light



Journey of Light



Advantages of Optical Fiber

- Wide Bandwidth — Flat OC192 129,024 Voice Channels
- Low Loss — 0.25dB/Km @ 1550nm
- Electromagnetic Immunity
- Light Weight
- Small Size
- Safety — Fiber is Dielectric, does not carry electricity
- Security

Optical Fiber

Two Types Of Fiber - Multimode & Singlemode

Multimode

- Used for Low Bandwidth (less than 650MHz), Short Haul Communications with distances of up to 3Km (850nm) & 10Km (1300nm)
- Two operating wavelengths, 850nm and 1300nm

Singlemode

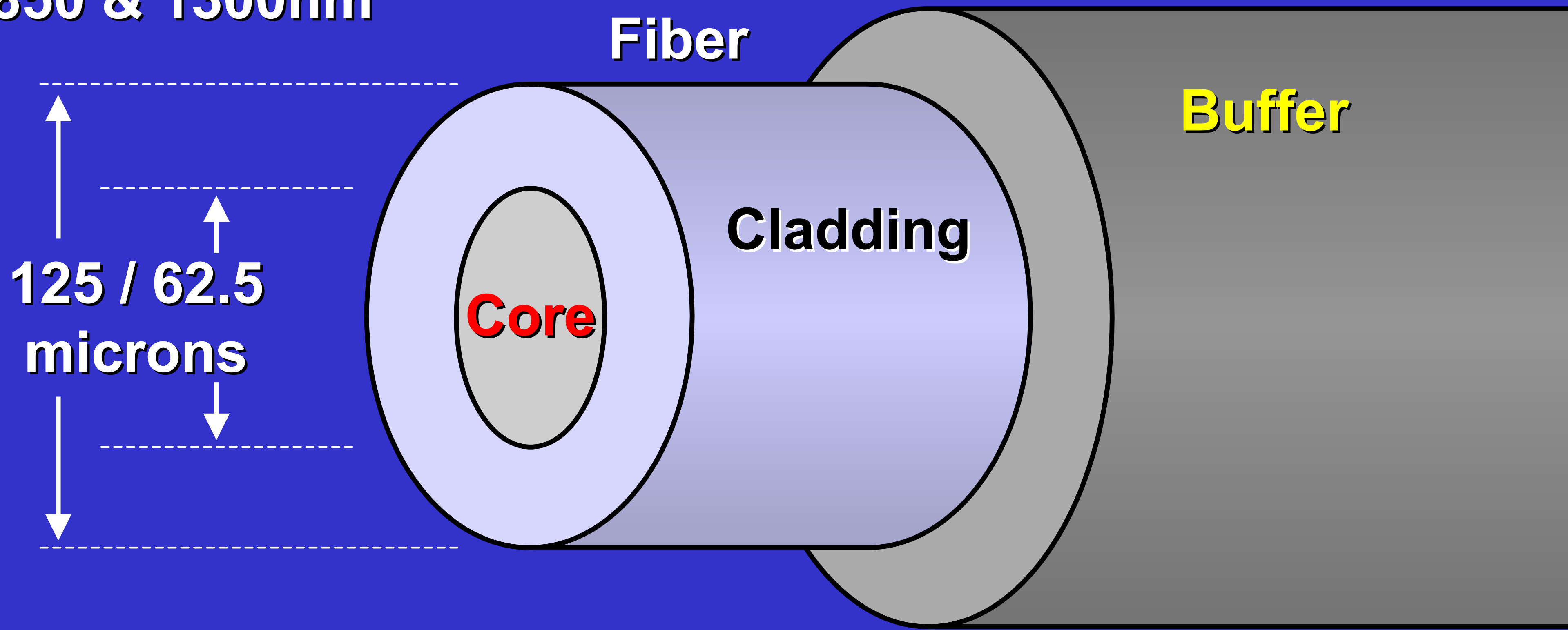
- Used for High Bandwidth, Long Haul Communications with distances of up to 40Km (1310nm) and 100Km (1550nm) or more
- Two operating wavelengths at 1310nm and 1550nm

Multimode

Core / Cladding sizes
50/125, 62.5/125 and
100/140 microns

Wavelength

850 & 1300nm



FDDI

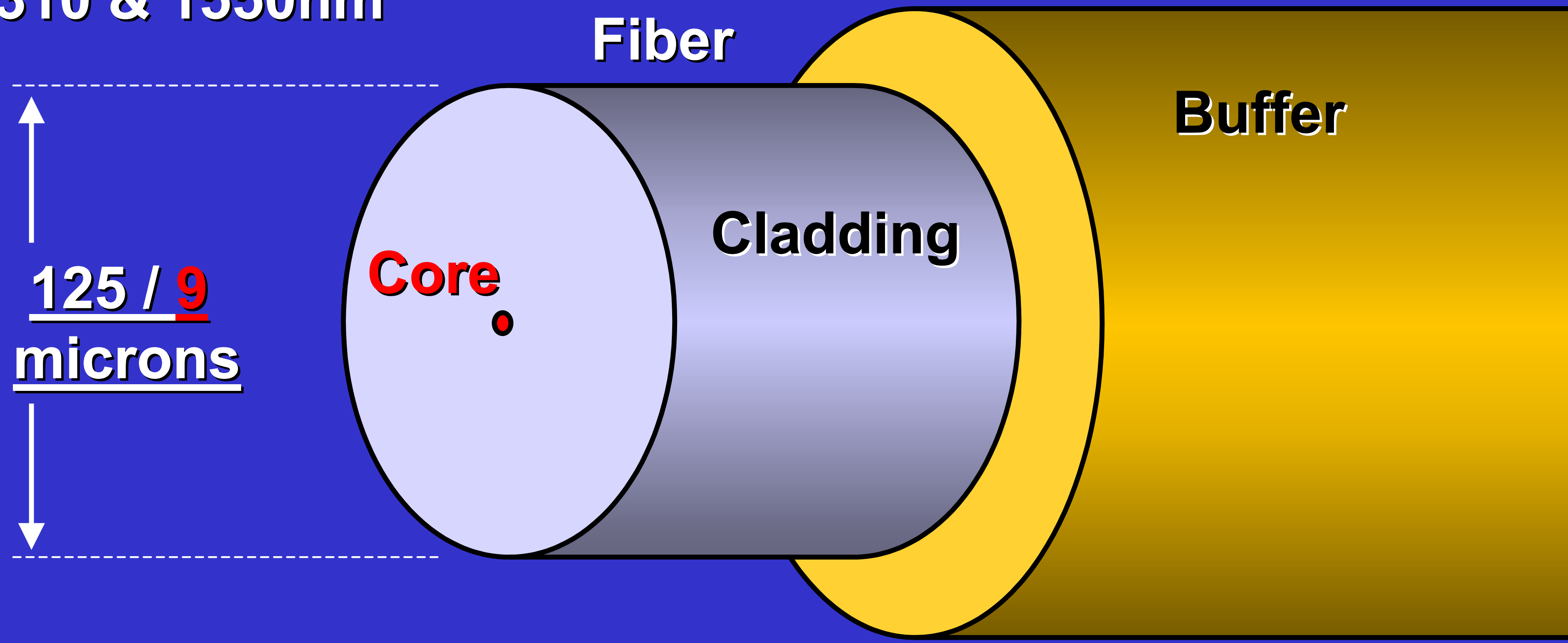
Fiber Distributed Data Interface

Singlemode

Wavelength

1310 & 1550nm

Core less than 10 microns
Cladding 125 microns



Attenuation vs. λ

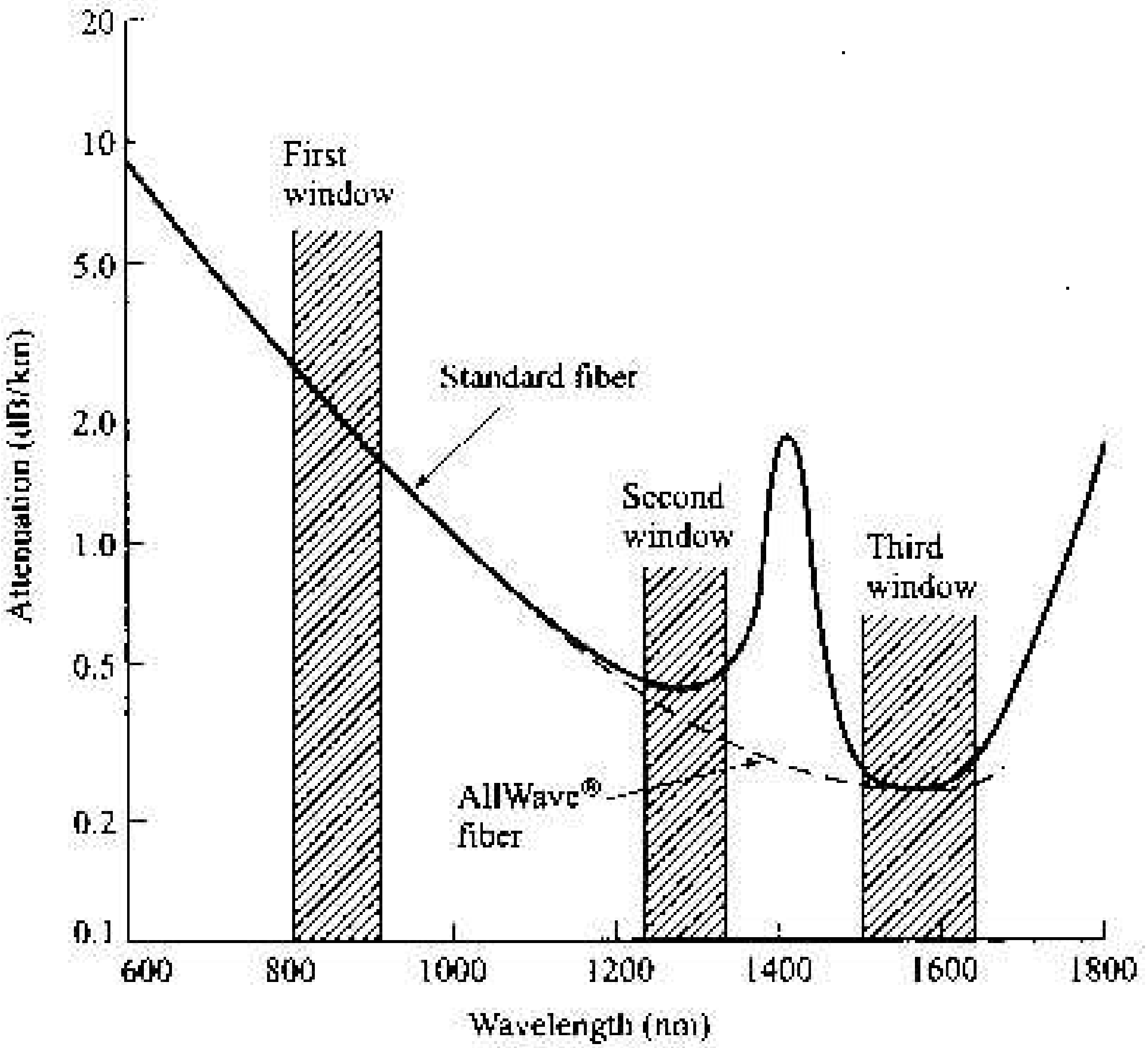
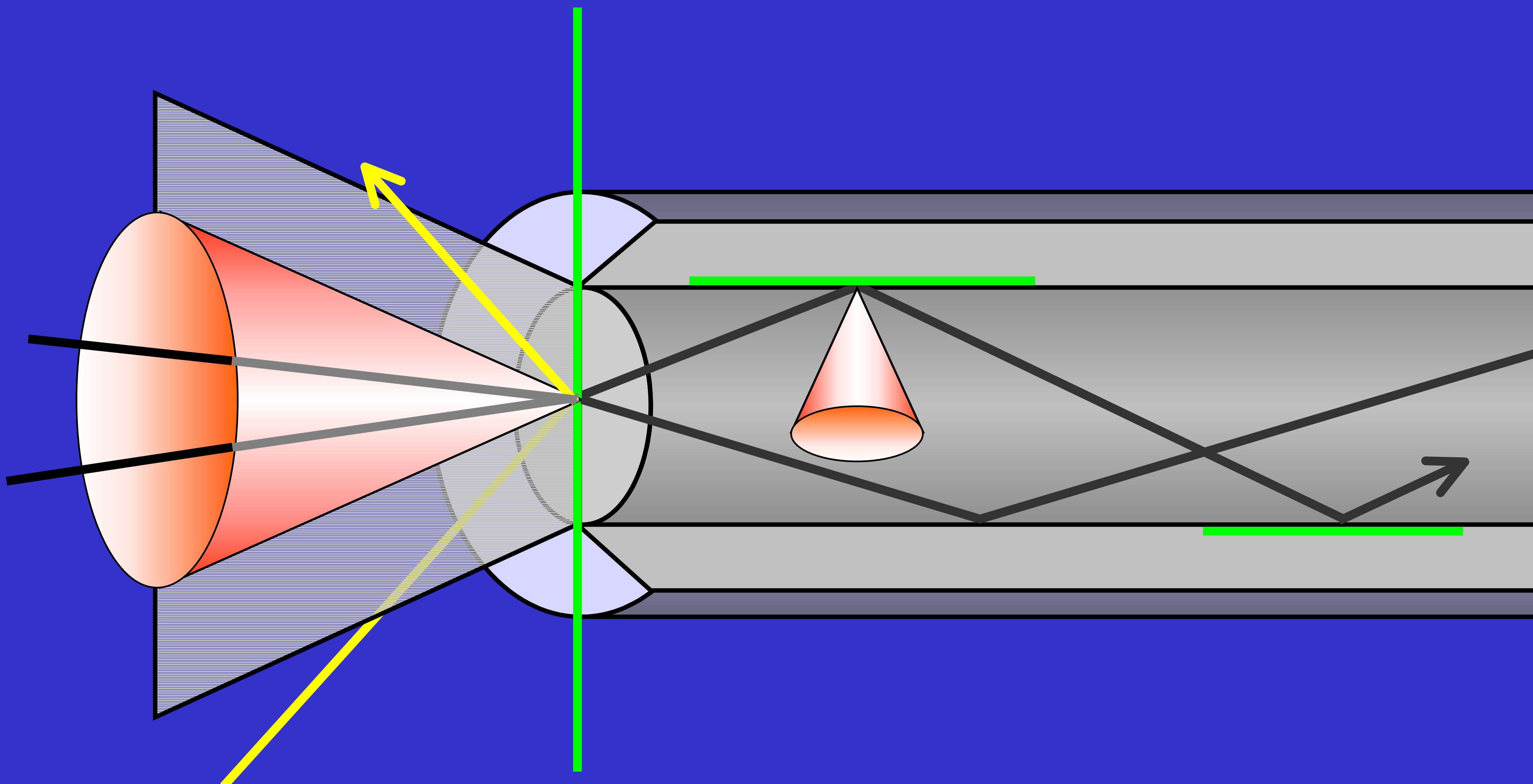


FIGURE 3-1
Optical fiber attenuation as a function of wavelength yields nominal values of 0.5 dB/km at 1300 nm and 0.3 dB/km at 1550 nm for standard single-mode fiber (solid curve). This fiber shows an attenuation peak around 1400 nm resulting from absorption by water molecules. The dashed curve is for a water-free AllWave® fiber (data courtesy of Lucent Technologies).

