- Introduction to Optical Fiber Data Communication

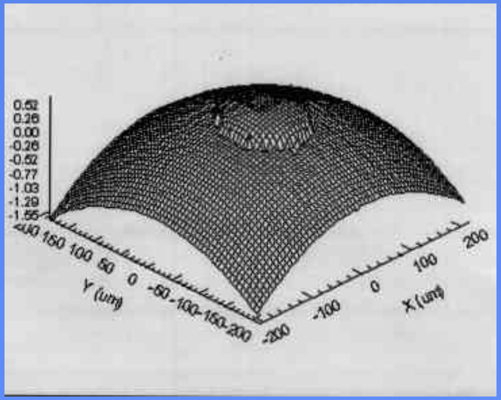
Version 7.12

Class 1

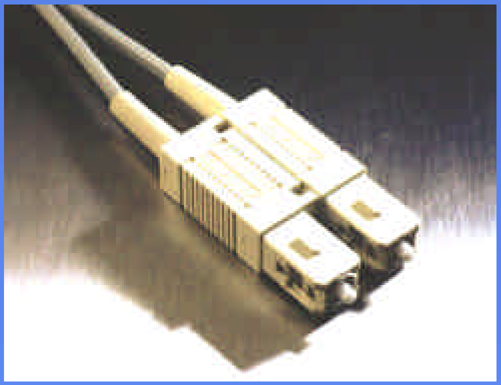
Solutions
for a small planet

Training Class Topics

Optical glass

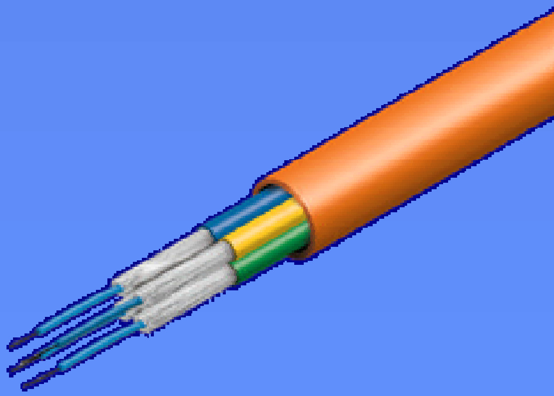


Performance



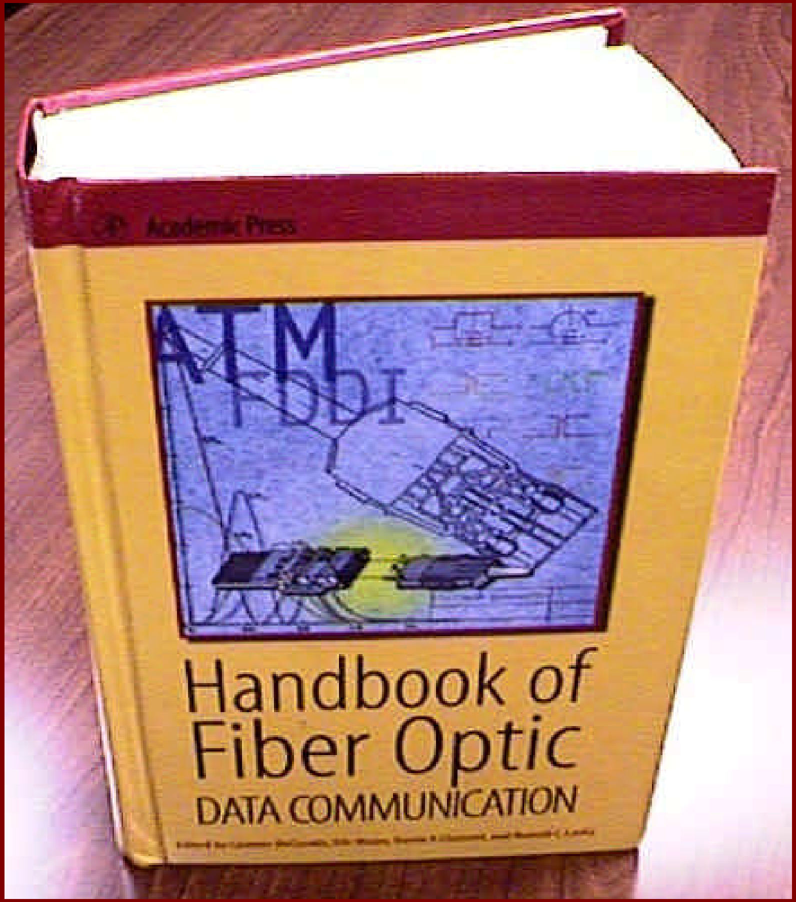
Connectors

Assembly



Cable design

Reference Text



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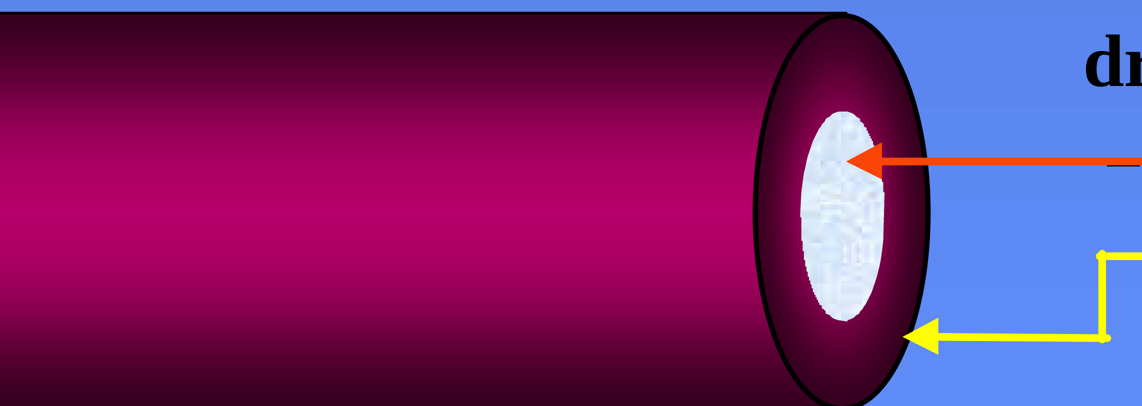
Training Class 1
3 Sections

- **Section 1: BASICS**
  - Optical glass
    - glass performance
    - dimensions
    - glass protection
  - Fundamentals of optical communication
  - Cable design
- **Section 2: CONNECTIONS**
  - Connectorization
  - Splicing
- **Section 3: LINKS**
  - Link Design
  - Testing
  - Installation basics

Section 1
BASICS

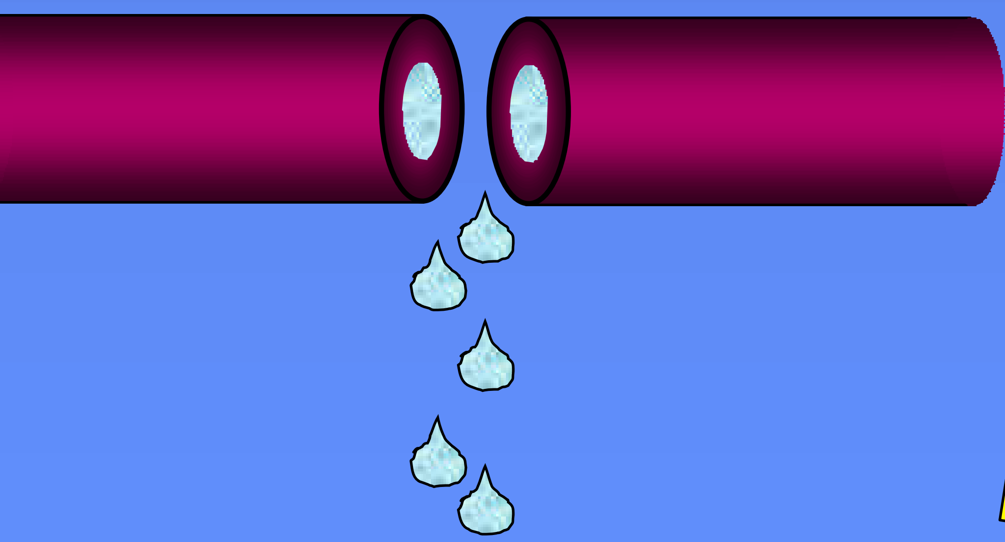


€ Consider the fiber a drinking straw

- The “core” is the hole
- The “cladding” is the outside plastic of the straw

Question: How can water flow from one drinking straw to another?

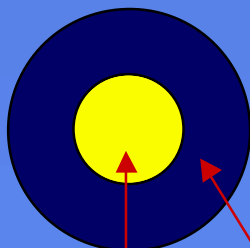
Answer: Push the ends together to ‘connect’ them!



Note: A few drips will escape at the connection point. This is called “loss”.

Water - an analogy for light

Optical Fiber Basics



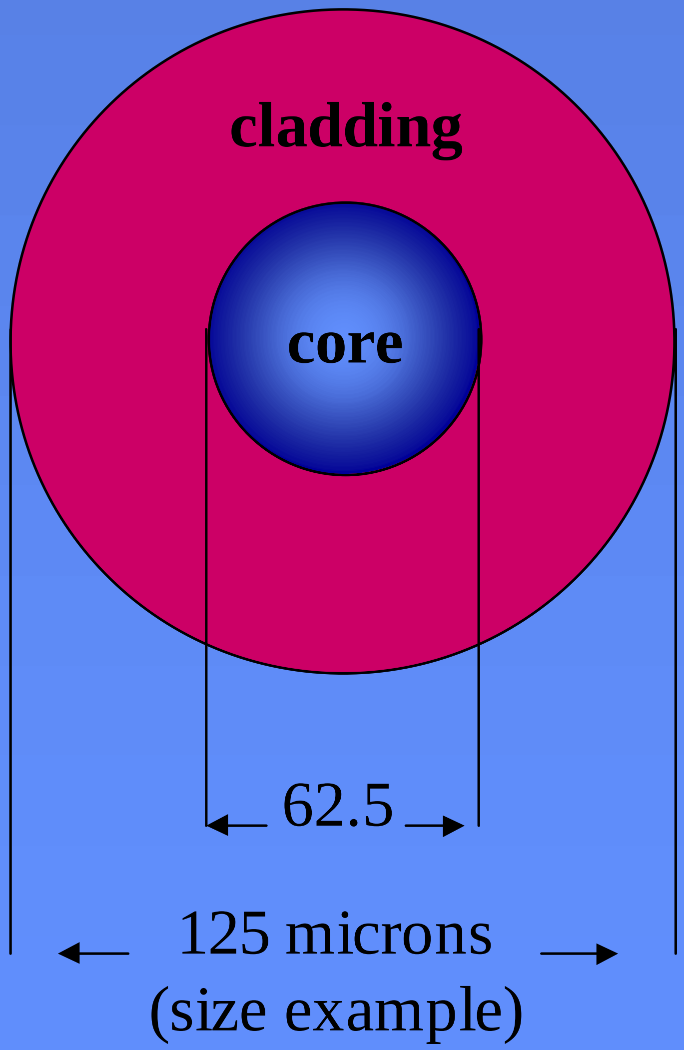
Note: Optical glass is not a tube with a hole in the center. It is solid glass with two inseparable sections: the core & the cladding

Cladding **- glass through which light <u>cannot</u> easily propagate**

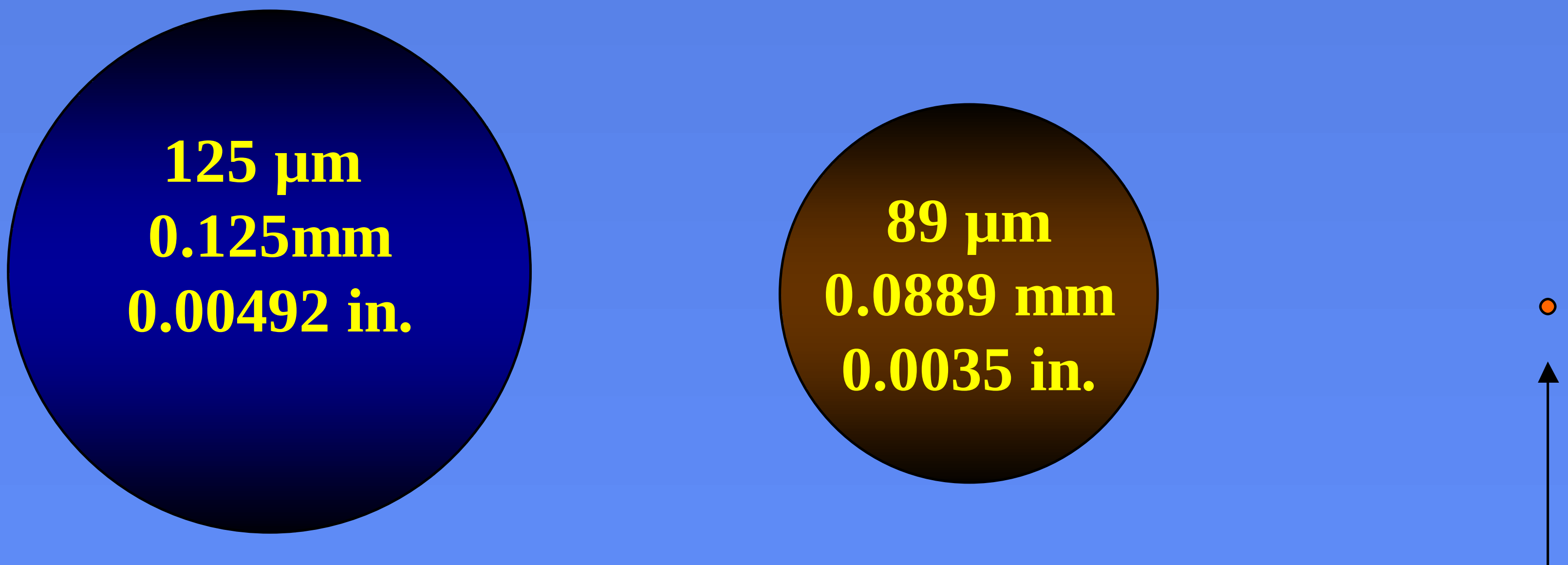
Core **- "clear" glass through which light propagates easily**

Fiber Sizes

- Multimode Glass
  - 62.5/125 is standard (TIA 568a, ISO 11801)
  - 50/125 is growing worldwide
  - 100/140 & 85/125 obsolete
- Singlemode Glass
  - 8.3 ~10/125 is standard
  - Telephony & CATV std.