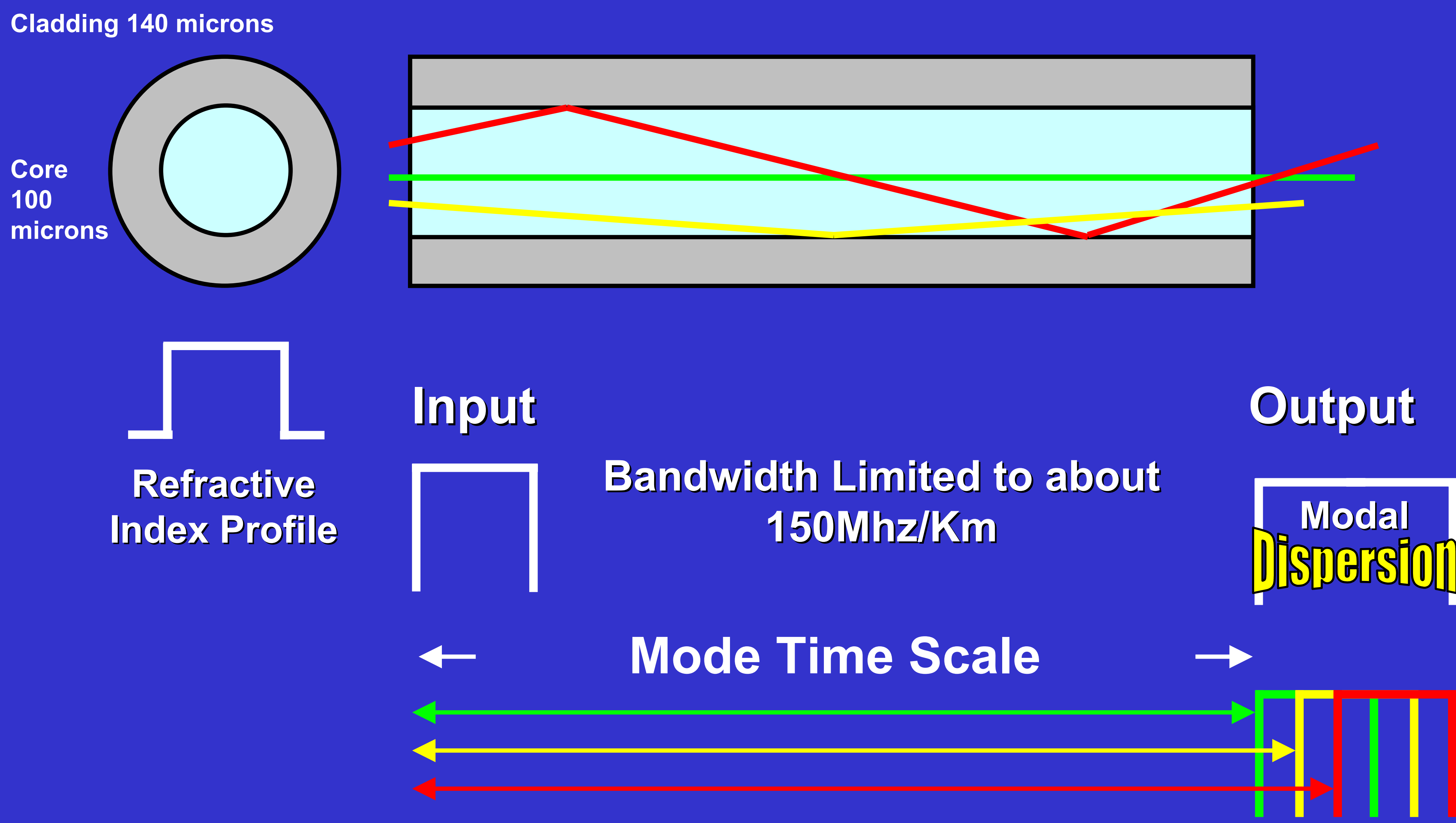
Multimode



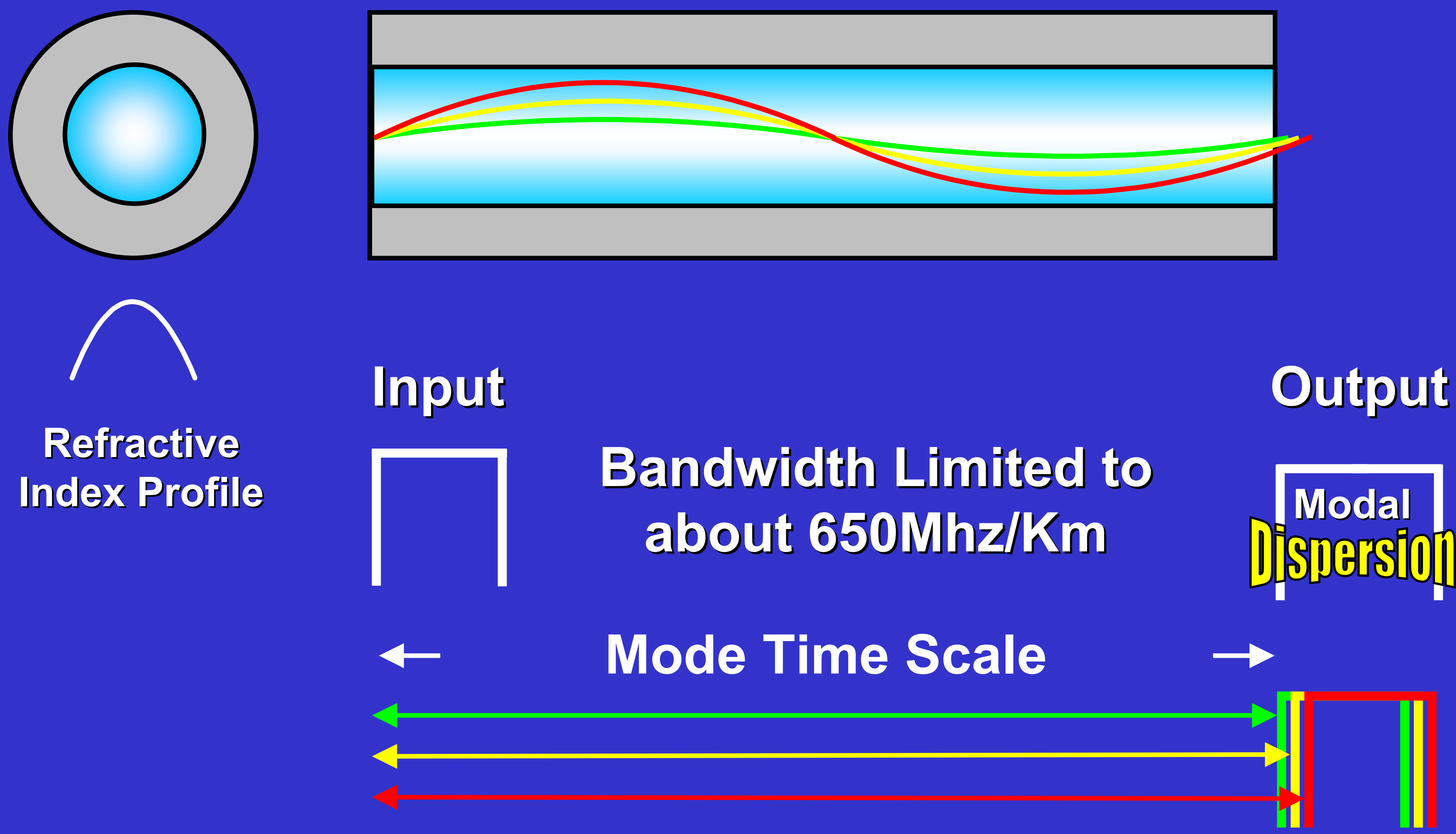
Refractive Index Profiles

- Multimode Stepped Index Fiber
- Multimode Graded Index Fiber
- Singlemode Stepped Index Fiber

Multimode Stepped Index Fiber

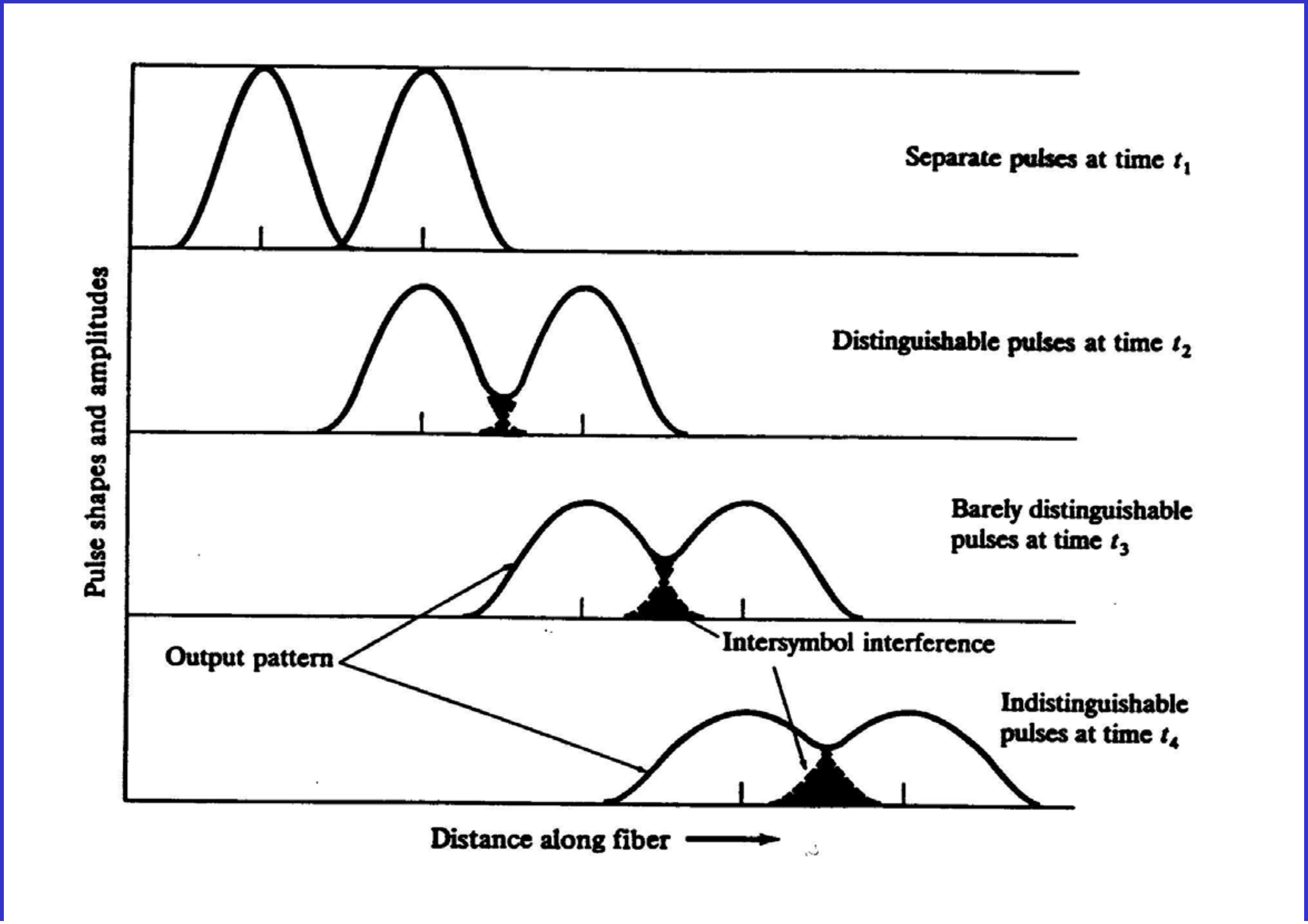


Multimode Graded Index Fiber



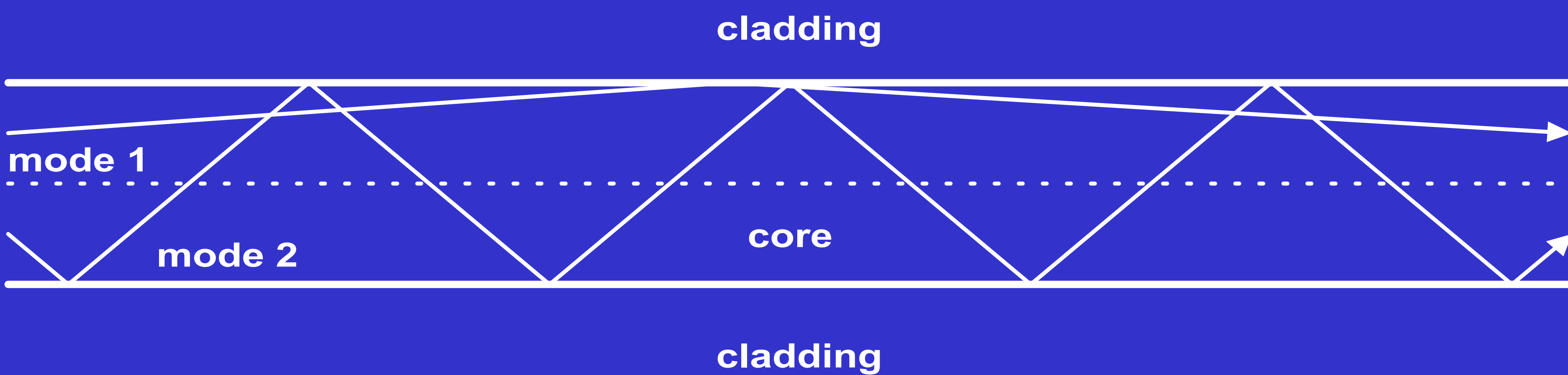
Signal Distortion

Important in determining the information capacity (bandwidth) of an optical fiber as a function of transmission distance.



Intermodal Dispersion

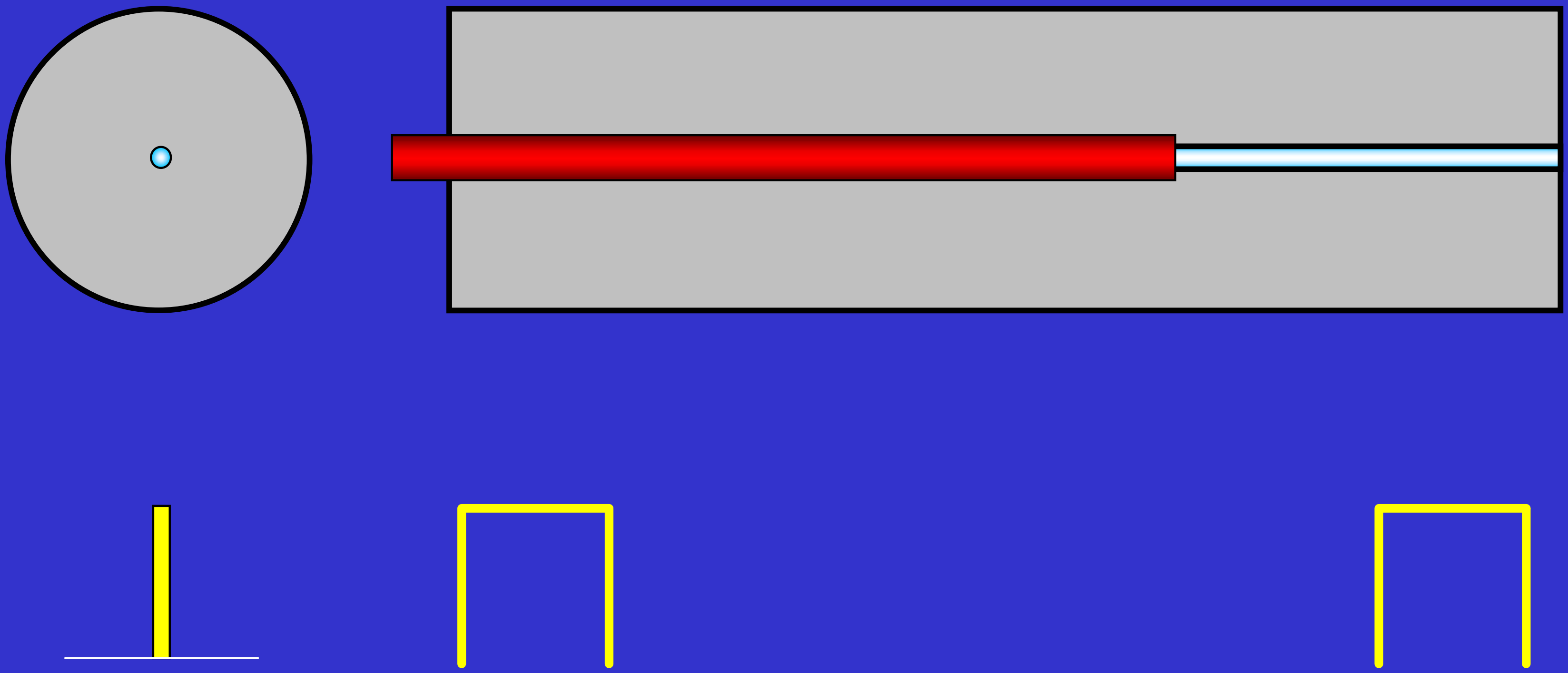
Intermodal dispersion - pulse spreading (in time) in multimode fibers, due to varying arrival times at the RX because each mode travels with a slightly different velocity.



Axial Cross-Sectio

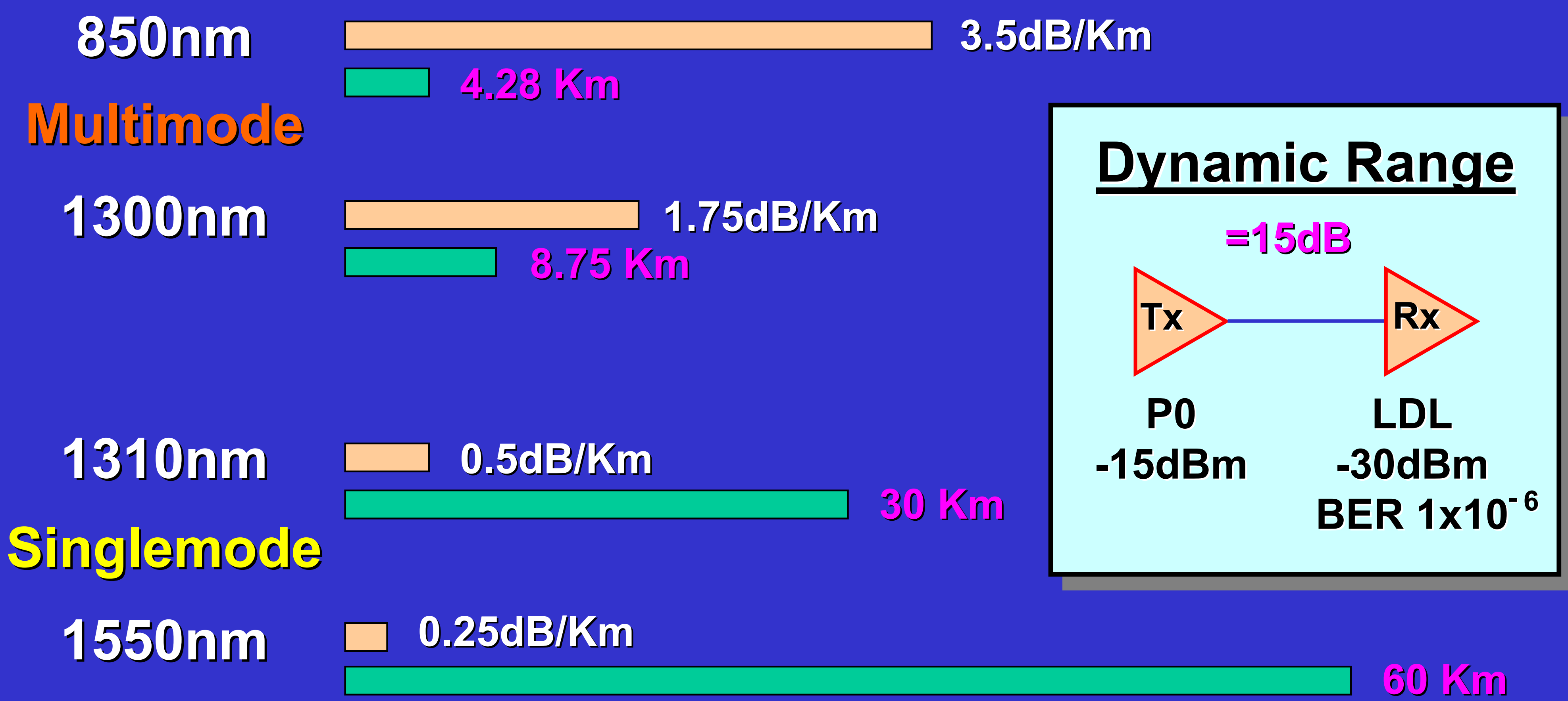
Singlemode Step Index Fiber

Stepped Index, Terahertz Bandwidth

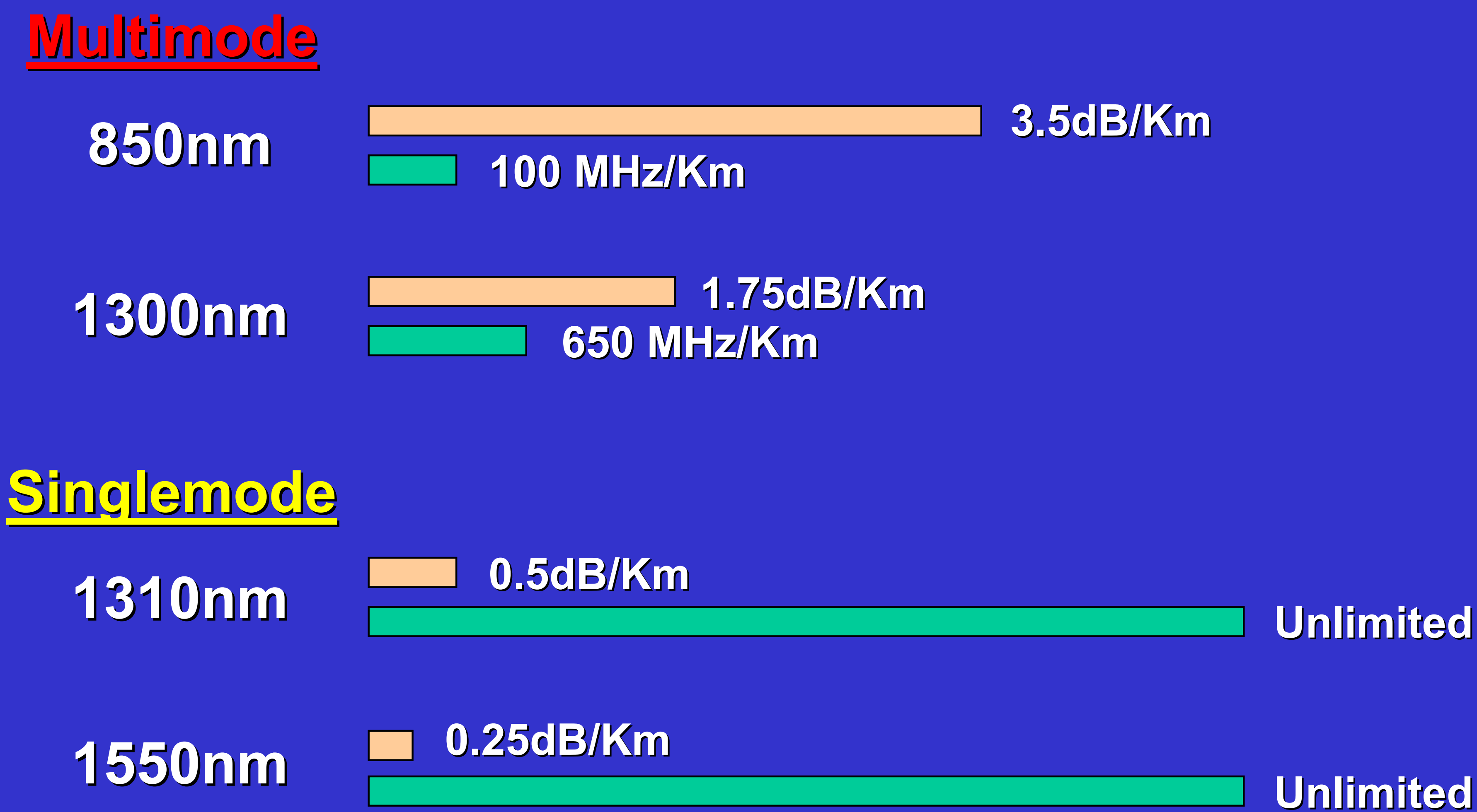


Refractive Index Profile

Wavelength / Attenuation / Distance



Wavelength / Attenuation / Bandwidth



Four Operating Wavelengths

850nm	Multimode	LED's
1300nm		
1310nm	Singlemode	ELED's
1550nm		LASER's

Fiber Cables

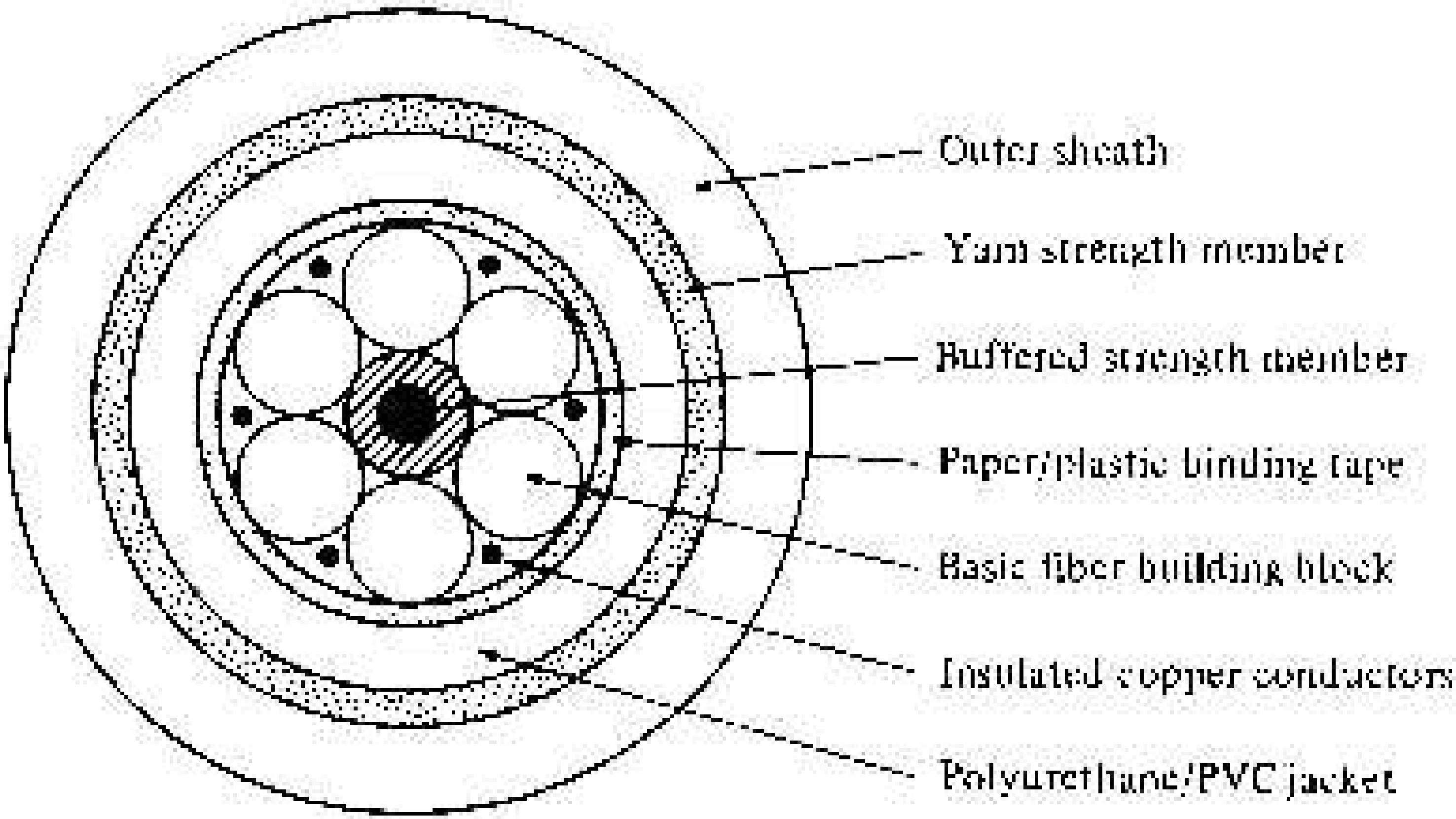


FIGURE 2-36
A typical six-fiber cable created by stranding six basic fiber-building blocks around a central strength member.

Point-to-Point Digital Transmission Links

- Link Requirements:
  - Transmission Distance
  - Data Rate or Bandwidth

A designer has the choice of the following:

1) Fiber -

- Multimode or single-mode
- Core size and refractive index profile
- Attenuation
- Numerical aperture

2) Source -

Laser diode or LED

Emission

Spectral width

Output power

Speed (bandwidth)

Effective emitting area

Emission pattern

3) Detector –

Sensitivity (or responsivity)

Speed (bandwidth)

Operating λ

Link Power Budget Analysis

$$P_S - P_R \geq [\ \alpha_f L + m(l_c) + n(l_{sp}) + \text{system margin}\ ]$$

where

α_f = fiber attenuation (dB/km)

L = fiber length (km)

m = number of connectors

l_c = loss per connector (dB)

n = number of splices

l_{sp} = loss per splice (dB)

P_S = source output power (dBm)

P_R = receiver sensitivity (dBm)

System Margin

- System margin is typically specified at 6 to 8 dB to allow for new components, component aging, and temperature fluctuations.

Link Rise Time Budget

- One accepted method for determining the dispersion limitiation of a fiber optic transmission system is to calculate the system rise time, t_{sys}, and ensure that it does not exceed 70% of the NRZ bit period.

$$t_{sys} = [\ (t_{tx})^2 + (t_{GVD})^2 + (t_{mod})^2 + (t_{rx})^2\ ]^{1/2}$$

Signal Coding

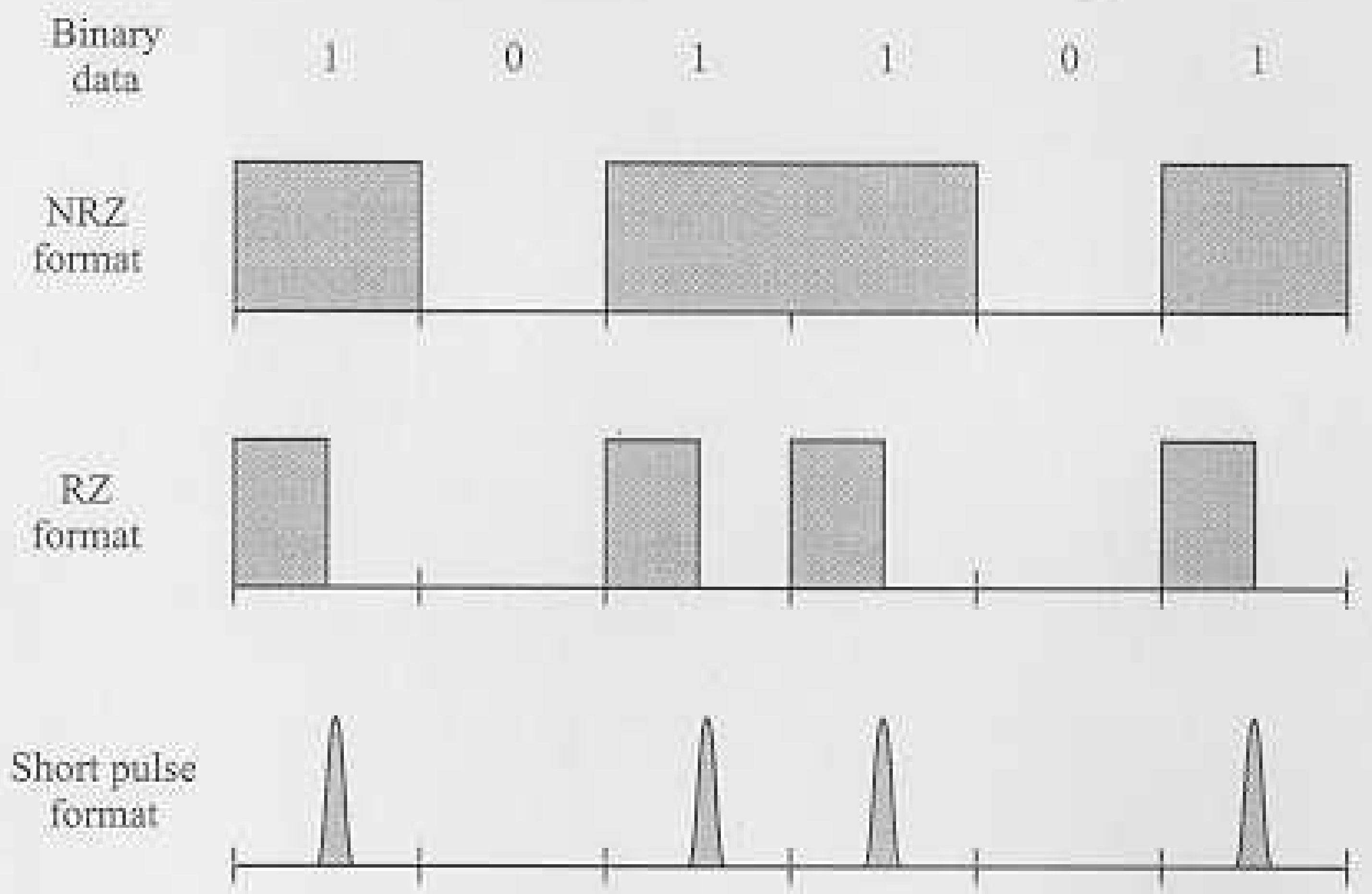


Figure 4.1 On–off keying (OOK) modulation of binary digital data.

where t_{tx} = transmitter rise time (spec'd by manufacturer)

t_{mat} = material dispersion rise time = $D\sigma_{\lambda}L$

or

t_{GVD} = group-velocity dispersion ≈ $|D|L\sigma_{\lambda}$

where D = material dispersion

σ_{λ} = source spectral width

L = fiber length

t_{mod} = modal rise time 0 for single-mode fiber

t_{rx} = receiver rise time (spec'd by manufacturer)

Exercise

A 1550 nm single-mode digital fiber optic link needs to operate at 622 Mb/s over 80 km without amplifiers. A single-mode InGaAsP laser launches an average optical power of 0 dBm into the fiber. The fiber has a loss of 0.25 dB/km, and there is a splice with a loss of 0.1 dB every km. The coupling loss at the receiver is 0.5 dB, and the receiver uses an InGaAs APD with a sensitivity of –39 dBm.

a) Find the system margin.

b) Find the system margin at 2.5 Gb/s with an APD sensitivity of –31 dBm.