How big is a glass fiber?



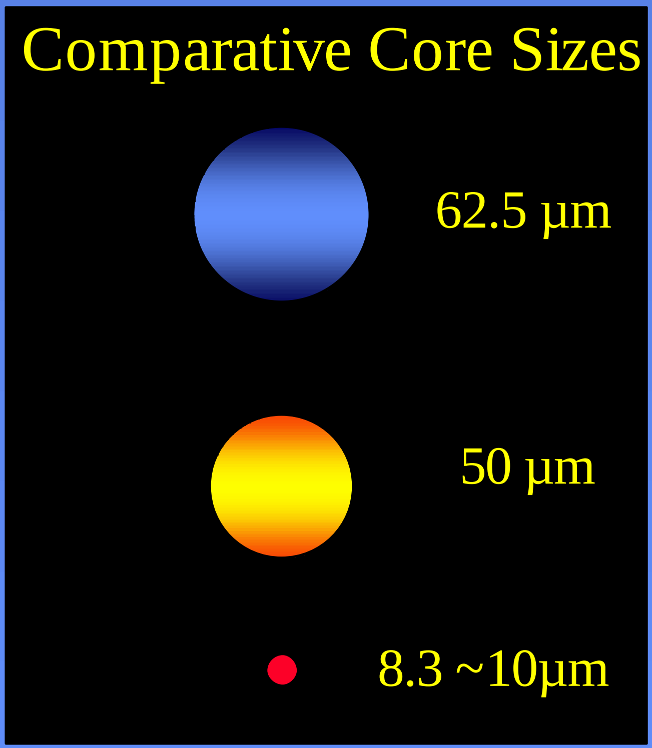
Optical Fiber

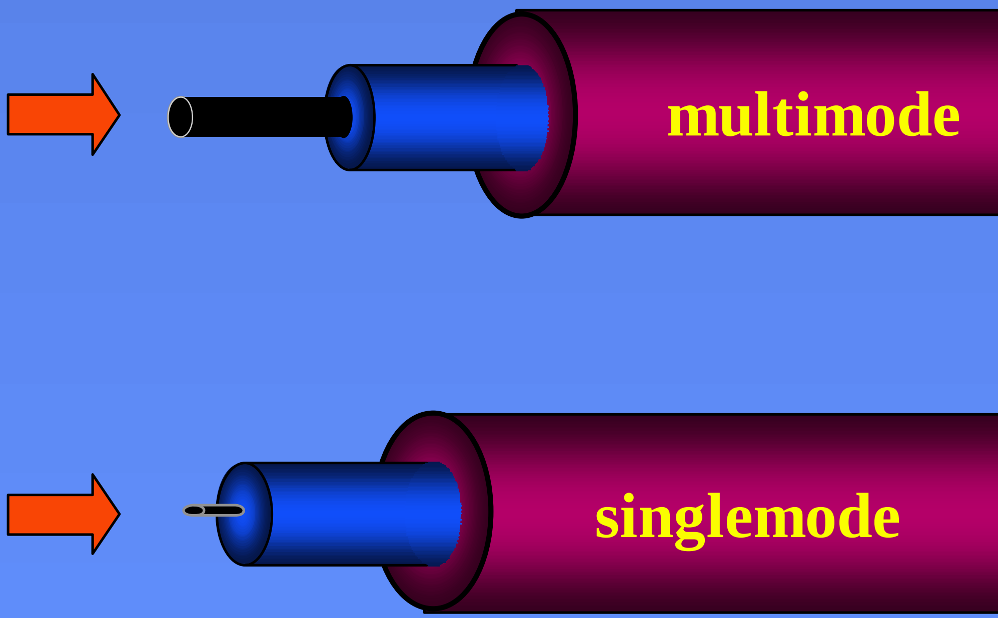
Human Hair

1 Micron
0.001 mm
1 µm
0.000039 in.

1 micron = 1 µm

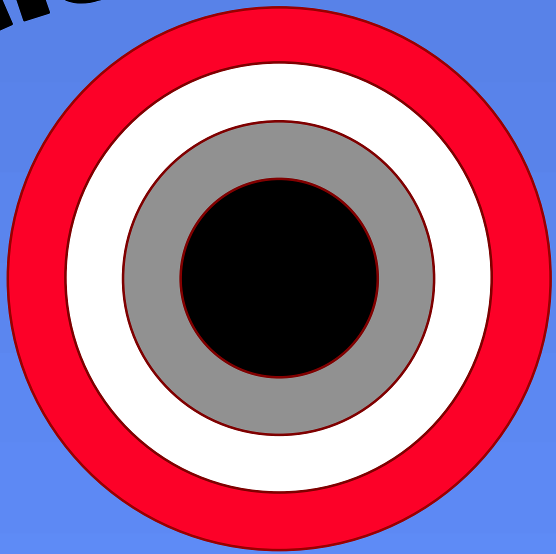
Core Size (microns or µm)

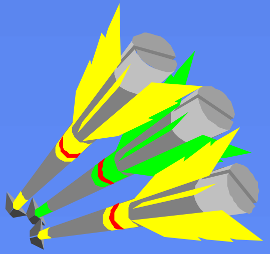


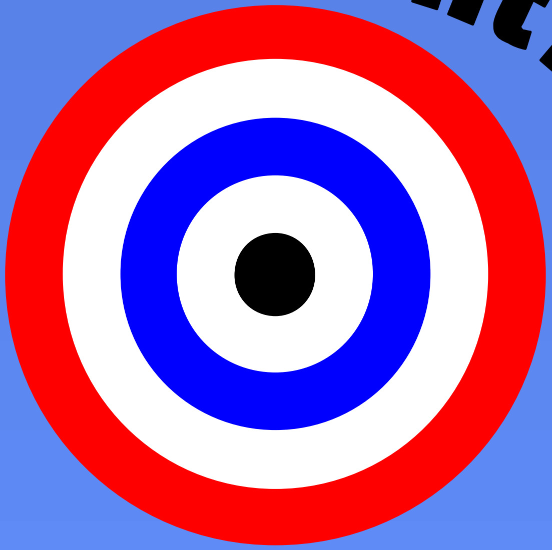


Note that the core of the multimode fiber is 5X to 7X bigger than the singlemode core

Which core is easier to hit?







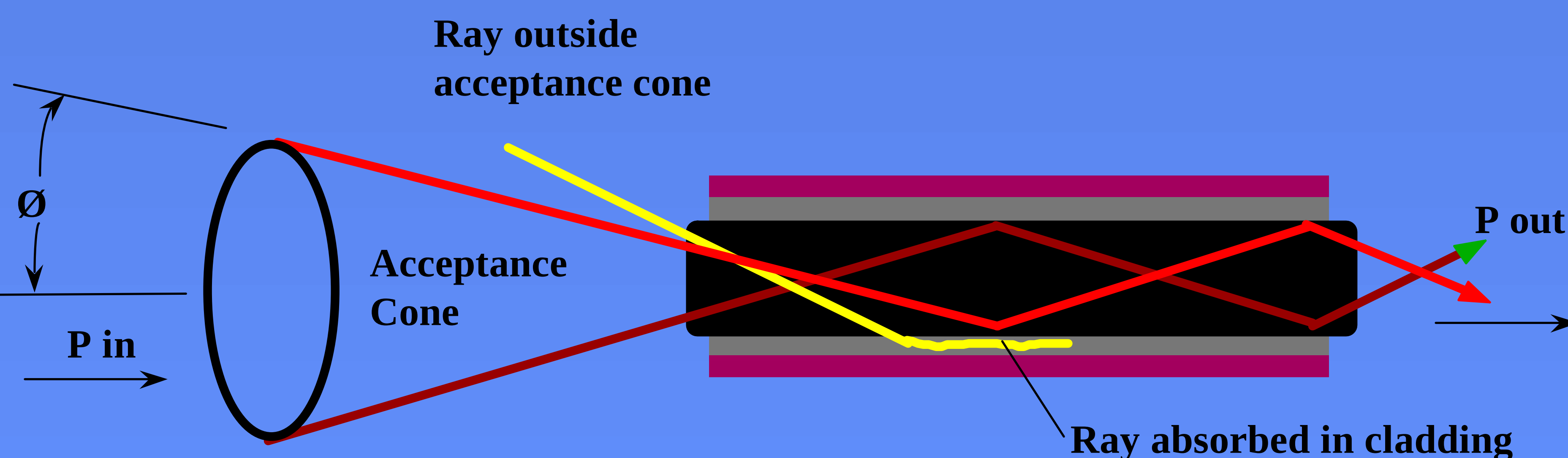
Multimode has
a large fiber core

Singlemode has
a tiny fiber core

A singlemode system requires a LASER with a focused light ‘beam’
..... higher costs because the ‘aim’ has to be more accurate

Numerical Aperture (NA)

(the bigger the NA, the easier to launch light into)



NA = SIN Ø

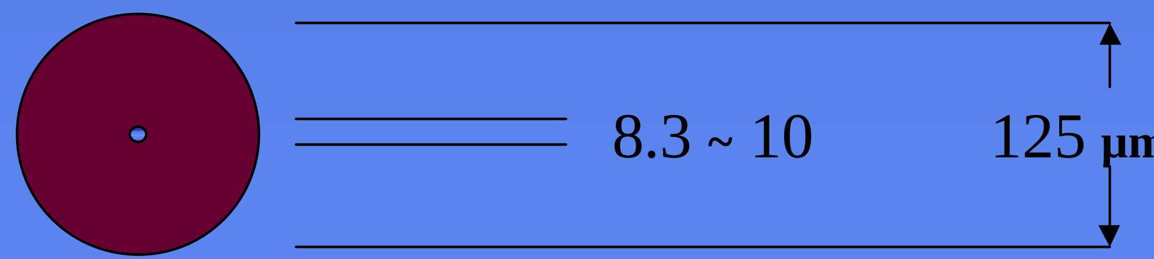
(Ø = Cone Half Angle)

Examples:
62.5/125 - 0.275 NA
~9/125 - 0.13 NA

Single-Mode vs. Multimode - Summary

Single-Mode

8.3~10 µm Core
125 µm Cladding
.13 Numerical Aperture



Multimode

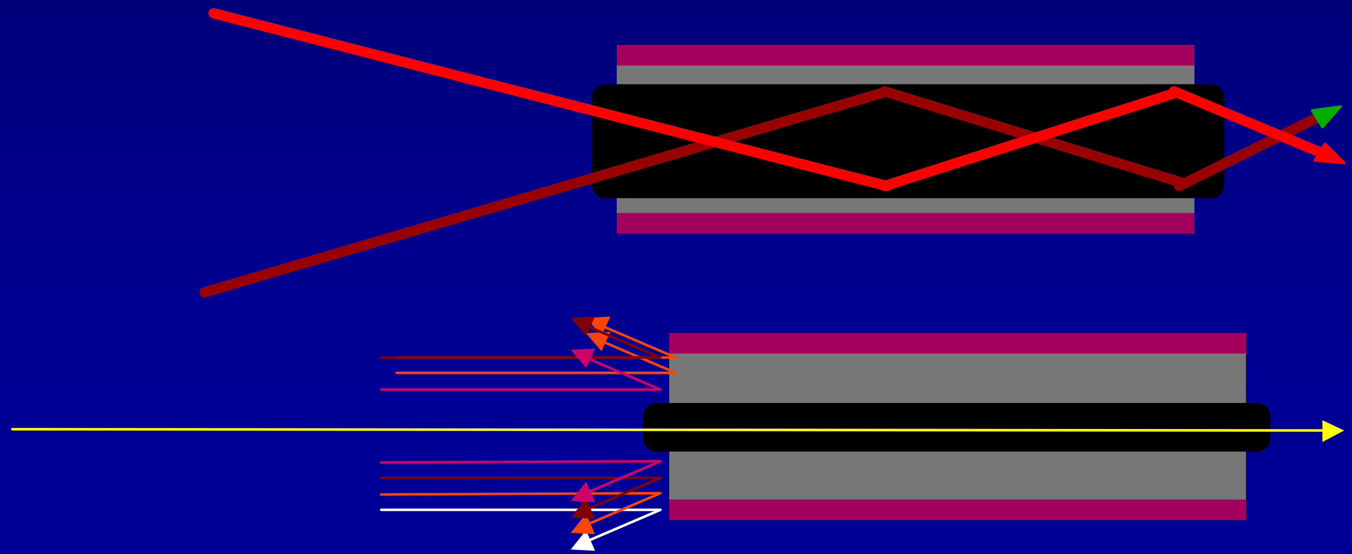
62.5 µm Core
125 µm Cladding
.275 Numerical Aperture

50 µm Core
125 µm Cladding
.20 Numerical Aperture

What is a mode?

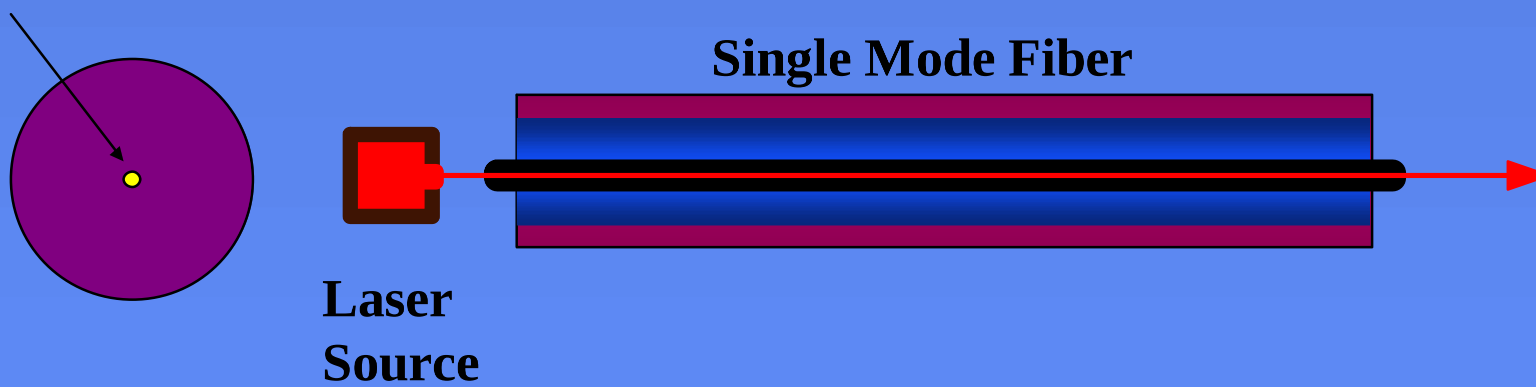
"When light is contained in a waveguide , it will propagate only in a limited number of ways (modes)……like rubber balls bouncing in a tube"

"Singlemode light transmission occurs when the core is so small, only one ray (mode) of light can propagate down the tube"



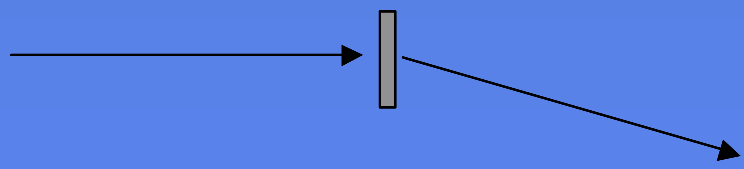
Single Mode Fiber

Mode field diameter is between 8.3~10 µm……an exact number not required



A Laser produces a tight beam of light rays, all with the same propagation mode, resulting in longer distances & higher data speeds through the ~ 10 micron glass core

Index of Refraction

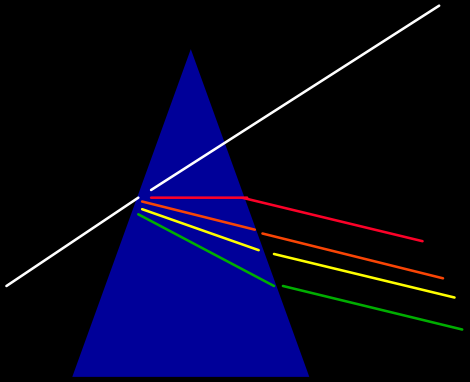


Light slows (and bends) as it passes through different mediums (examples: air to water).

The index of refraction (n) is the ratio of the speed of light in a vacuum (c in v) to its velocity in a material (c in m)

$$n = \frac{\text{c in vacuum}}{\text{c in material}}$$

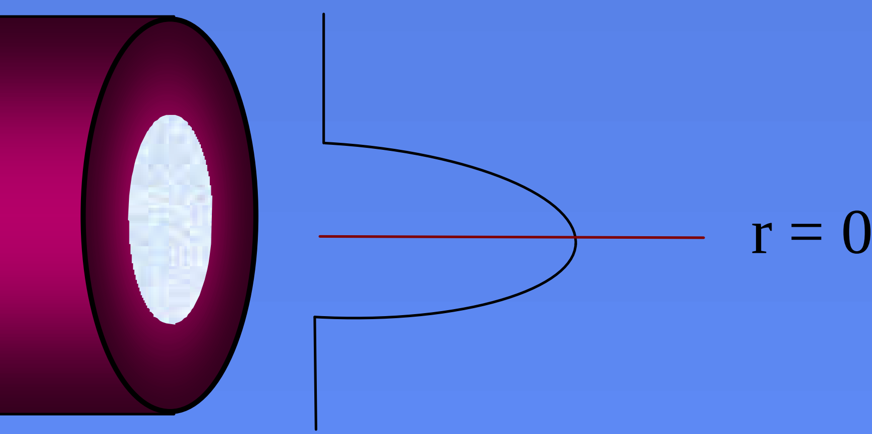
Material	Index (n)	Light Speed (km/s)
Vacuum	1.0	300,000
Water	1.33	225,000
Glass	1.5	200,000
Diamond	2.0	150,000



Sunlight refracted as it passes through droplets of water results in a rainbow…the simplest example of the chromatic nature of light

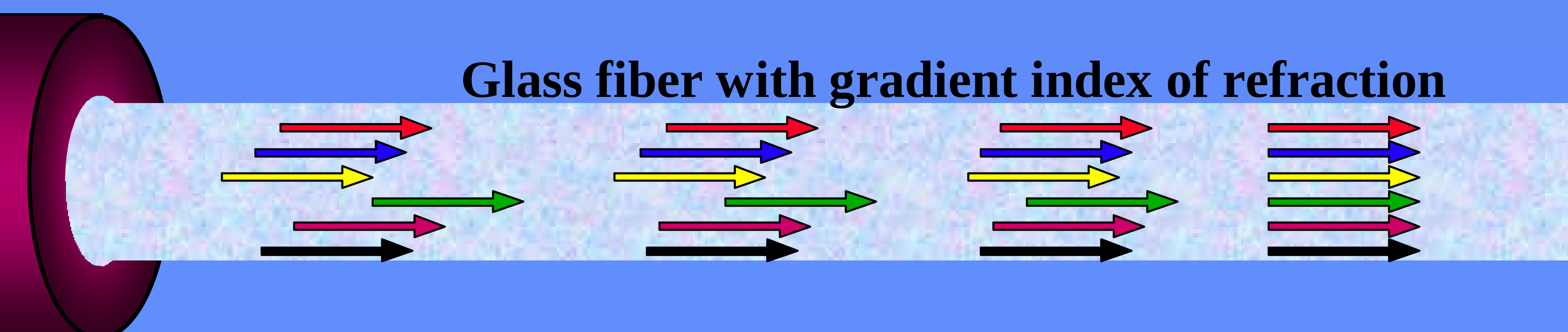
The bent light has different speeds, hence its location in the rainbow.

Index of refraction profile of multimode gradient index glass

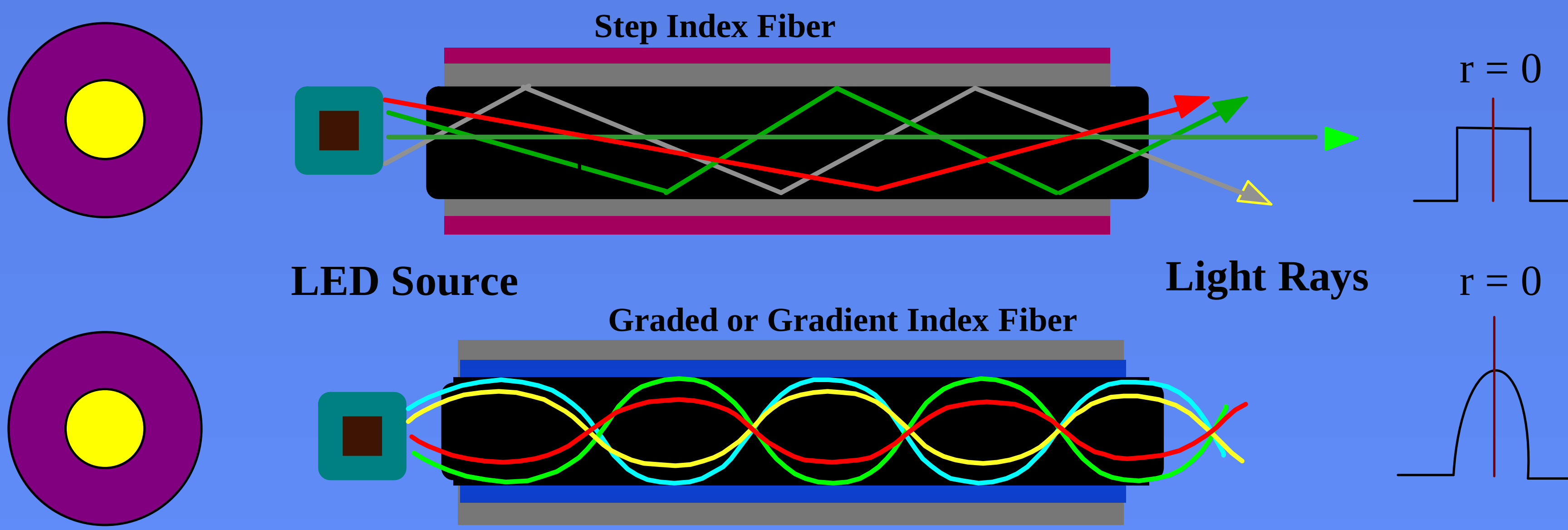


"Gradient Index Glass slows down the faster light modes and speeds up the slower ones"