Solution

$$P_S - P_R \geq [\ \alpha_f L + m(l_c) + n(l_{sp}) + \text{system margin}\ ]$$

so we can calculate the system margin from

$$\text{system margin} \leq P_S - P_R - \alpha_f L - m(l_c) - n(l_{sp})$$

where $P_S = 0$ dBm

$\alpha_f = 0.25$ dB/km

$L = 80$ km

$m = 1$

$l_c = 0.5$ dB

$n = 79$

$l_{sp} = 0.1$ dB

Solution (continued)

a) $P_R = –39$ dBm for a data rate of 622 Mb/s

system margin ≤ 0 dBm – (-39 dBm) – (0.25 dB/km)(80 km) – (1)(0.5 dB) – (79)(0.1 dB)

system margin ≤ 10.6 dB, which is very respectable

b) $P_R = –31$ dBm for a data rate of 2.5 Gb/s

system margin ≤ 0 dBm – (-31 dBm) – (0.25 dB/km)(80 km) – (1)(0.5 dB) – (79)(0.1 dB)

system margin ≤ 2.6 dB, which is really not good enough to ensure long-term, problem-free operation of the link

Exercise

You are assisting with the design of an OC-192 fiber optic transmission link. Given a 1550 nm laser diode with a rise time of 25 ps and a spectral width of 0.1 nm, and a receiver with a rise time of 25 ps:

a) Determine the maximum dispersion-limited transmission distance through a fiber optimized for a 1310 nm source (assume a material dispersion of 15 ps/nm-km).

b) Determine the maximum dispersion-limited transmission distance through a dispersion-shifted fiber optimized for a 1550 nm source (assume a material dispersion of 2 ps/nm-km).

Solution

$$t_{sys} = \left[\left(t_{tx}\right)^2 + \left(t_{GVD}\right)^2 + \left(t_{\mathrm{mod}}\right)^2 + \left(t_{rx}\right)^2 \right]^{1/2}$$

substituting for $t_{GVD} = |D| L\sigma_{\lambda}$

$$t_{sys} = \left[\left(t_{tx}\right)^2 + \left(|D| L\sigma_{\lambda}\right)^2 + \left(t_{\mathrm{mod}}\right)^2 + \left(t_{rx}\right)^2 \right]^{1/2}$$

and solving for L

$$L = \frac{\left[\left(t_{sys}\right)^2 - \left(t_{tx}\right)^2 - \left(t_{\mathrm{mod}}\right)^2 - \left(t_{rx}\right)^2 \right]^{1/2}}{|D|\sigma_{\lambda}}$$

Solution (continued)

From the problem statement,

$$t_{tx} = 25\ ps$$

$$t_{\text{mod}} \approx 0$$

$$t_{rx} = 25\ ps$$

$$\sigma_{\lambda} = 0.1\ nm$$

For an OC-192, the data rate is approximately 10 Gb/s, so the NRZ bit period is $T_b = 1 \times 10^{-10}$ s = 100 ps. Thus, t_{sys} should not exceed 70% of T_b, so set $t_{sys} = 70\ ps$.

Solution (continued)

a) transmission through a fiber optimized for a 1310 nm source with $D = 15\, ps/nm \cdot km$.

$$L_{\max} = \frac{\left[(70\,ps)^2 - (25\,ps)^2 - (25\,ps)^2\right]^{1/2}}{(15\,ps/nm \cdot km)(0.1 nm)}$$

$$\boxed{L_{\max} = 40.28 km}$$

b) transmission through a dispersion-shifted fiber optimized for a 1550 nm source with $D = 2\, ps/nm\text{-}km$.

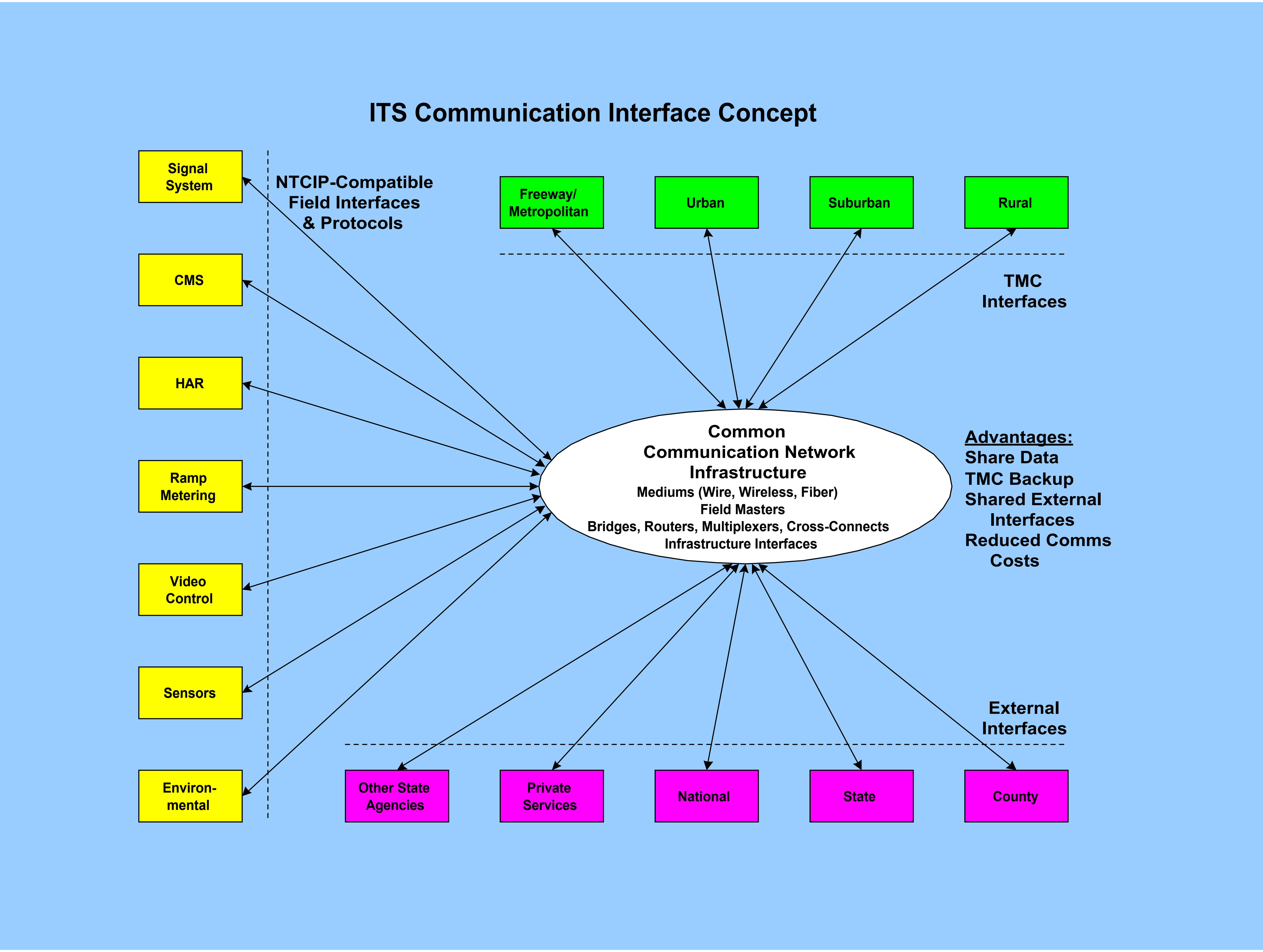
$$L_{\max} = \frac{\left[(70\,ps)^2 - (25\,ps)^2 - (25\,ps)^2\right]^{1/2}}{(2\,ps/nm \cdot km)(0.1 nm)}$$

$$\boxed{L_{\max} = 302.08 km}$$

End of Part 1

Fiber Optic Networks for Traffic and Transportation Systems

Part 2


ITS Communication Interface Concept
Signal System
CMS
HAR
Ramp Metering
Video Control
Sensors
Environ-mental
NTCIP-Compatible Field Interfaces & Protocols
Freeway/ Metropolitan
Urban
Suburban
Rural
TMC Interfaces
Common Communication Network Infrastructure
Mediums (Wire, Wireless, Fiber)
Field Masters
Bridges, Routers, Multiplexers, Cross-Connects
Infrastructure Interfaces
Advantages:
Share Data
TMC Backup
Shared External Interfaces
Reduced Comms Costs
External Interfaces
Other State Agencies
Private Services
National
State
County

Agency Options

- **Install-Operate-Maintain**
- **Lease**
- **Public/Private Partnerships**

Network Requirements

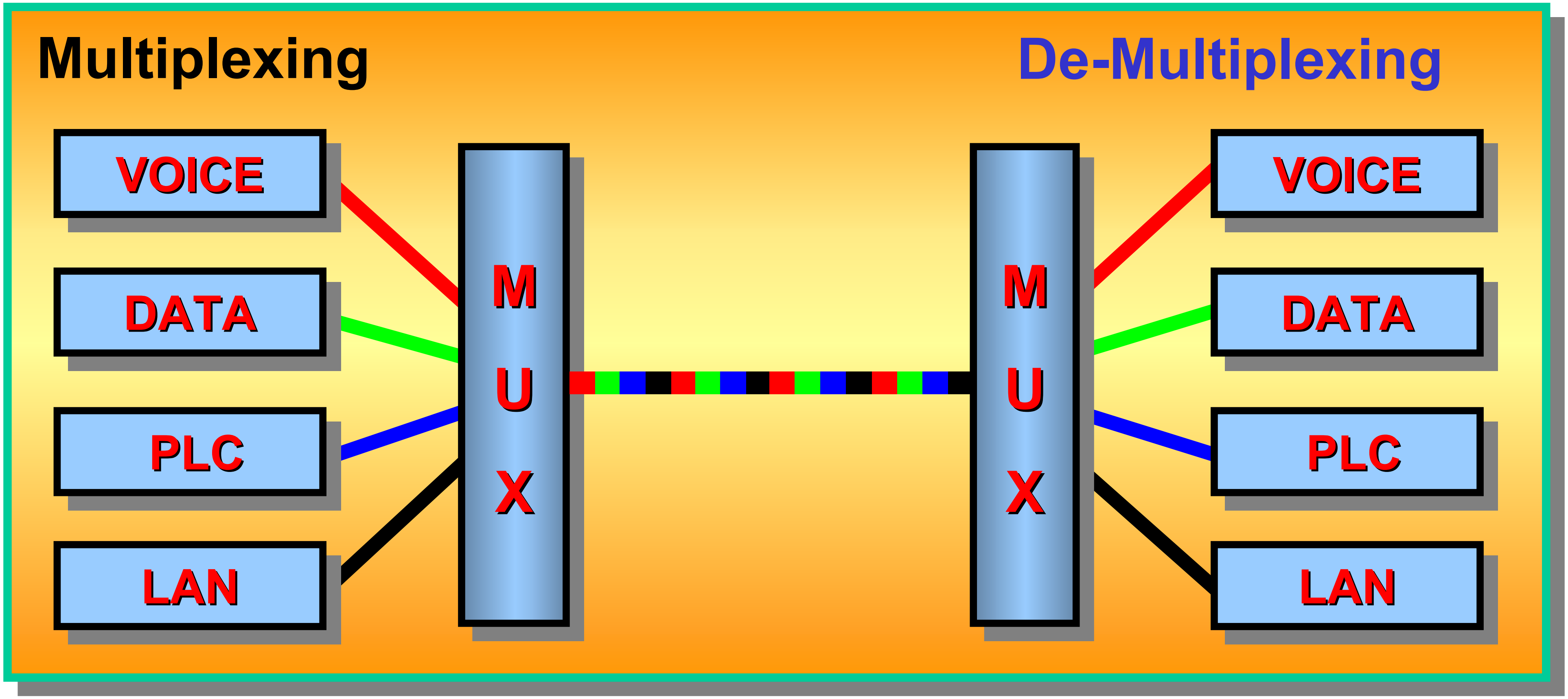
- **Data** - Signal systems, VMS, video PTZ, vehicle detectors, sensors, etc.
- **Voice** - Craft interfaces, HAR, emergency call boxes.
- **Video** - Incident monitoring, surveillance, video detection.

❖ Analog vs. Digital Video? The answer drives required network bandwidth.