Glass fiber with gradient index of refraction

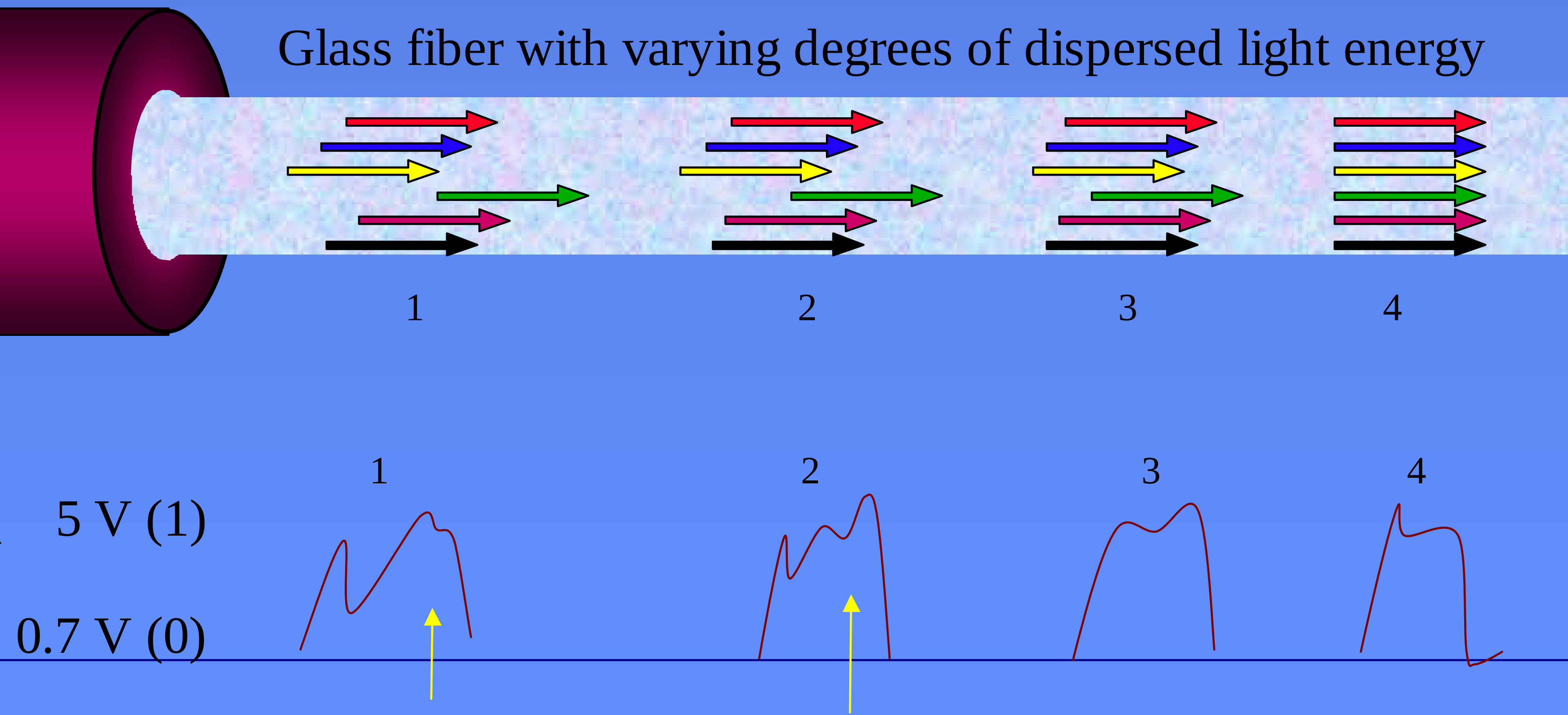


Gradient Index vs Step Index Glass



•The index of refraction of gradient glass is changing from the center of the core to the edge of the core, constantly “bending” the light rays and focusing the beam.

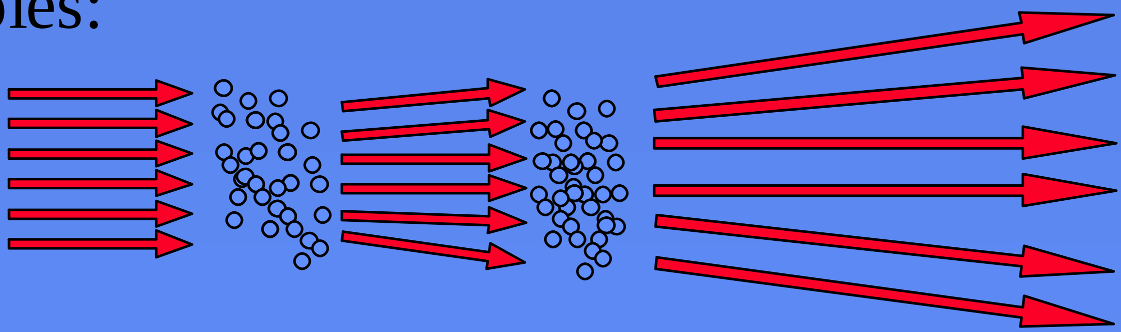
Impact of "dispersed light energy" arrival on data waveform



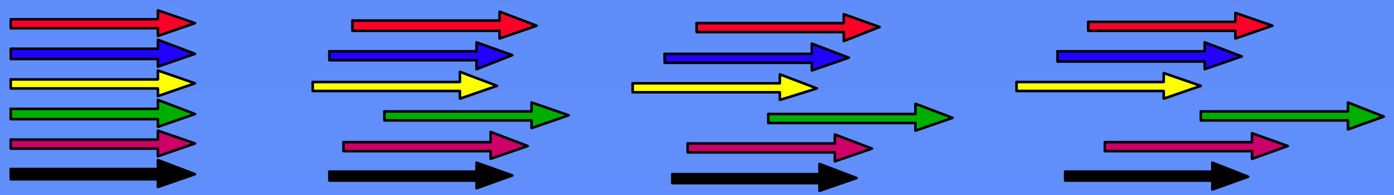
System cannot distinguish a "0" from a "1"

Dispersion

- There are several dispersive factors: modal, chromatic, material, waveguide & profile
- Examples:

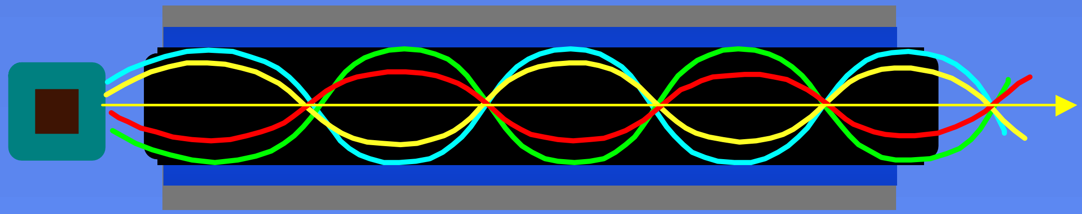


Dispersion due to glass impurities



Chromatic dispersion

Multimode Dispersion
the 2 primary causes



Modal dispersion is due to the path that the modes travel in the glass.

Chromatic dispersion is due to the various wavelengths of light traveling in the fiber.

Dispersion is the reason why multimode fiber has limited bandwidth!

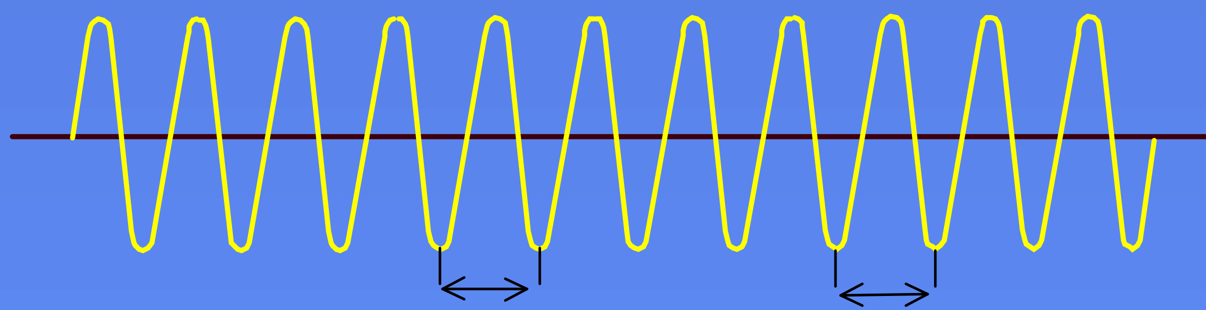
Fiber Performance Attributes

- **Attenuation**
- **Bandwidth**

} **These are the key attributes to specify**

- **Fiber Geometry**
- **Numerical Aperture (NA)**
- **Proof Test**
- But first, an explanation of the optical windows…………..

Wavelength



This distance would be called a wavelength (λ)

1 cycle

Definitions:

* Frequency = cycles per second

* Wavelength = linear distance traveled by a wave in one cycle

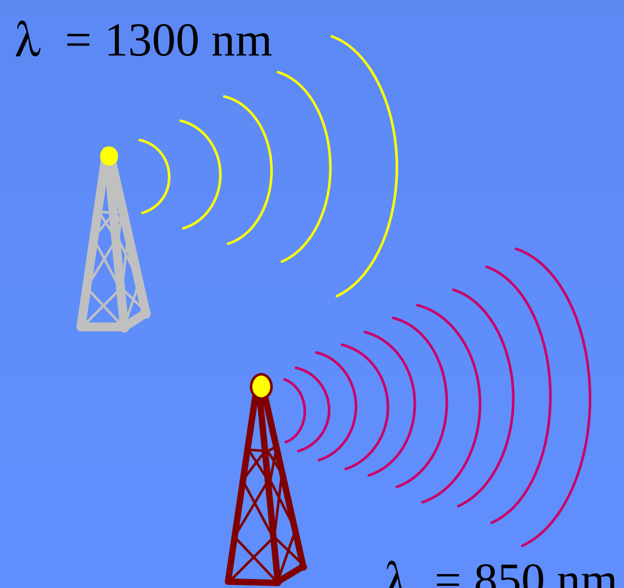
Examples:

Typical SHORTWAVE optical fiber wavelength is 850 nanometers.

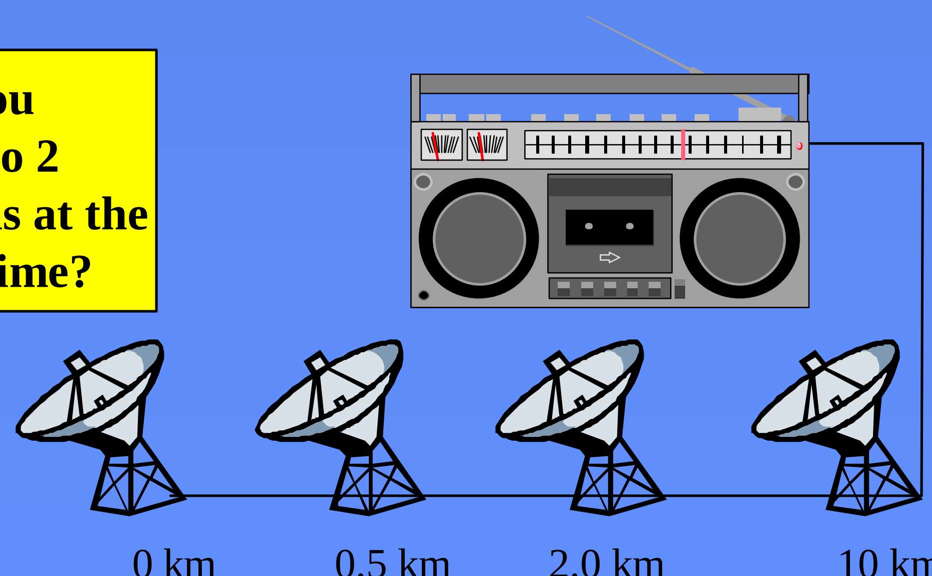
Typical LONGWAVE wavelength is 1300 nanometers

Imagine 2 radio stations broadcasting simultaneously……………

- Attenuation equates to signal loss over distance
- Bandwidth measures the data volume & clarity vs distance
- 2 radio stations equates with two transmission "windows"



Can you listen to 2 stations at the same time?



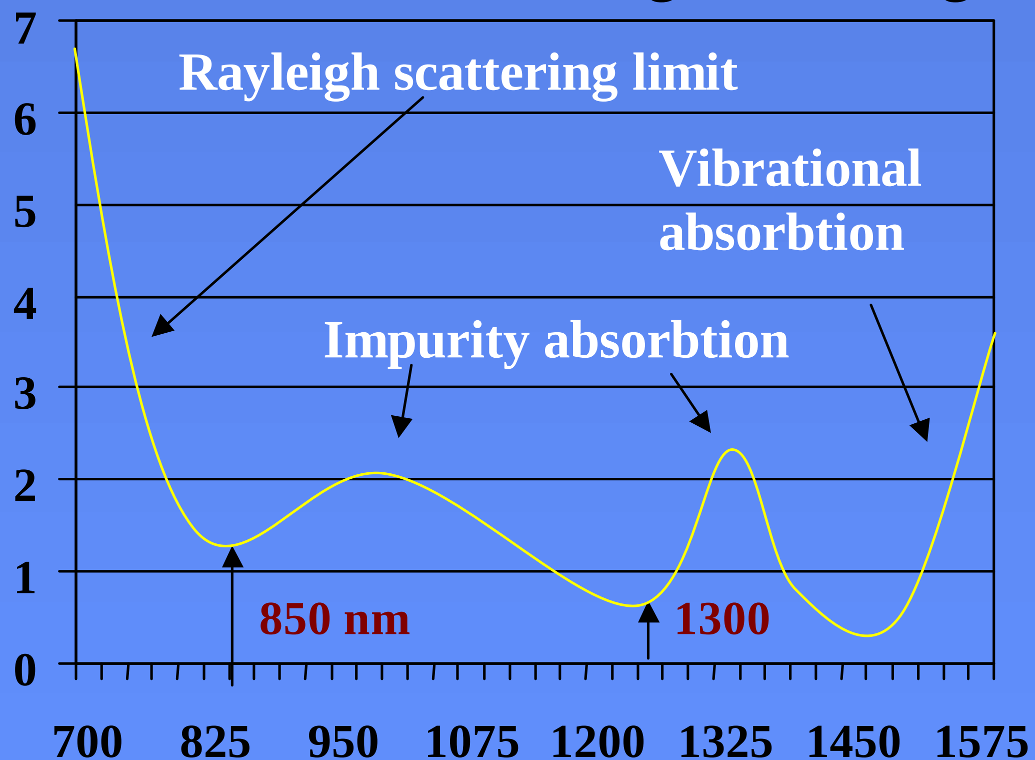
Are both stations equally clear vs distance?