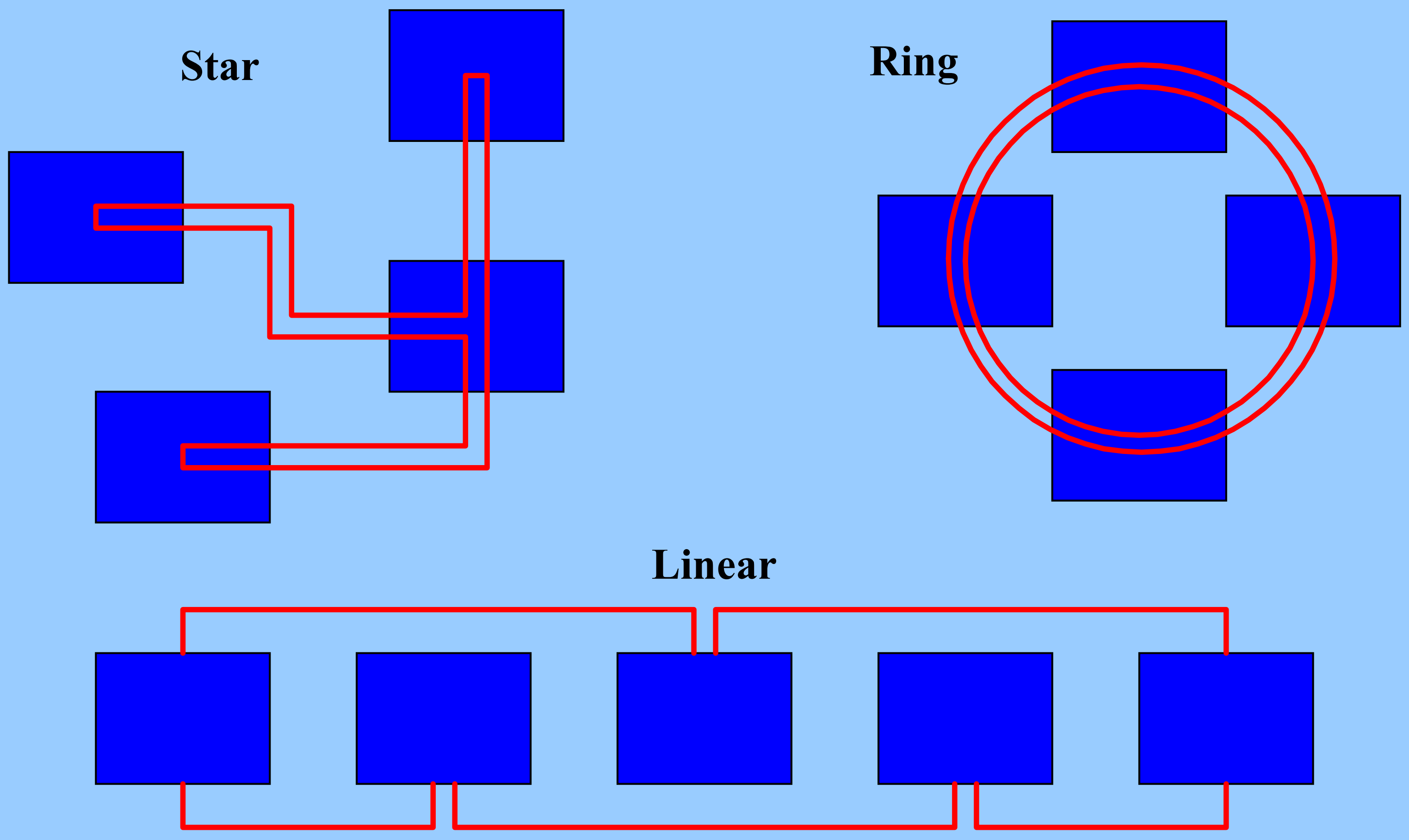
Multiplexing

Combines Two or More Signals into a Composite Signal for Transmission

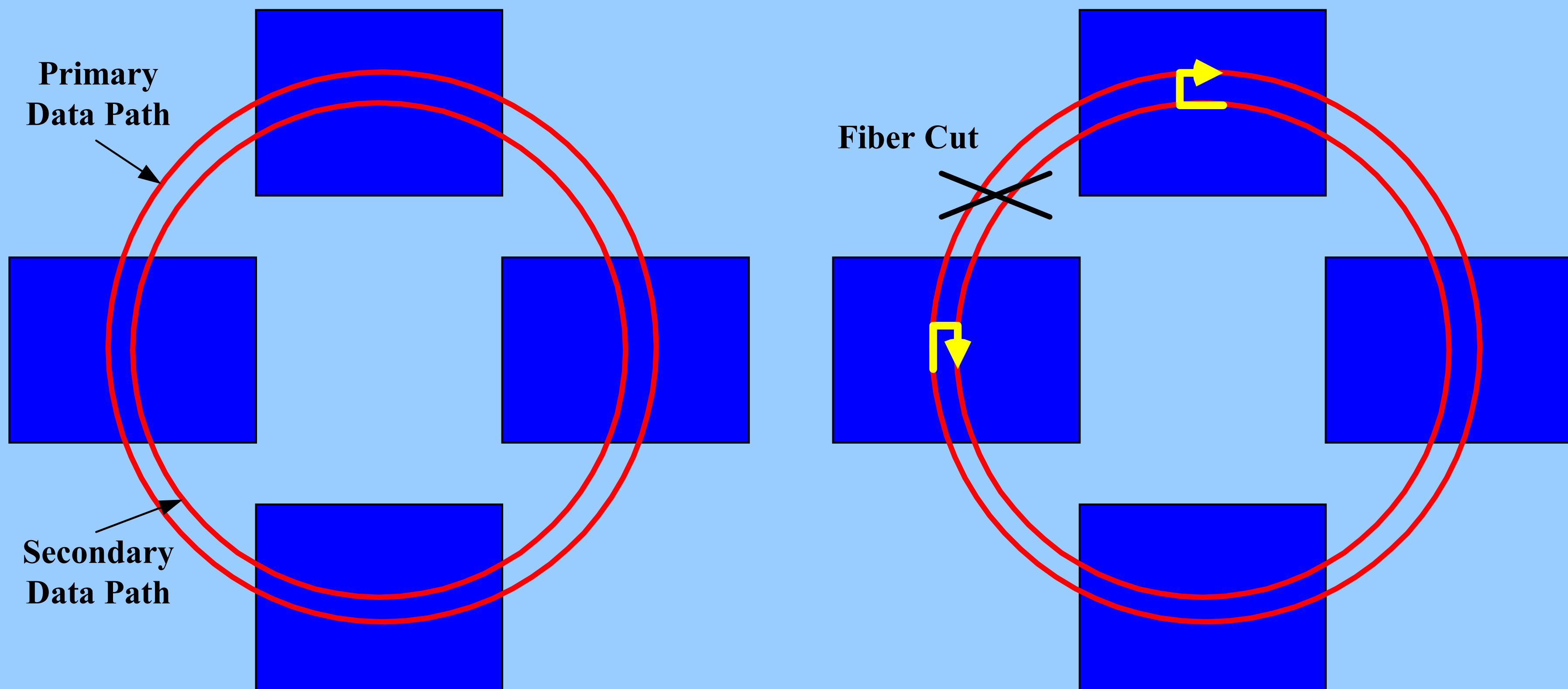
Separates out the Input Signals from the Composite to form Corresponding Outputs