Why are 850 & 1300 nm used as the standard multimode wavelengths?

Attenuation vs Wavelength - Silica glass

Attenuation (dB/Km)

(Signal Loss over distance)

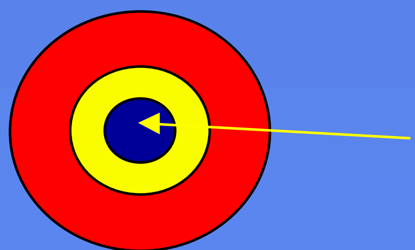


Wavelength of Light (nm)

The lowest signal loss in silica glass occurs at these two points

Glass Windows (Wavelength)

Simplex Fiber Cable



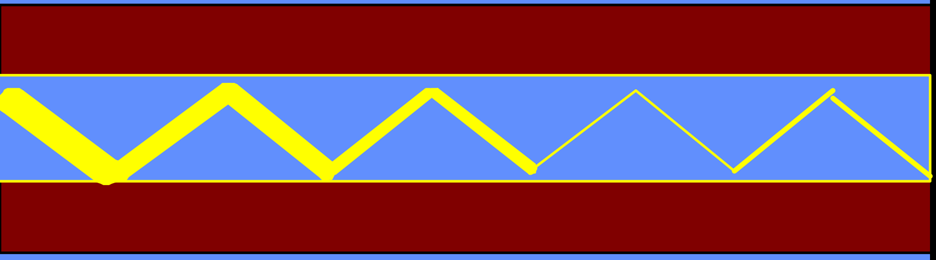
Discussing the attenuation and bandwidth of this optical fiber is meaningless unless we know what wavelength of light we are using

EXAMPLES

Fiber Type (core/clad)	Wavelength (nanometers)	Min.Bandwidth (MHz-Km)	Attenuation (dB/Km)
50 / 125	850 / 1300	400 / 400	3.0 / 1.3
62.5 / 125	850 / 1300	160 / 500	3.75 / 1.5
8.3 / 125	1300 / 1550	n / a	0.55 / 0.45

Fiber Performance Attributes

- **Attenuation**
  - The loss of signal magnitude with respect to distance.
  - Conventional Wavelengths: **850nm & 1300nm, Multimode**
    1300nm & 1550nm, Single-Mode
  - For any data rate, loss remains constant at a given wavelength.
  - Attenuation is measured in dB/Km at a specified wavelength (example: 3.0 dB/Km @ 850 nm wavelength)



The optical signal weakens as it propagates down the fiber; therefore, the received signal is less than the transmitted.

Fiber Performance Attributes

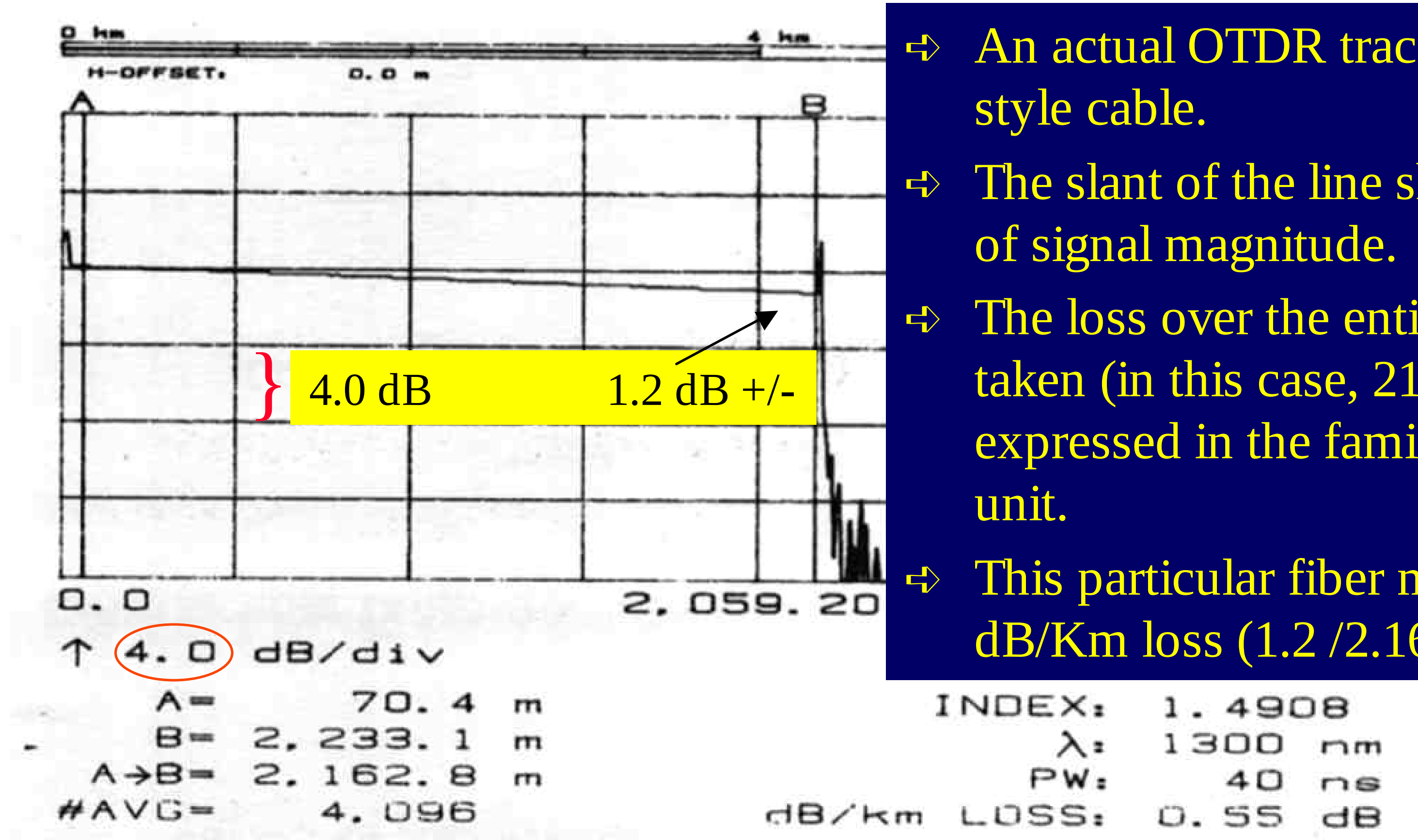
- **Attenuation**
  - Low attenuation values are desired for any wavelength; i.e., the lower the attenuation value, the more signal is received.
  - Typical attenuation values for network cables exceed standard requirements by a significant margin. These values are for FDDI grade, 62.5/125μm fiber.

Wavelength	TIA /EIA-568A (maximum)	IBM ACS (typical)	IBM ACS (~ 50% of product)
850nm 1300nm	3.75 dB / km 1.5 dB / km	3.5 dB / km 1.0 dB / km	2.9 dB / km 0.9 dB / km

IBM ACS fiber typically offers 33% better attenuation than TIA/EIA or ISO requirements.

Fiber Performance Attributes

◆ Attenuation

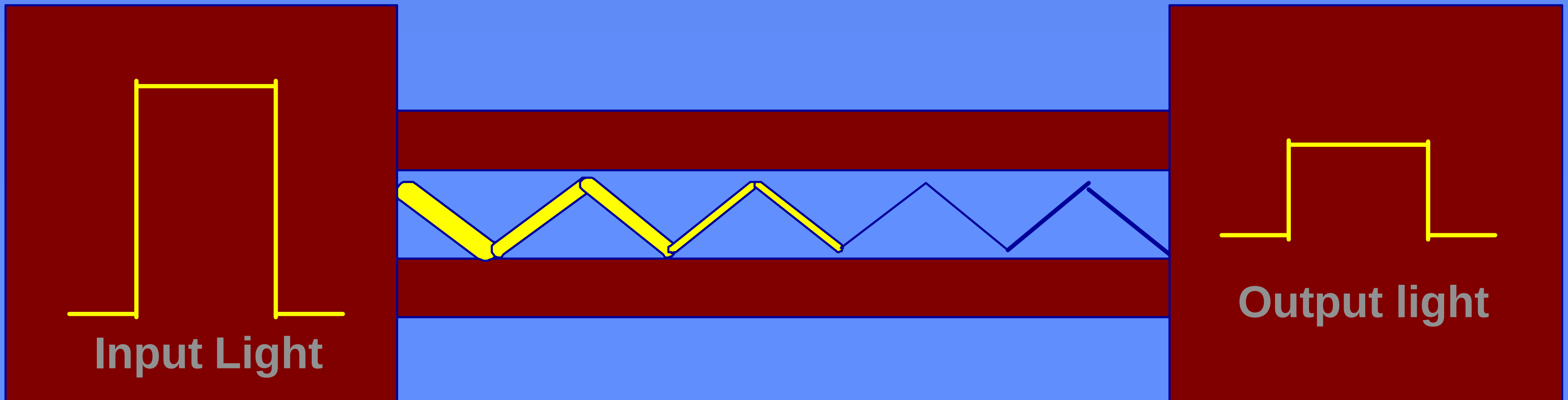


- An actual OTDR trace on an IBM style cable.
- The slant of the line shows the loss of signal magnitude.
- The loss over the entire length is taken (in this case, 2162.8m) and expressed in the familiar dB/Km unit.
- This particular fiber measured 0.55 dB/Km loss (1.2 /2.16=0.55 dB/km)

Attenuation (Loss)

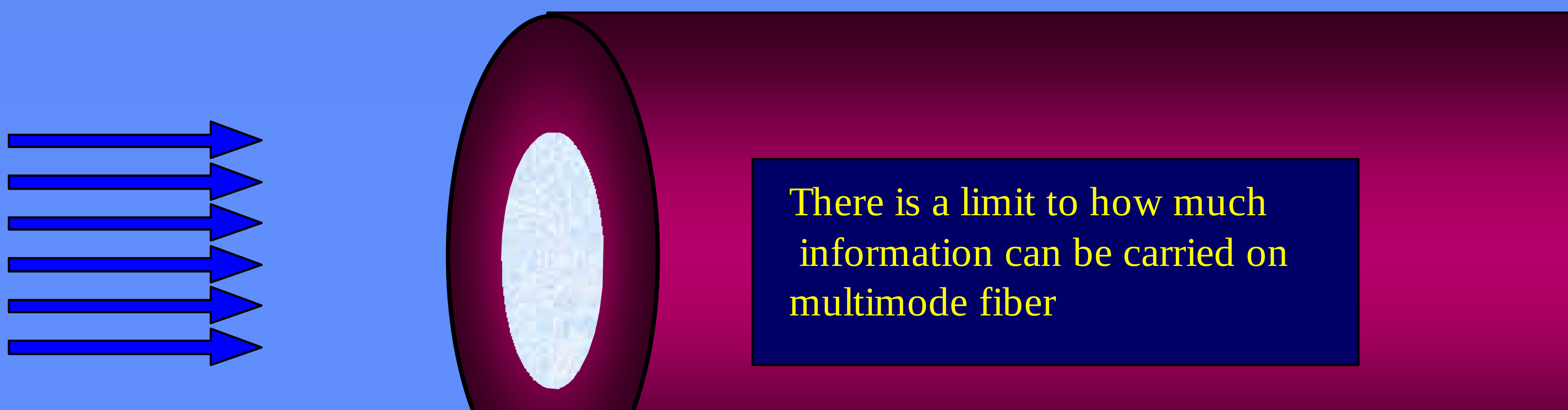
- **Fibers inherently lose light**
  - **At the connection or splice points (connection loss)**
  - **Throughout the length of the glass (cable attenuation)**
- **Examples of loss & impact on transmission of light**

-3 dB	=	50% Light Transmission (50% power loss)
-10 dB	=	10% Light Transmission (90% power loss)
-20 dB	=	1% Light Transmission (99% power loss)