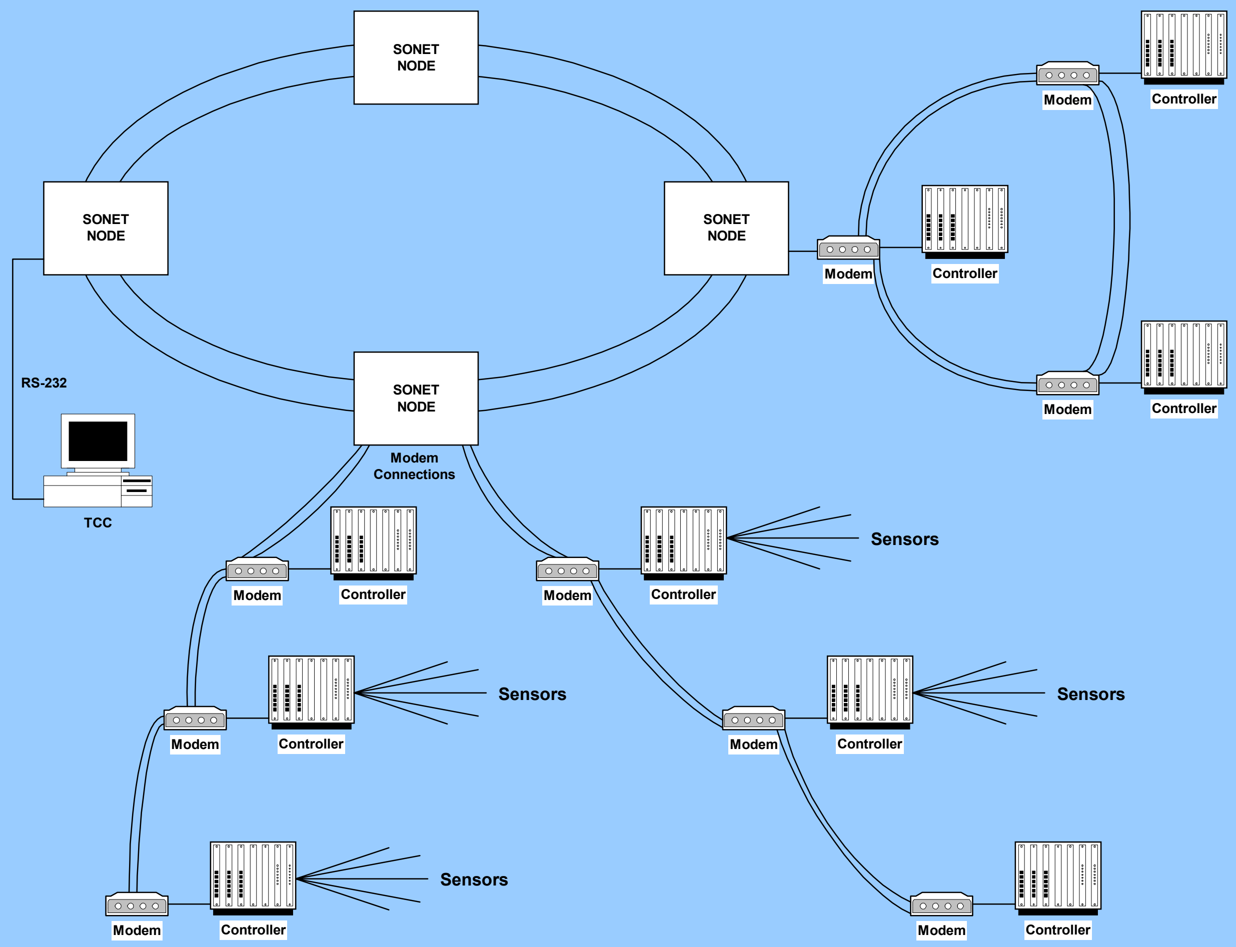
Network Topologies



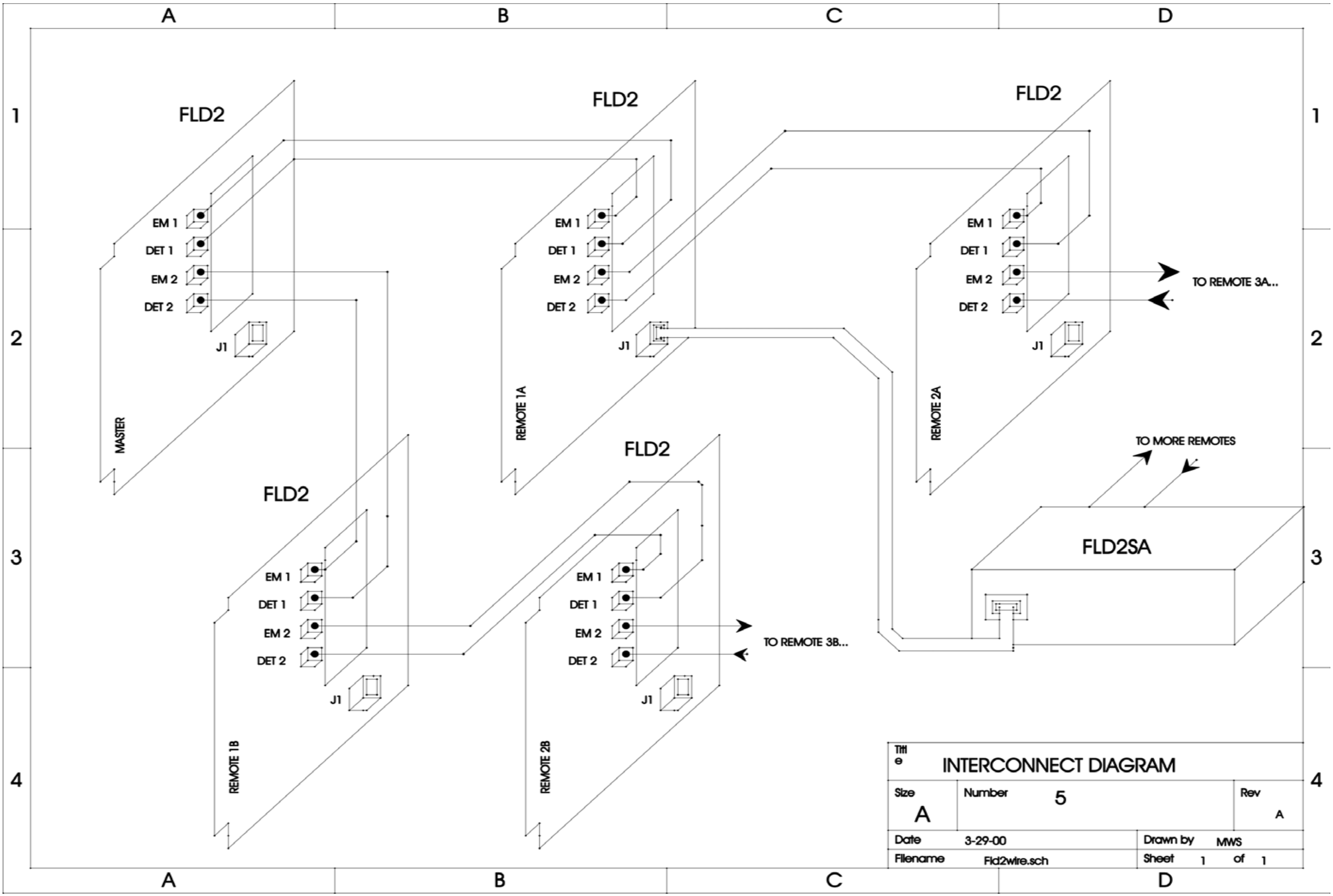
Fault-Tolerant Ring Topologies



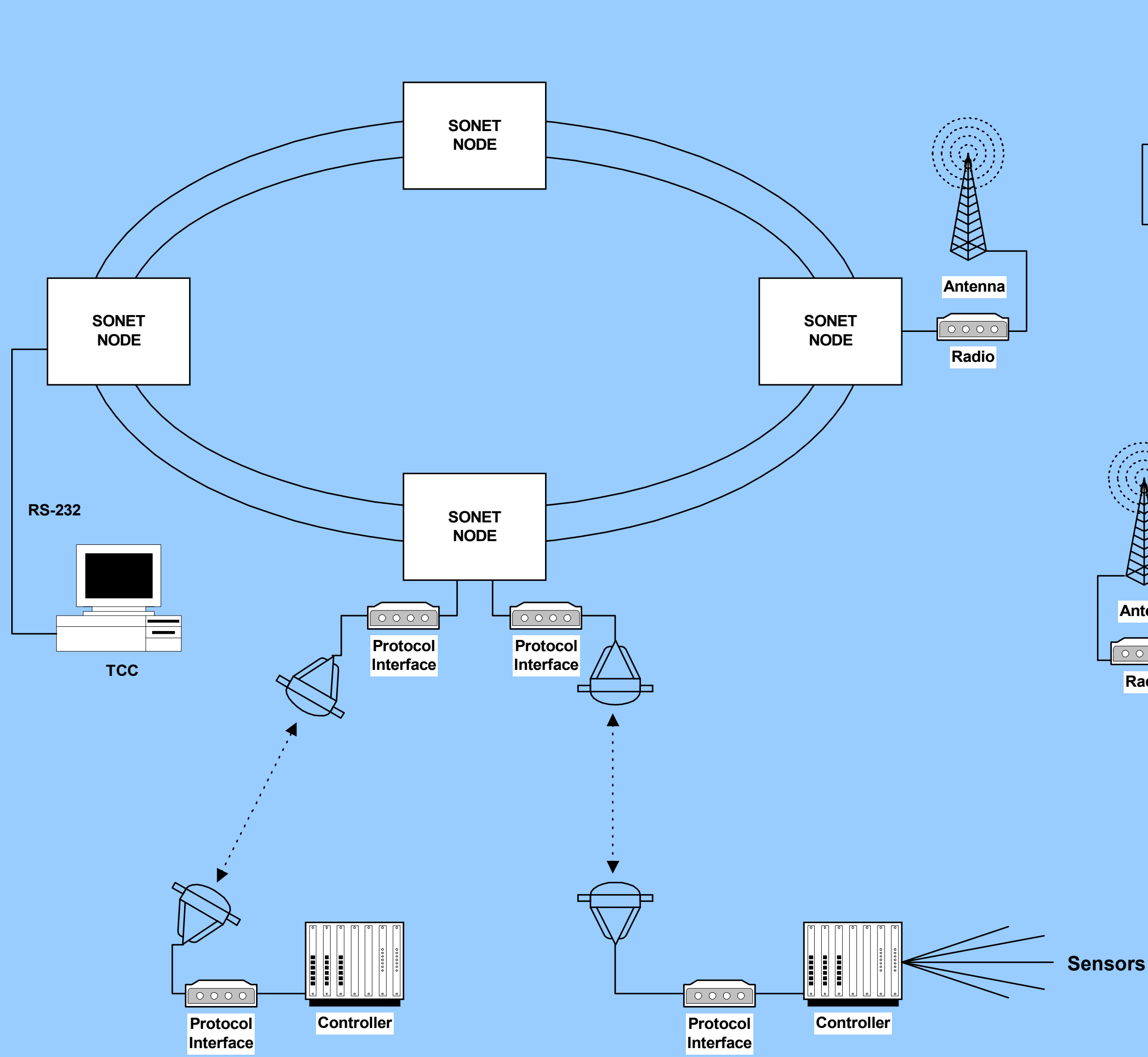
Typical Fiber Network Application



Interconnect Diagram



Hybrid Fiber/Wireless Network

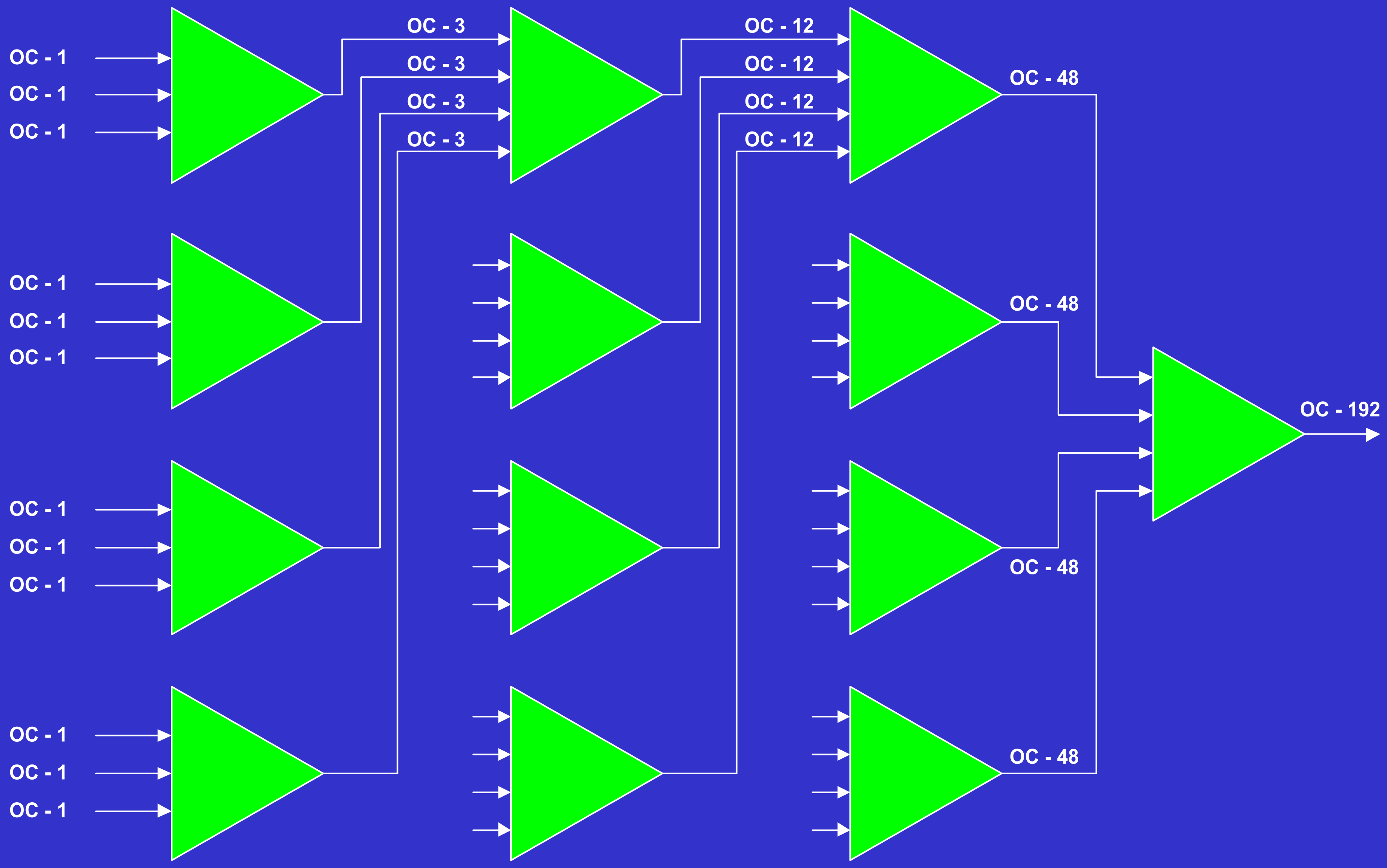


SONET
Synchronous Optical Network

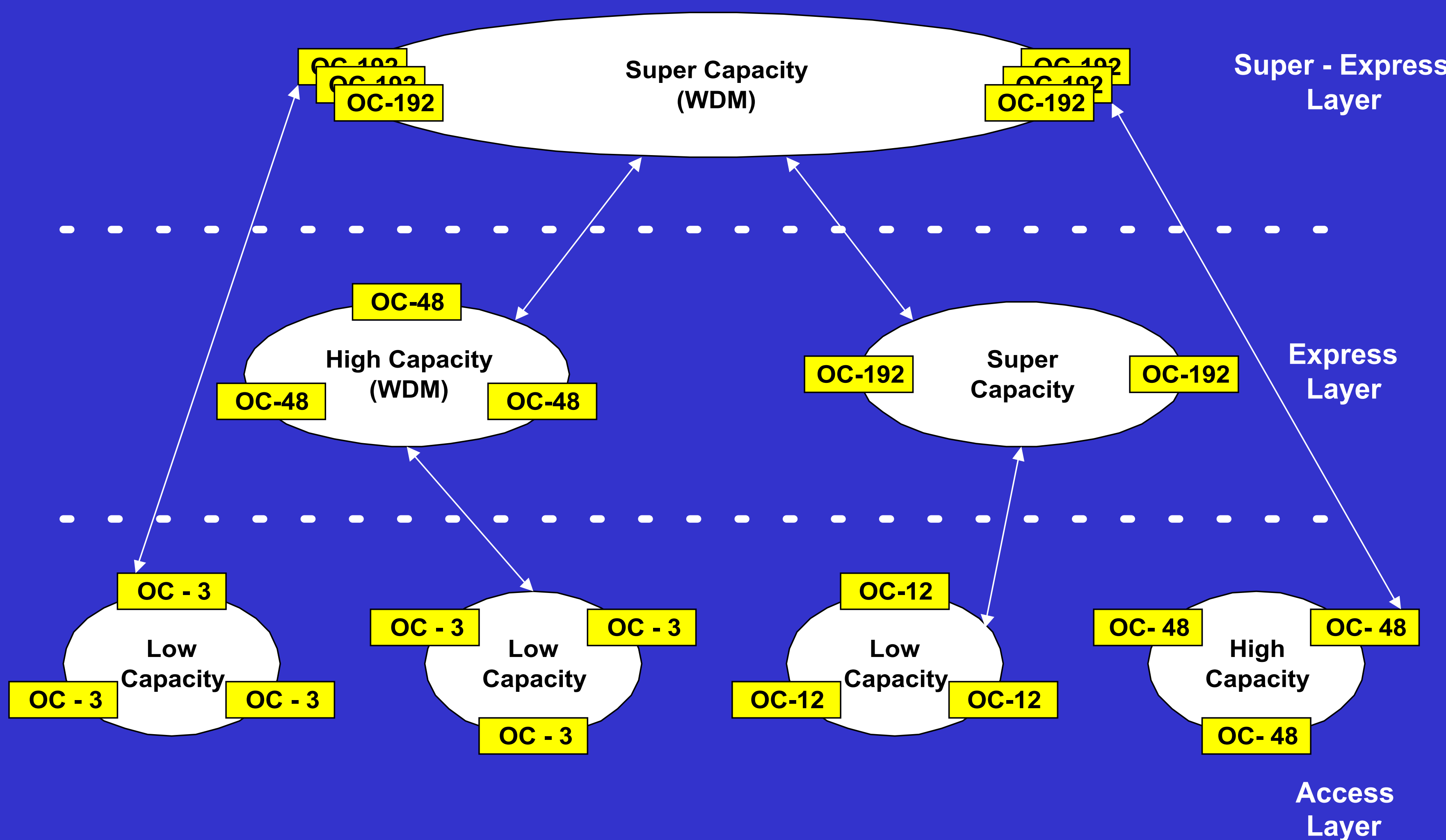
SONET Level (optical)	SONET Level (electrical)	Line Rate (Mb/s)	SDH Level
OC-1	STS-1	51.84	STM-0
OC-3	STS-3	155.52	STM-1
OC-12	STS-12	622.08	STM-4
OC-24	STS-24	1,244.16	STM-8
OC-36	STS-36	1,866.24	STM-12
OC-48	STS-48	2,488.32	STM-16
OC-192	STS-192	9,953.28	STM-64

OC - Optical Carrier
STS - Synchronous Transport Signal
STM - Synchronous Transport Module

SONET Multiplexing



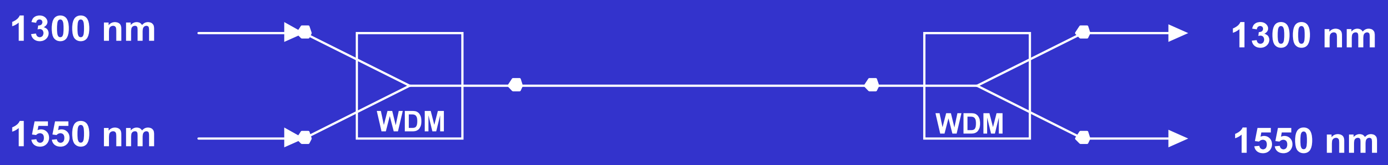
SONET Networking



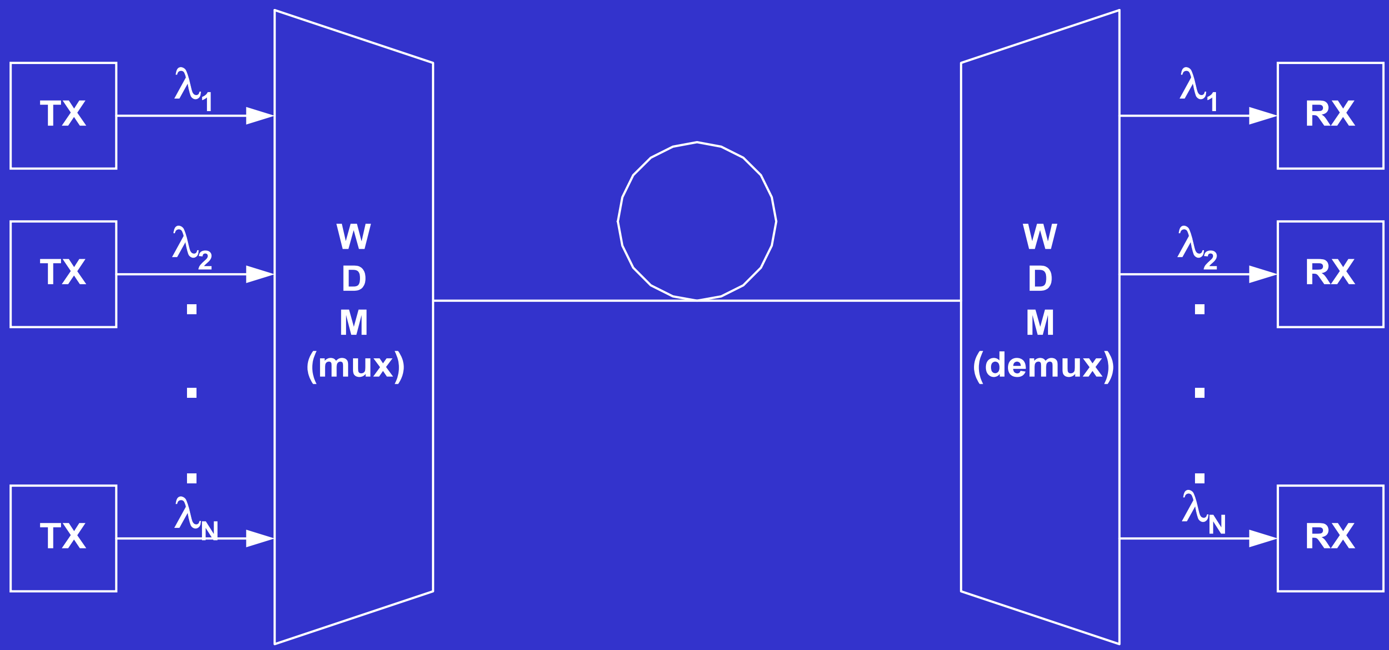
Transmission Over SONET

- PCM Digital Hierarchy
- ATM Over SONET
- Packet Over SONET (POS) or IP over SONET

Wavelength Division Multiplexing (WDM)



Dense WDM (DWDM)



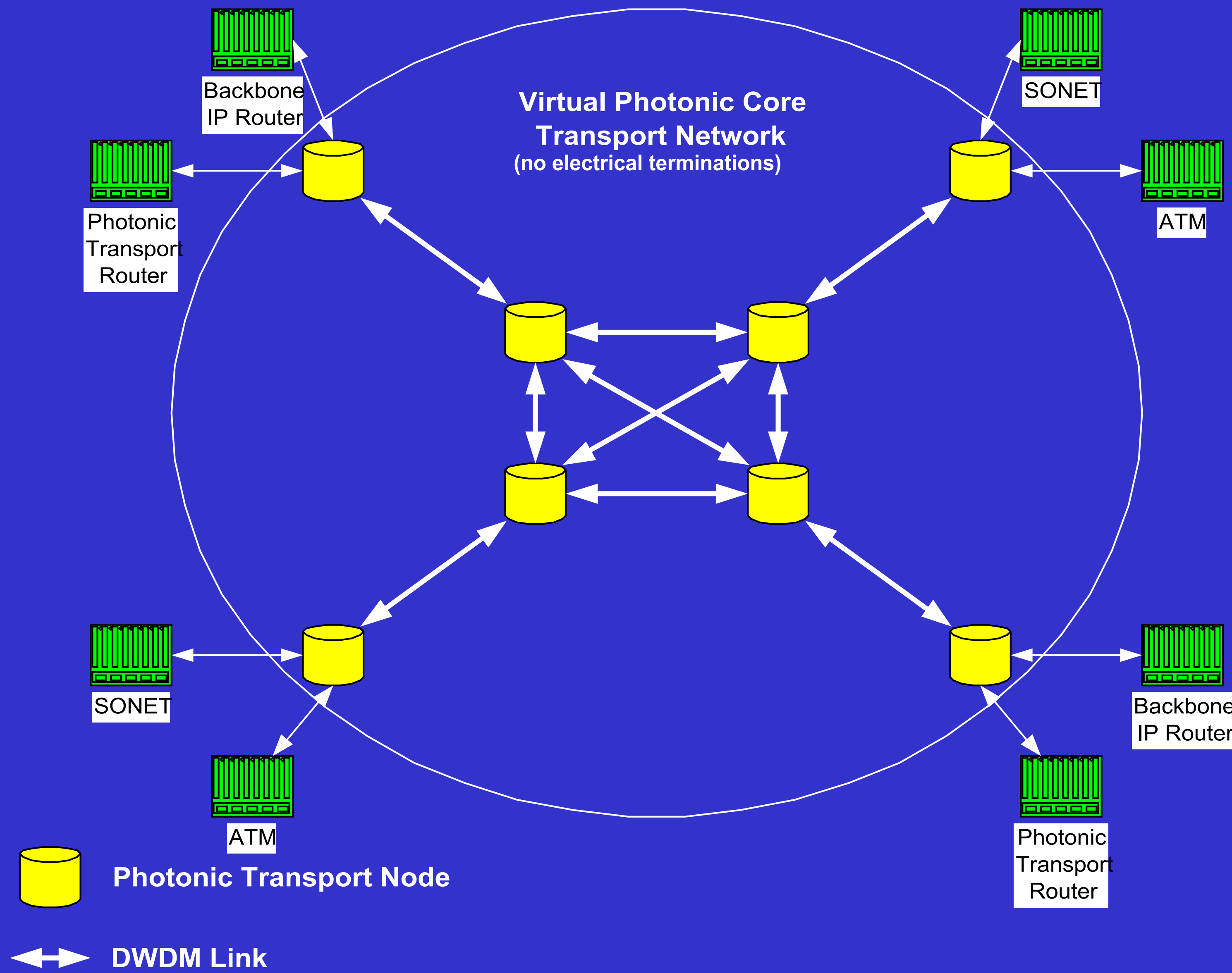
Optical Transport Network (OTN) G.709

- For data rates of 10 Gb/s and above, optical transmission lengths decrease
  - ➢ OTN uses Forward Error Correction (FEC) to increase optical link distance
- Need to transport a wide range of services
  - ➢ OTN offers flexible payload management with minimum additional overhead

Optical Transport Network (OTN) G.709

- Minimize O/E/O conversions
  - ➢ End-to-end transport of optical channels without O/E/O conversions
- Ability to manage emerging DWDM networks
  - ➢ OTN offers management capabilities in the optical domain

Optical Transport Network



End of Part 2

Part 3

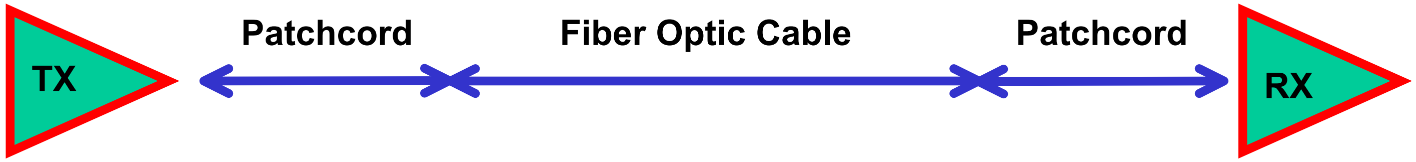
Troubleshooting Problems

Test & Measurement

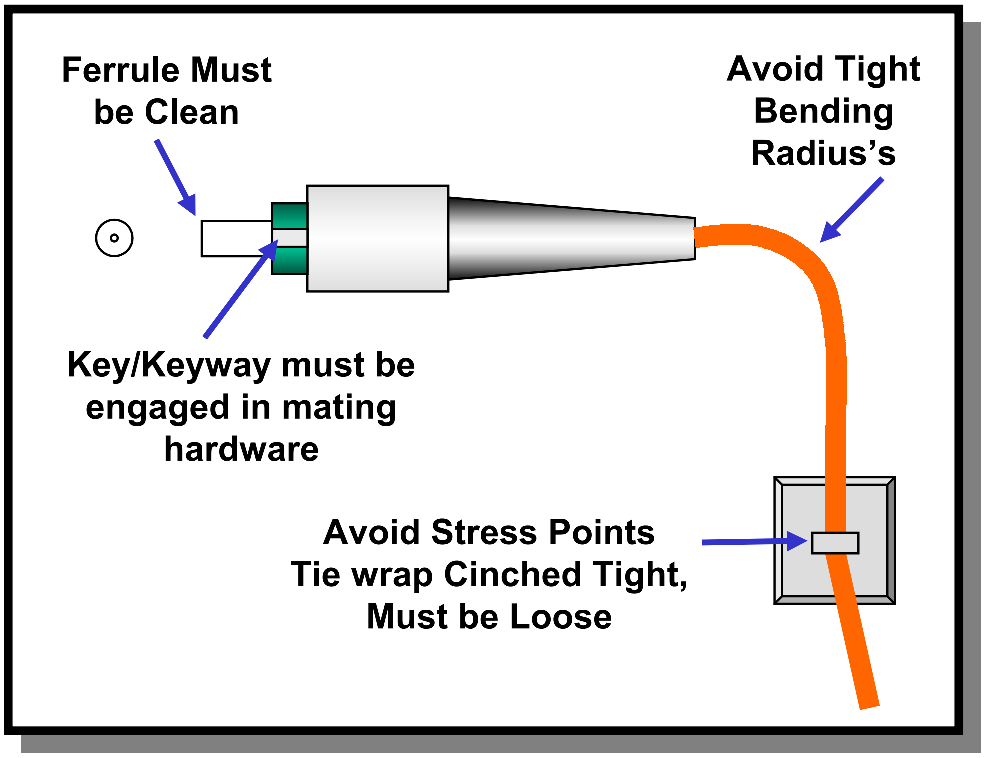
Problems

Typical Problems

- Low Levels

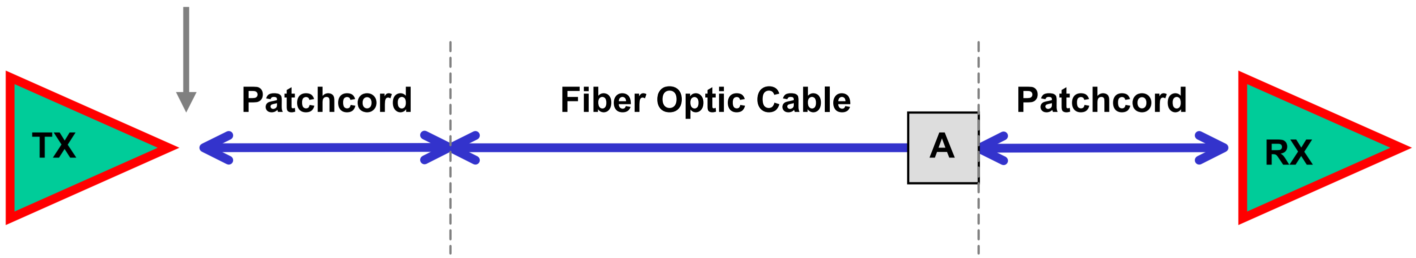


- Dirty Connectors
- Connectors not seated properly
- Pinched Fibers
- Tight bending radius's
- Bad Patchcords
- Low Transmit Levels

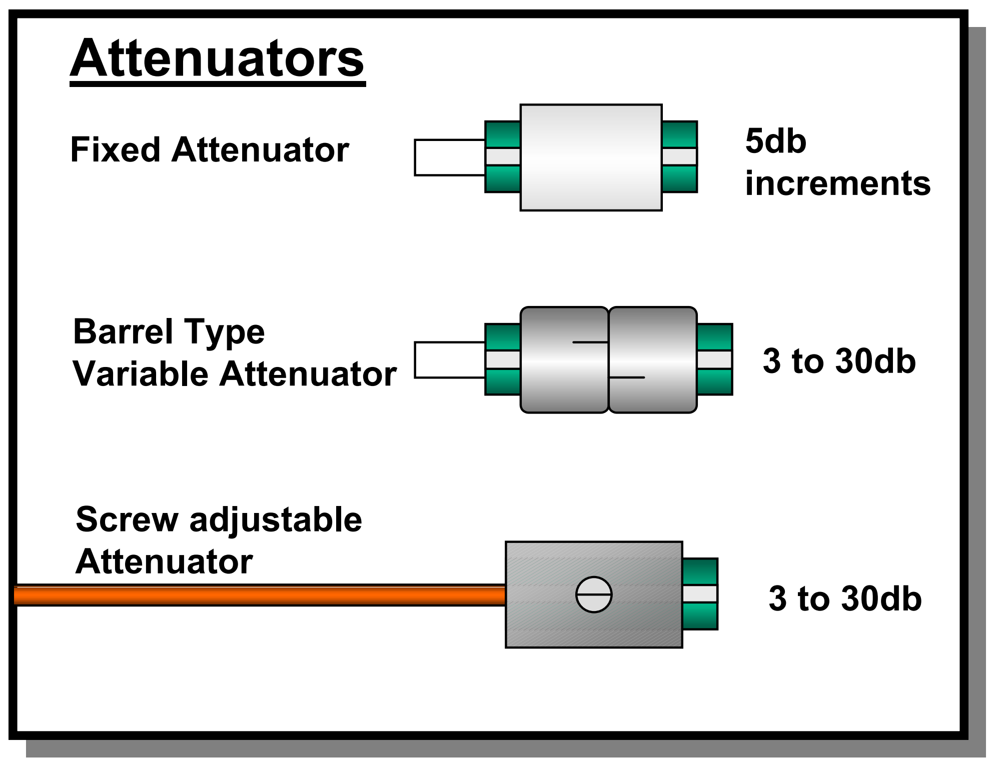


Typical Problems

- **High Levels**

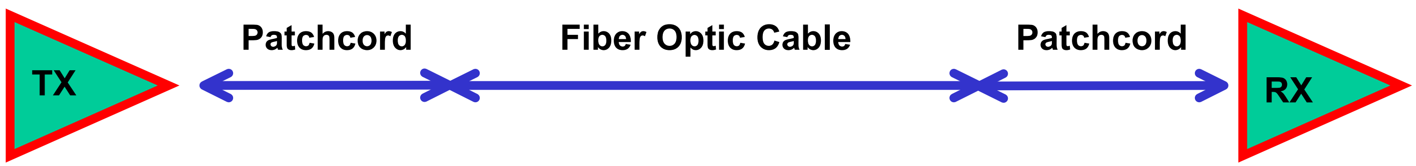


- High Transmit Levels (LASER)
- Not enough Loss in Fiber Plant

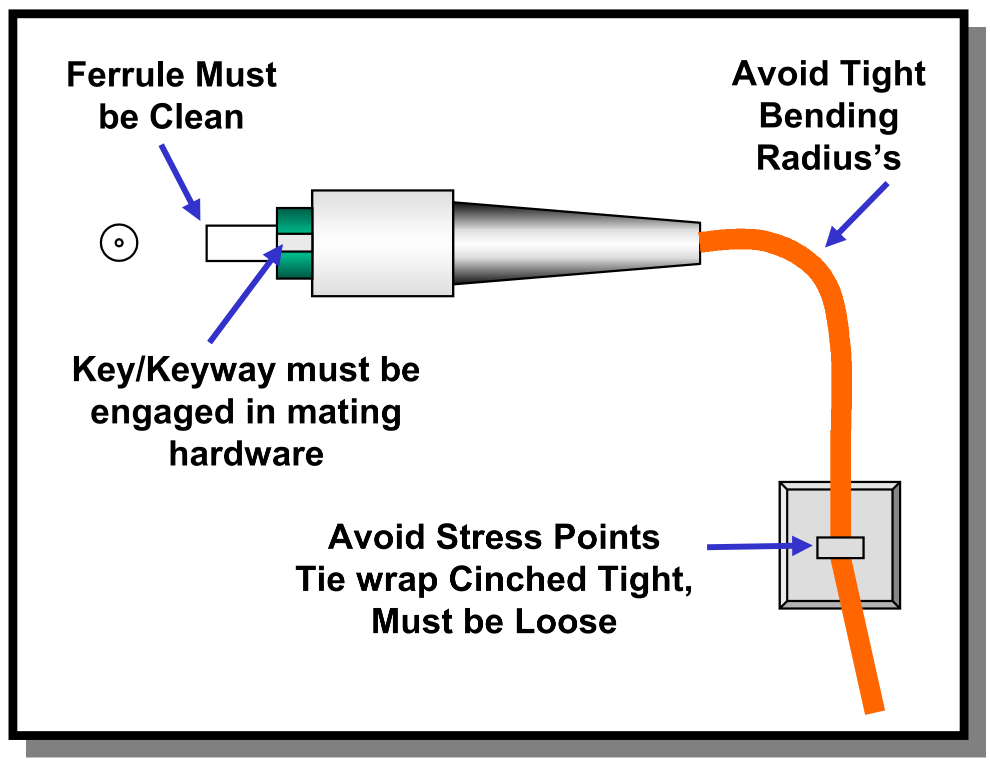


Typical Problems

- No Receive Level

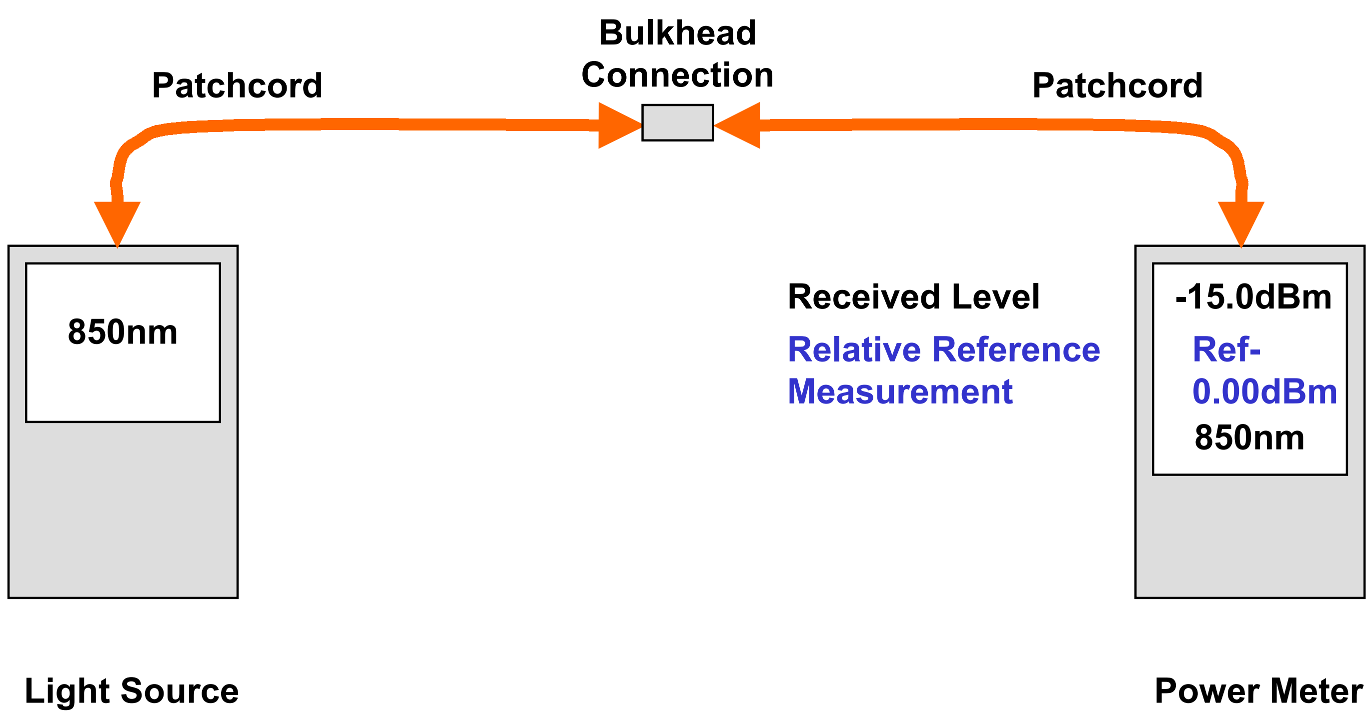


- Dirty Connectors
- Connectors not seated properly
- Bad Patchcord (Open)
- No Transmit Output
- Wrong Fiber