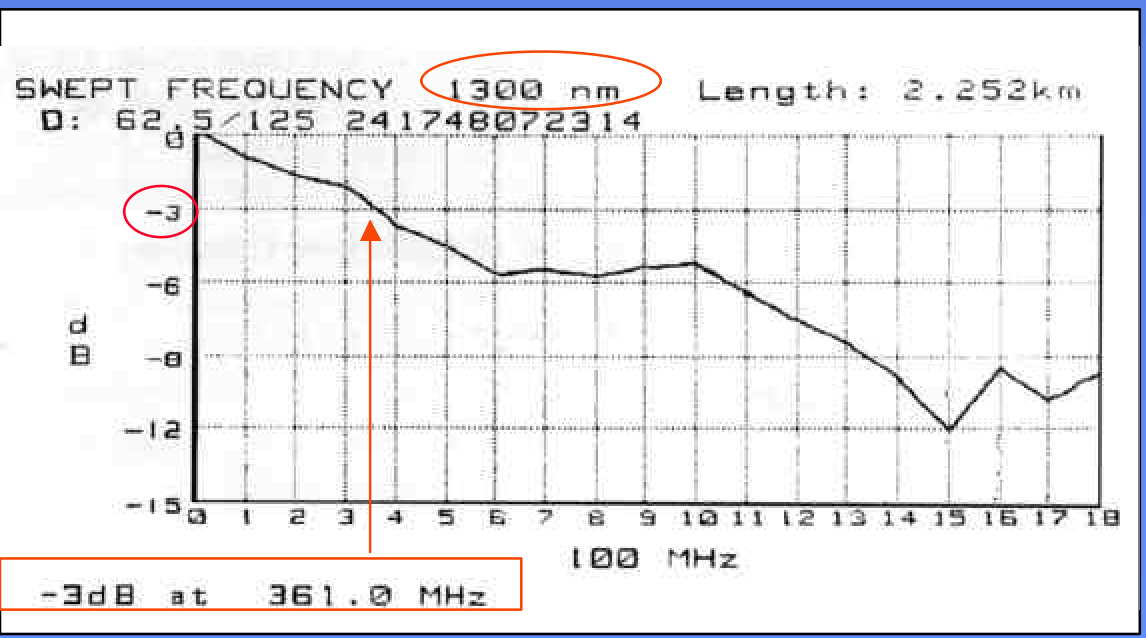
Fiber Performance Attributes

- Bandwidth * Length Product (called Bandwidth)
  - The carrying capacity of fiber is defined in terms of the bandwidth*length product (MHz-Km).
  - Conventional Wavelengths: 850nm & 1300nm, Multimode
  - Dispersion, the major factor limiting capacity, increases with frequency (the higher the frequency, the smaller the wavelength).



Fiber Performance Attributes

◆ Bandwidth (normalized)



- An actual bandwidth trace on an IBM style cable showing the declining power vs. increasing frequency.
- The -3dB power level falls at 361 MHz. The length of this cable is 2252m.
- Bandwidth is calculated: (2252/1000)*361=813 MHz-Km

Note: Bandwidth is calculated as the point where power drops by 50% (-3 dB), normalized to 1 Km (1000 m)

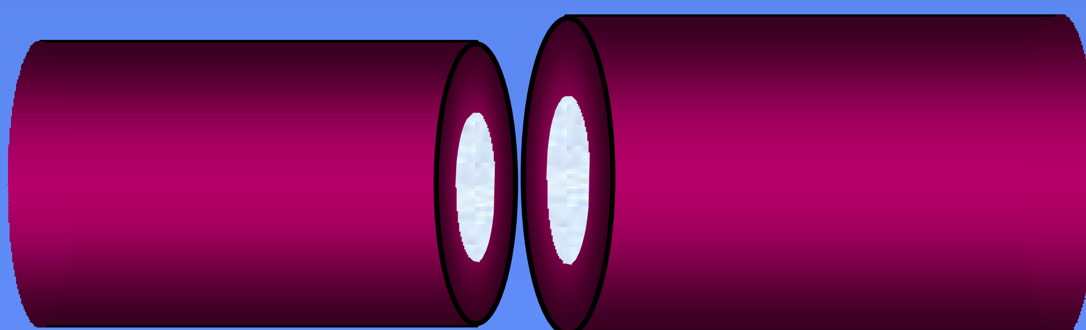
Fiber Performance Attributes

- **Bandwidth**
  - **A higher bandwidth value is desired for any wavelength; i.e., higher bandwidth means increased carrying capacity and higher possible data rates.**
  - **IBM's listed bandwidth values meet all standard requirements, but typical values are significantly higher. These values are for FDDI grade, 62.5/125µm fiber.**

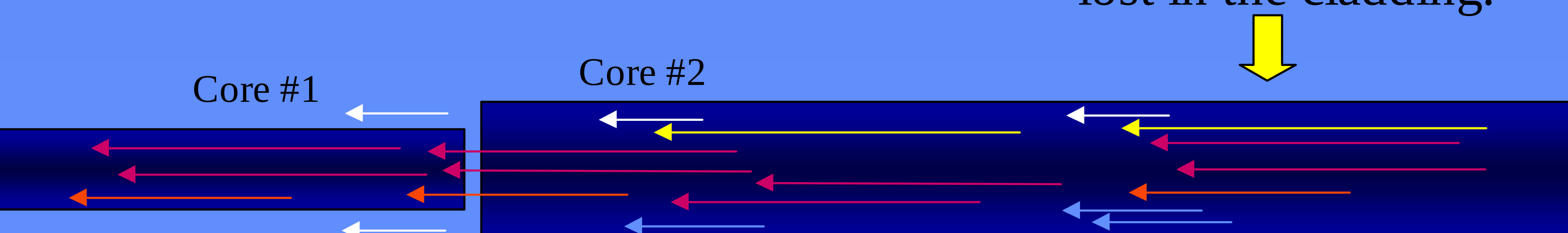
Wave length	TIA / EIA-568A (minimum)	IBM Standard (minimum)	IBM (typical)
850nm 1300nm	160 MHz*km 500 MHz* km	160 MHz*km 500 MHz*km	200 MHz*km 800 MHz*km

Bandwidth is typically not measured in the field but by glass supplier

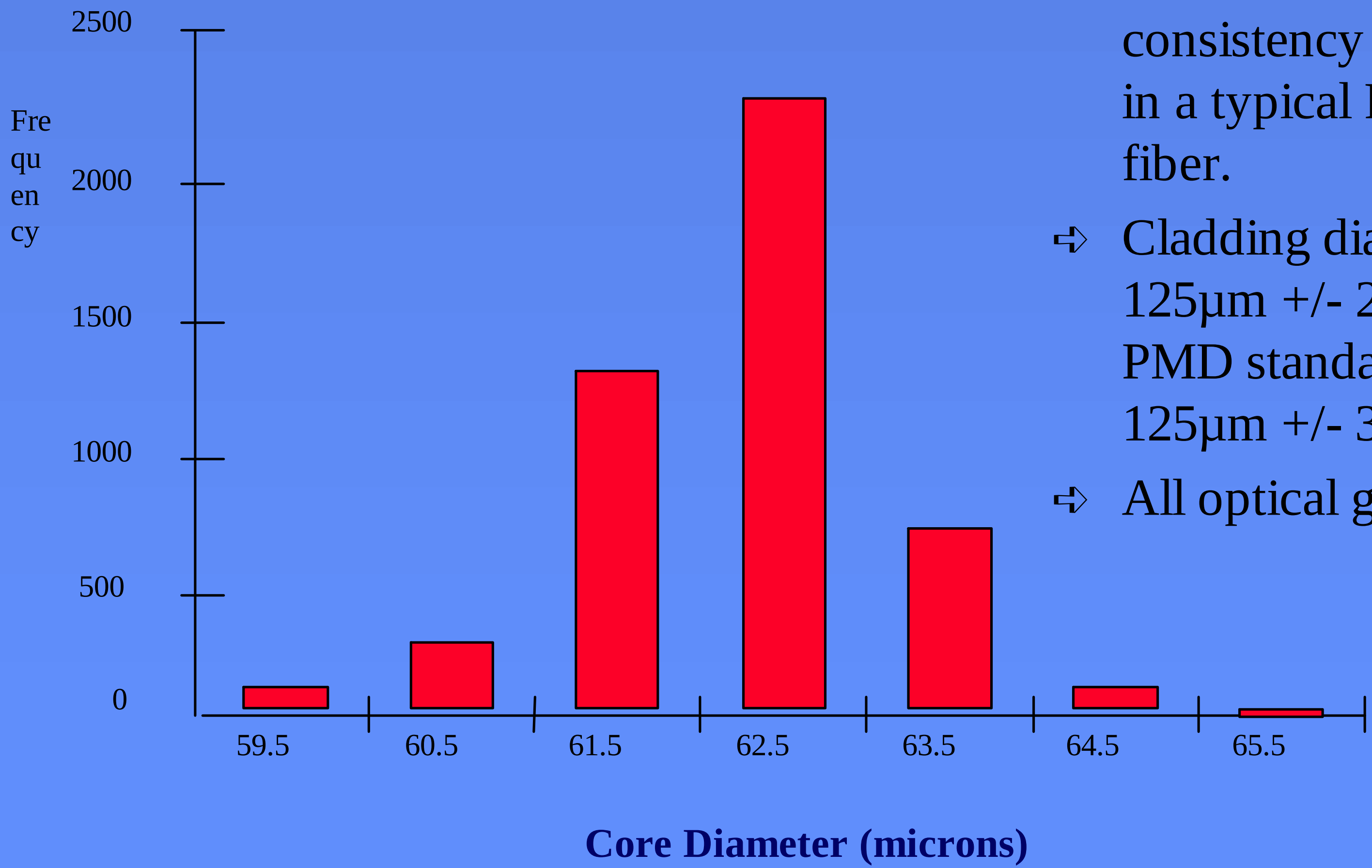
- **Fiber Geometry (core & cladding tolerances)**
  - Tight tolerances assure uniformity and the ability to mate different components in a system.
  - Most optical loss in a typical system link is due to connector losses from mismatched fiber sections.



Note that these 2 fibers are not exactly the same size. The result is that light is lost in the cladding.



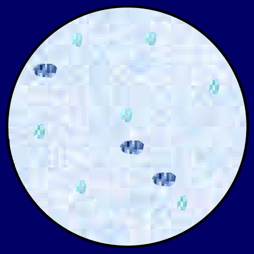
◆ Fiber Geometry



- 62.5µm is the core size diameter for most standard premises networks.
- This chart demonstrates the consistency of the core diameter in a typical FDDI grade IBM fiber.
- Cladding diameter is held to 125µm +/- 2µm. The FDDI-PMD standard only requires 125µm +/- 3µm.
- All optical glass is not equal!

Fiber Proof (Strength) Testing

- Proof testing is a measure of the strength of the glass while under strain
- Optical glass may have microscopic bubbles or flaws which may result in failure over time, especially when exposed to moisture
- Ensure that glass is purchased from a reputable glass supplier with 100% proof testing



Optical Glass Considerations Final Points

- Buying optical glass is similar to buying a diamond
  - Optical Glass is sorted & sold by grade (performance)
    - low quality glass is very inexpensive
    - If a fiber cable is very inexpensive, verify that the optical glass quality meets industry standards
  - Assembly / cable users must select the grade of glass to be used
    - Most customers don’t realize that there is more than just attenuation & bandwidth to specify

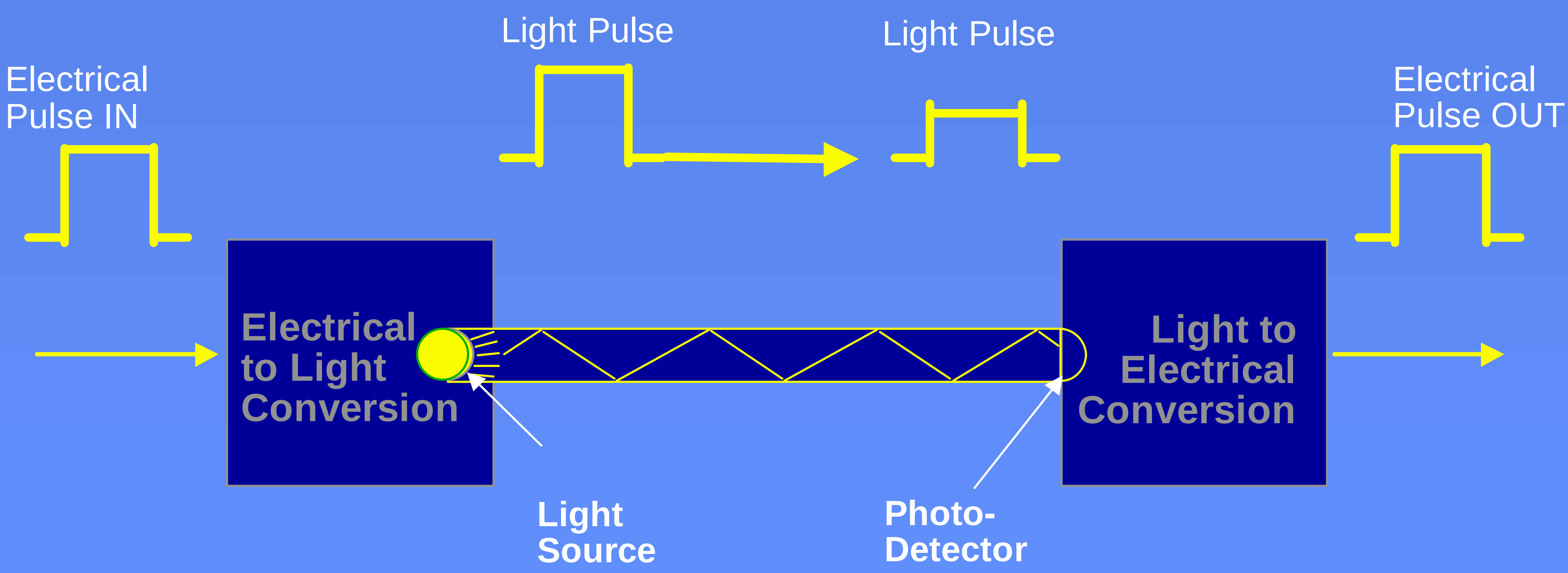
10 Minute Break

Optical Communication Terminology Basics

OFFICIAL LASER WARNING

A Laser may bore a hole through your eye but the theory will bore you to tears

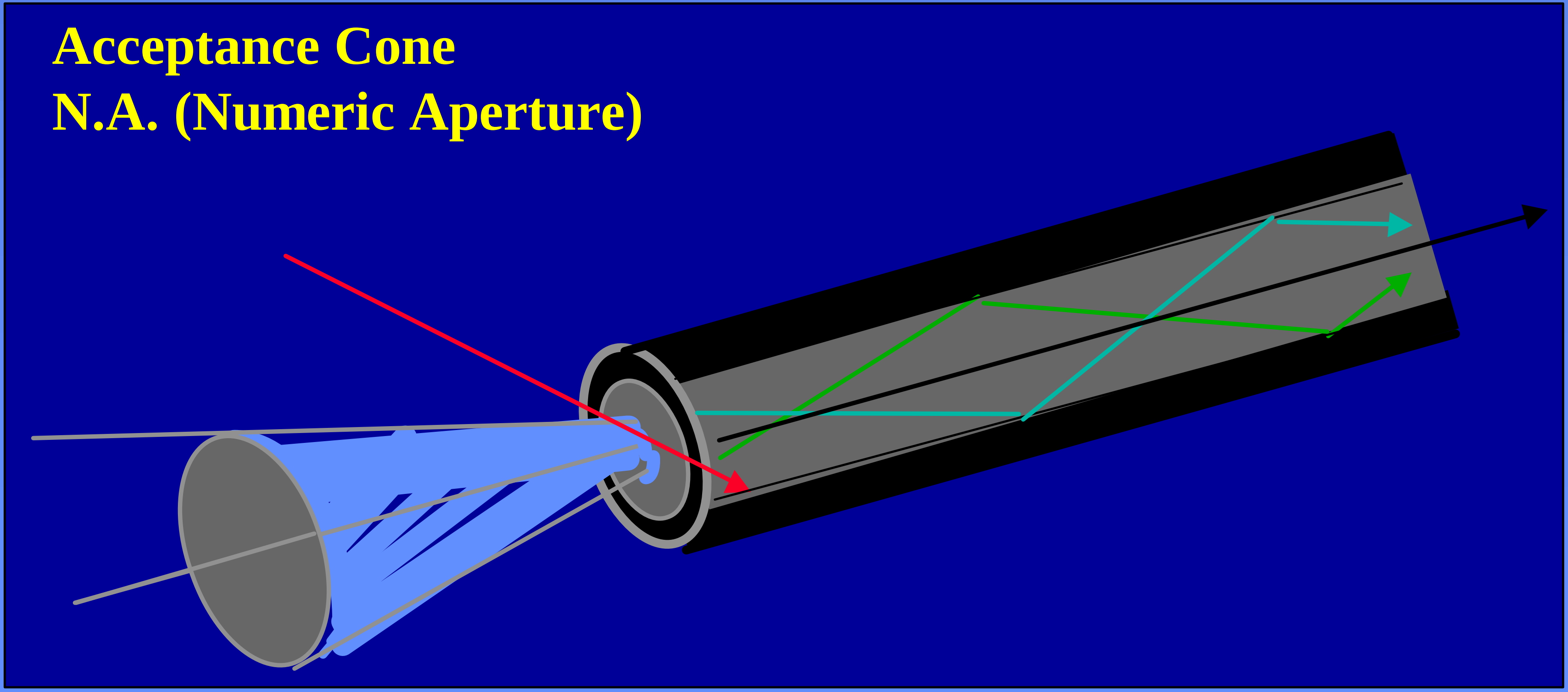
Communication Fundamentals



Electrical Pulse In = Electrical Pulse Out

What is the transmitter's prime directive?

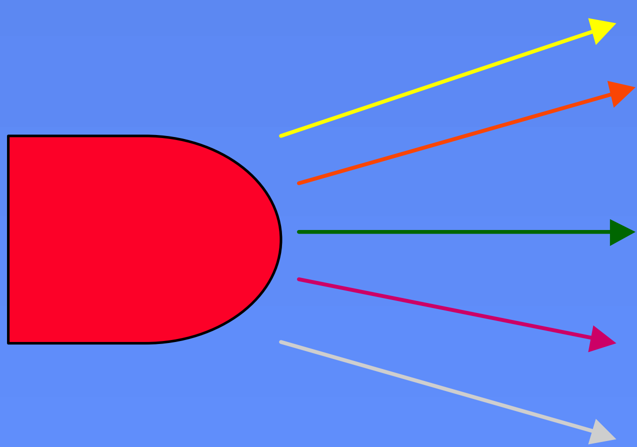
Answer: To get light into the acceptance cone of the glass



Light Sources

VCSELs are new!!

- Types
  - Light Emitting Diodes (LEDs)
  - Conventional Lasers
  - VCSELs (Vertical Cavity Surface Emitting Lasers)

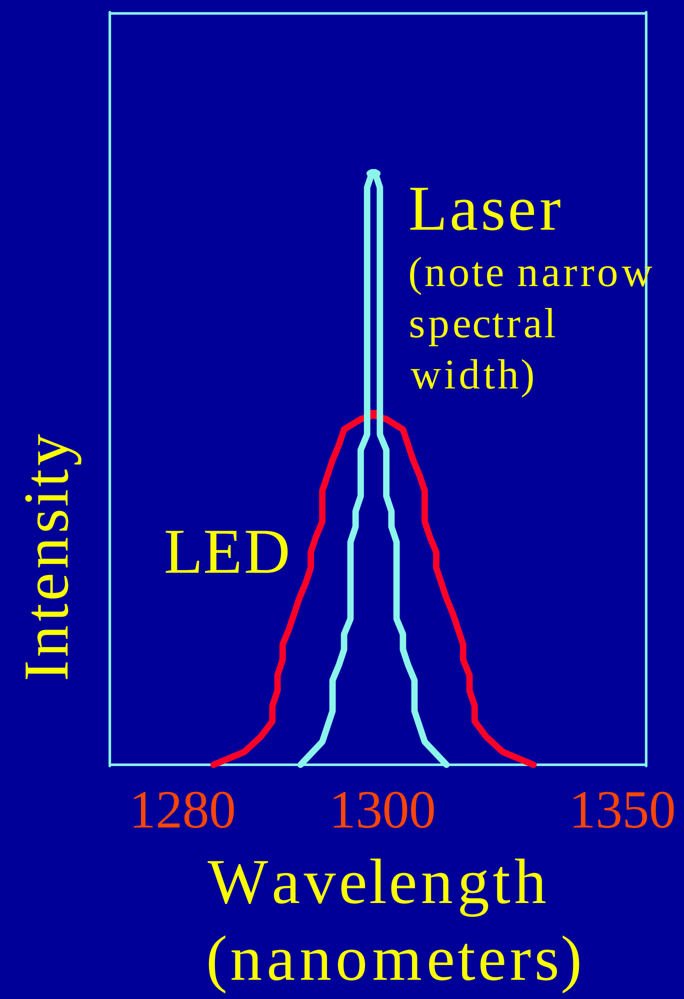


LEDs = wide light spread, many wavelengths

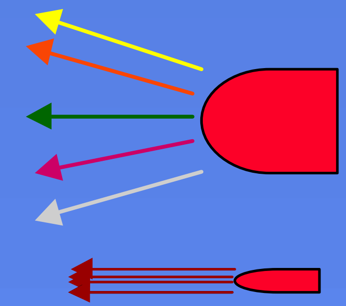
LASER = tightly focused beam, few wavelengths

Transmitters

- Light source characteristics
  - Center wavelength
    - May have nominal value of:
      - 850 nm
      - 1300 nm
      - 1550 nm
  - Spectral width
    - Wide spectral width leads to broadening of light pulses (Dispersion)



Transmitters

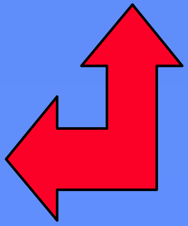


- LED
  - Low cost, low power, distances < 2 Km
  - Unfocused beam, many light modes
  - 850 & 1300 nm wavelengths - multimode
- “Telco” Laser
  - High cost, medium to high power, distances > 5 Km
  - Focused beam, very few or one mode
  - 1300 nm common, 1550 nm increasing
- VCSELs (Vertical cavity surface emitting laser)
  - Can be used for single and multimode -very new…
  - Currently 850 nm wavelength
  - Much lower cost to manufacture & test than std. lasers

Transmitters

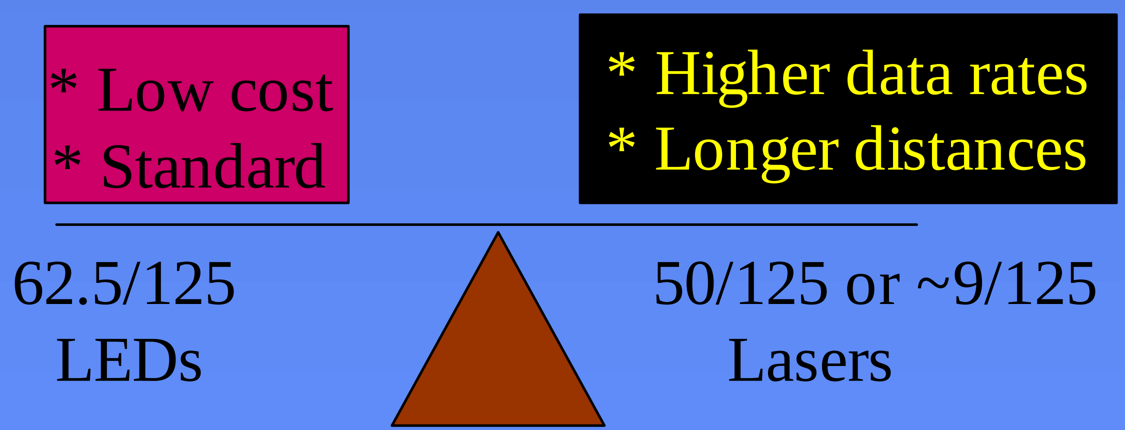
- Reflection & laser sources
  - Reflections of laser “light” can impact the communication link
  - Reflections in Laser links are the result of poor connectorization & polishing of the end face

Most Lasers require excellent connector surface finishes for proper light launch



Speed vs Distance vs Cost

Source + Receiver + Glass = Working Link

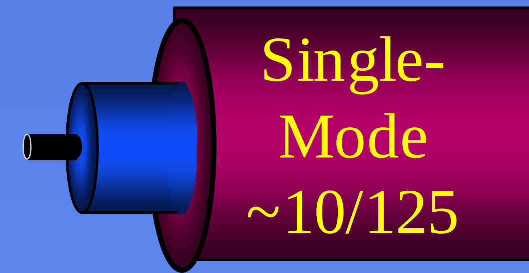


Light Sources & Glass Choices……

Example: FibreChannel options

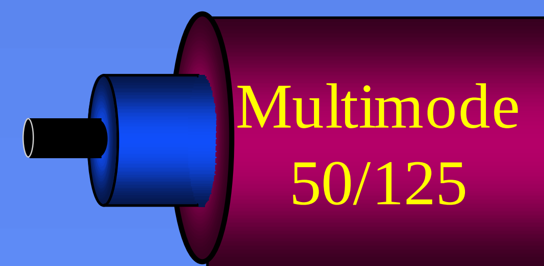
9~10 micrometer singlemode fiber

100 MB/s	up to 10 km	1062.5 Mbaud	1300 nm laser
50 MB/s	up to 10 km	531.25 Mbaud	1300 nm laser
25 MB/s	up to 10 km	265.6 Mbaud	1300 nm laser