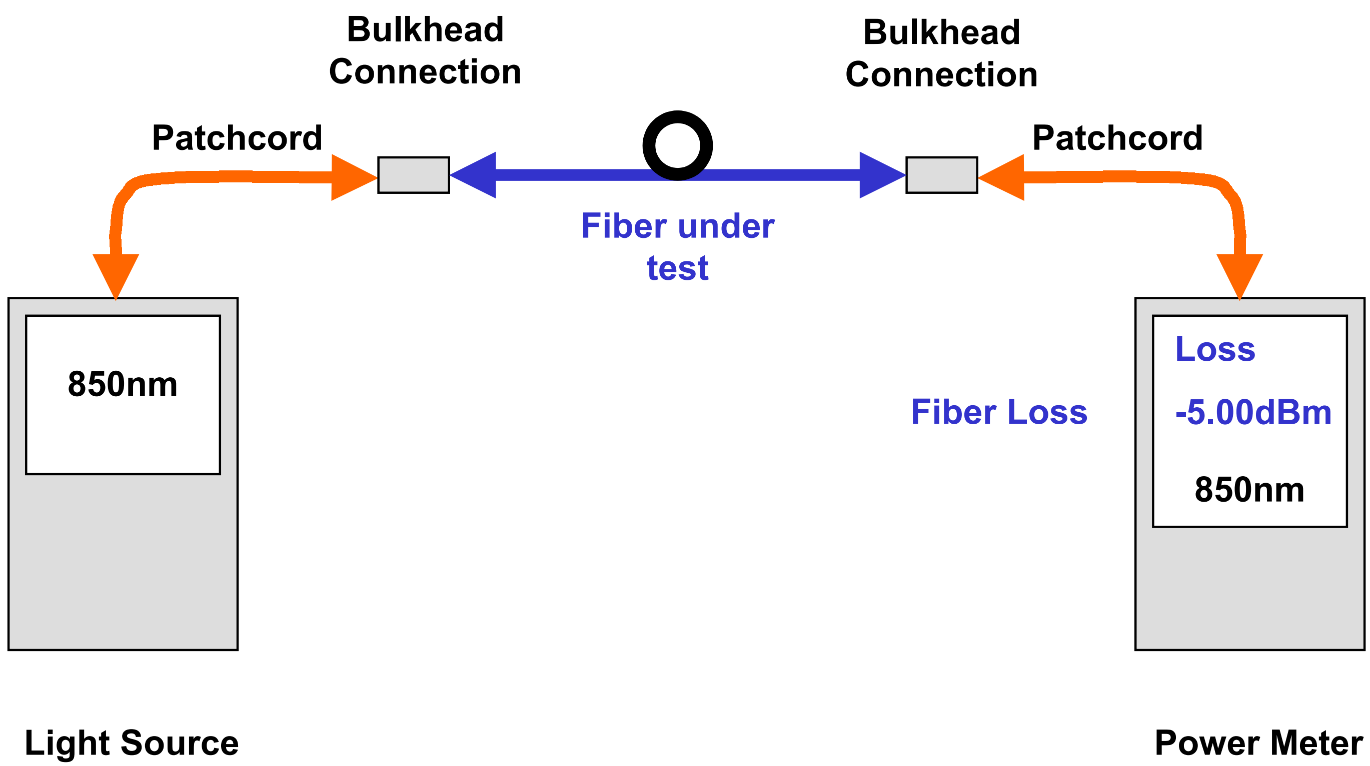
Optical Loss Measurements

Reference Measurement



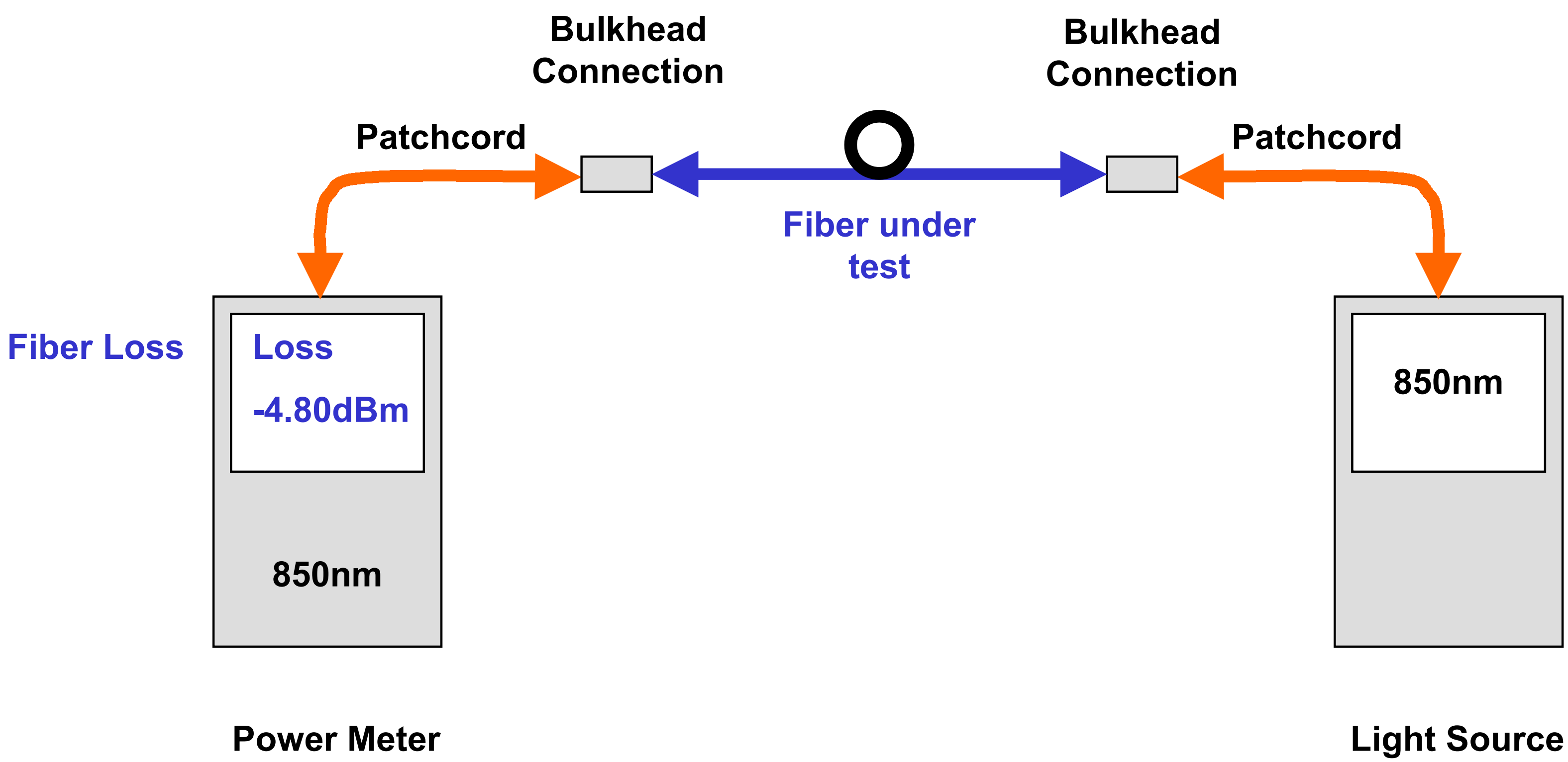
Optical Loss Measurements

Attenuation Measurement ---Forward Direction



Optical Loss Measurements

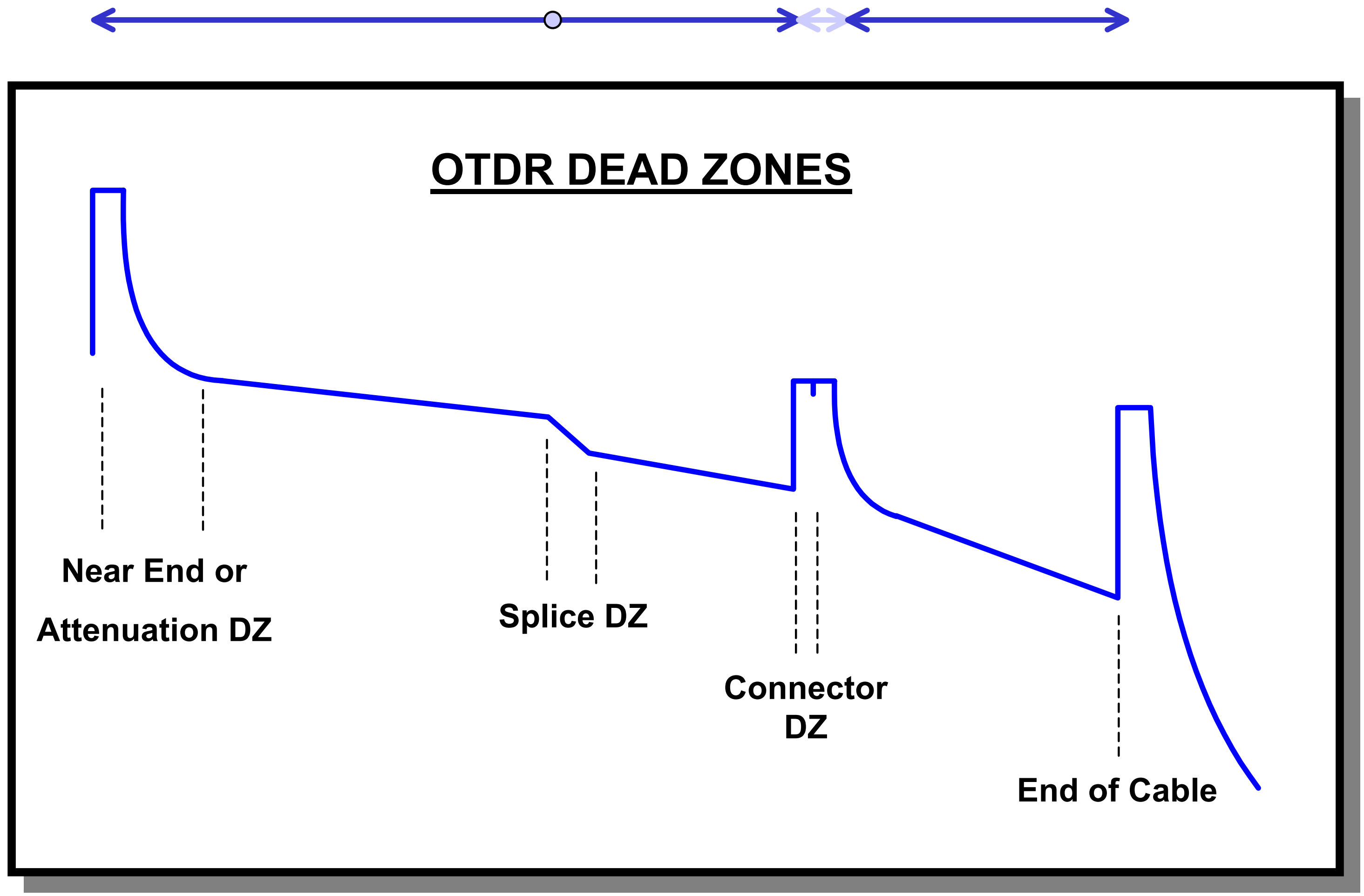
Attenuation Measurement ---Reverse Direction



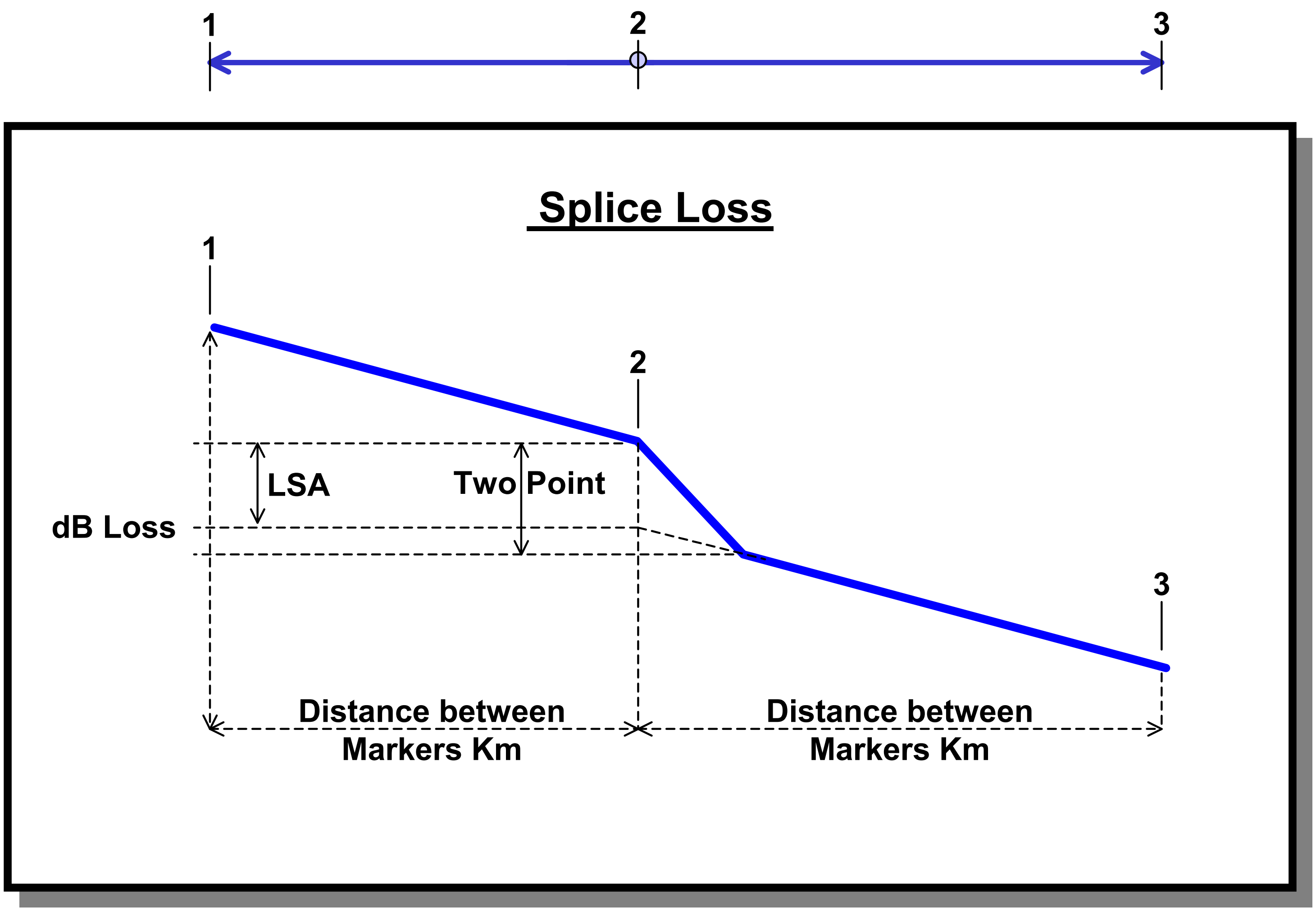
Recording the Results

Cable #	Fiber	AB Loss	BA Loss

OTDR Measurements



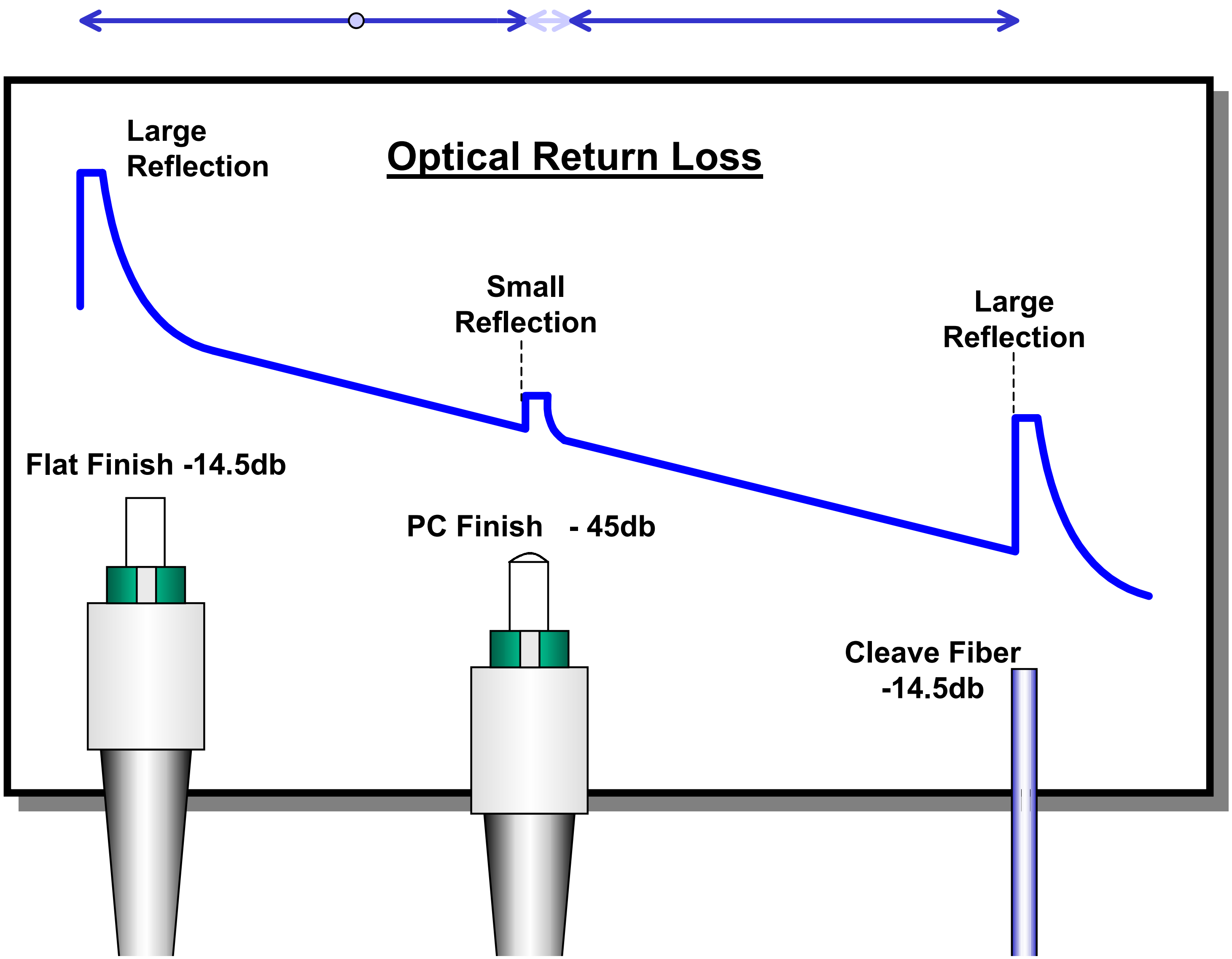
OTDR Measurements



OTDR Measurements----

Optical Return Loss ---- Problems with Reflections

- Increases Bit Error Rates
- Increases Noise in Analog Systems
- Dirty Connectors also cause Reflections



Set up an Electronic Data Base

Fiber Characterization

- **Record losses for all useable wavelengths**
- **Bi- Directional Loss Measurements**
- **OTDR traces for 850 / 1300nm Multimode and 1310 / 1550nm Singlemode**
- **Bi- Directional traces for each fiber**

End of Part 3