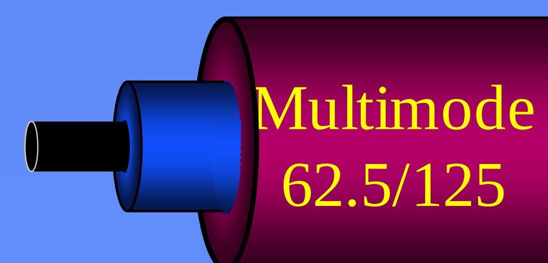
50 micrometer multimode fiber

100 MB/s	up to 0.5 km	1062.5 Mbaud	850 nm laser
50 MB/s	up to 1 km	531.25 Mbaud	850 nm laser
25 MB/s	up to 2 km	265.6 Mbaud	850 nm laser
12.5 MB/s	up to 10 km	132.8 Mbaud	1300 nm LED



62.5 micrometer multimode fiber

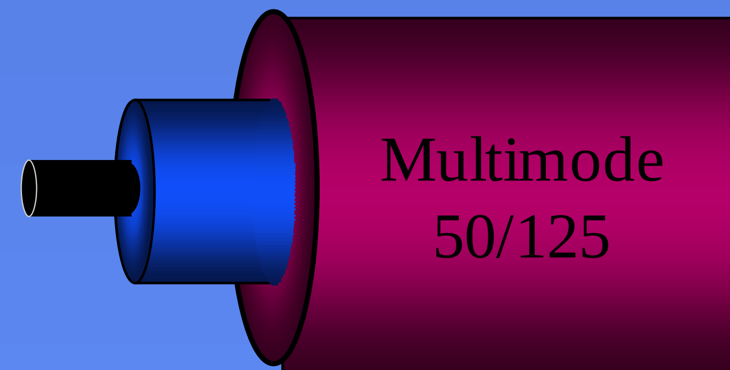
50 MB/s	up to 600 m	531.2 Mbaud	850 nm laser
25 MB/s	up to 1 km	265.6 Mbaud	1300 nm LED
12.5 MB/s	up to 2 km	132.8 Mbaud	1300 nm LED

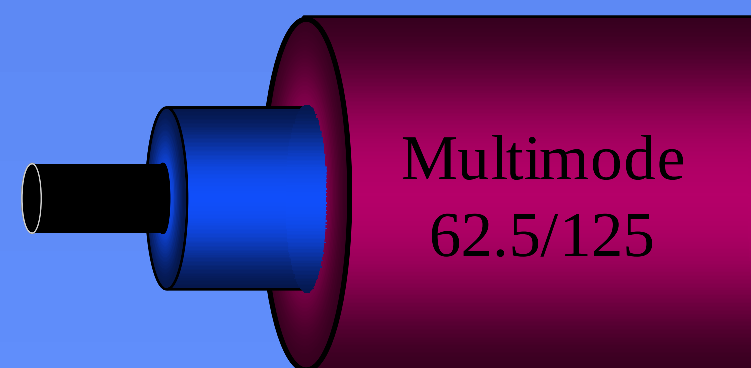


Note: these are examples only…not every option is shown

50 versus 62.5 core glass fiber

- 50 / 125 glass
  - more difficult launch
  - high bandwidth available at 850 or 1300 nm
    - >500 MHz-Km is common
  - new VCSEL laser technology operates at the 850 nm window…not 1300 nm
    - **see next 2 slides**
- 62.5 / 125 glass
  - most popular multimode glass supported by many standards (ISO 11801 etc.)
  - good 1300 nm bandwidth..>500 MHz-Km
  - poor performance @ 850 nm
    - see next 2 slides





Bandwidth

The battle between 62.5 & 50

Glass Type	Bandwidth @ 850 nm	Bandwidth @ 1300 nm
50/125	500 MHz-Km	500 MHz-Km
62.5/125	*160 MHz-Km*	500 MHz-Km

This is the problem….the new VCSELs (low cost lasers) only operate at the 850 nm window…this B/W is too low!

Optical Fiber & Speed

- Industry standards prefer 62.5/125 glass
  - technical pressures are making 50/125 or singlemode look like better choices
  - there is no easy answer
    - stay with 62.5/125 for standardization…but sacrifice distance
    - go with 50/125 for performance and cost but sacrifice standardization
    - go for ~9/125 singlemode for speed and distance but sacrifice cost
- When Lasers $ = LED $, problem solved

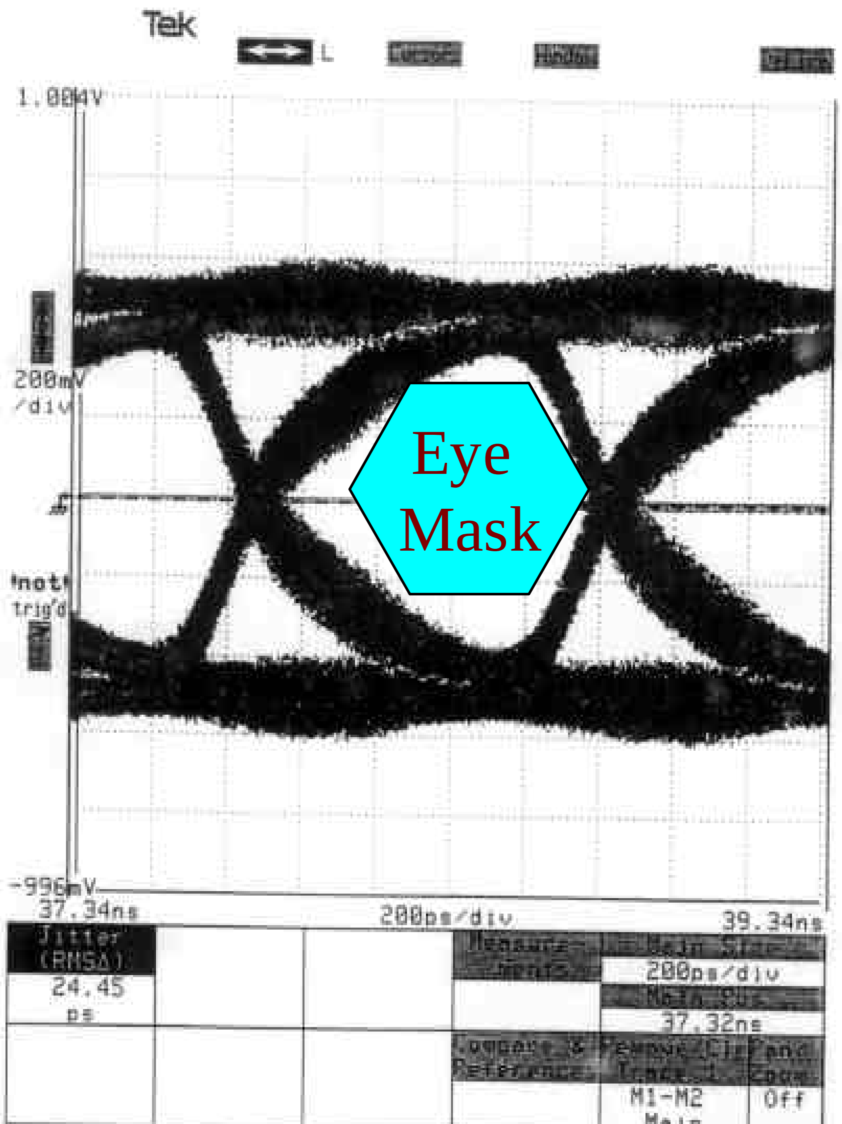
No easy decisions

Fiber Performance Attributes

- Attenuation (decibels per Kilometer…dB/Km)
  - **Low attenuation values are desired for any wavelength; i.e., the lower the attenuation value, the more signal is received.**

Glass Type (market available)	attenuation @ 850 nm	attenuation @ 1300nm
Singlemode 9/125	n/a	0.7
Multimode 50/125	3.5	1.50
Multimode 62.5/125	3.75	1.50

Very little difference in attenuation between 50 & 62.5



The real technical question:

What fiber, source & receiver combination results in a good eye-pattern at the lowest cost?

Eye pattern tests indicate if the system can accurately detect 0s & 1s

The 4 Key Elements

- Decision #1
  - **What optical glass size?**
    - This usually means 62.5 / 125 multimode or 8.3 / 125 singlemode
    - However, 50/125 is a strong contender for 1 Gb/s +, Fibrechannel
- Decision #2
  - **What attenuation & bandwidth is needed?**
- Decision #3
  - **What is the transmission system?**
    - LED or Laser?
- Decision #4
  - **What cable features are needed for this application?**
    - Rodent protection, aerial messenger wire, duct or direct burial, indoor, flammability etc.
- **In the next section, we will examine decision #4**

Break

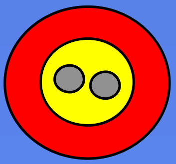
5 Minutes

Optical Cable Design

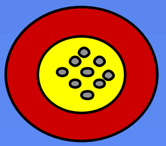
1. **Glass Type & Performance**
2. **Environmental**
3. **Flammability**
4. **Number of Fibers**
5. **Mixture of Fiber Types**
6. **Strength / Durability / Penetration**
7. **Active Devices - present & future**

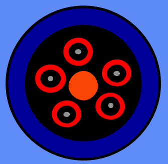
• 3 Styles of Cable Due to Environment

- Jumper or patch cable
  - Used for office outlet or patch panel to device cabling
  - Simplex (1 fiber) or duplex (2 fiber) styles
  - Designed for flex life, robustness, flexibility

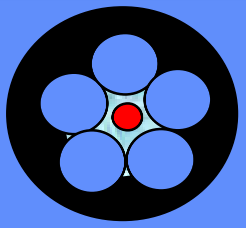


- Indoor cable
  - Light duty (fibers with overall Kevlar) is common
  - Heavy duty (individual Kevlar for each fiber) is rare
  - Flammability ratings available: Riser, Plenum, LSZH



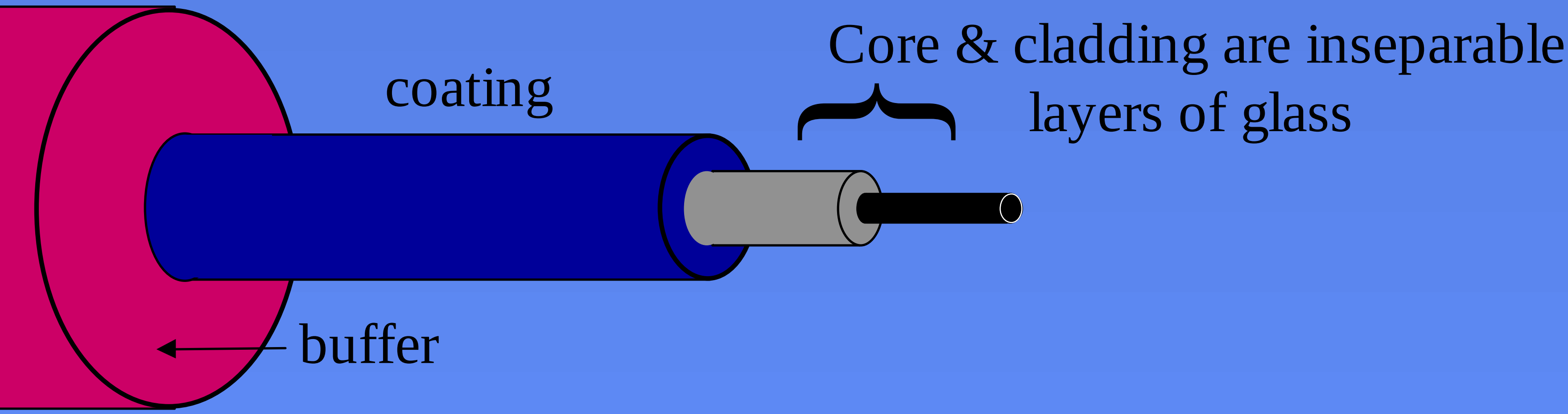


- Outdoor cable
  - Loose tube is most common style
  - Rodent protected, non-metallic styles available

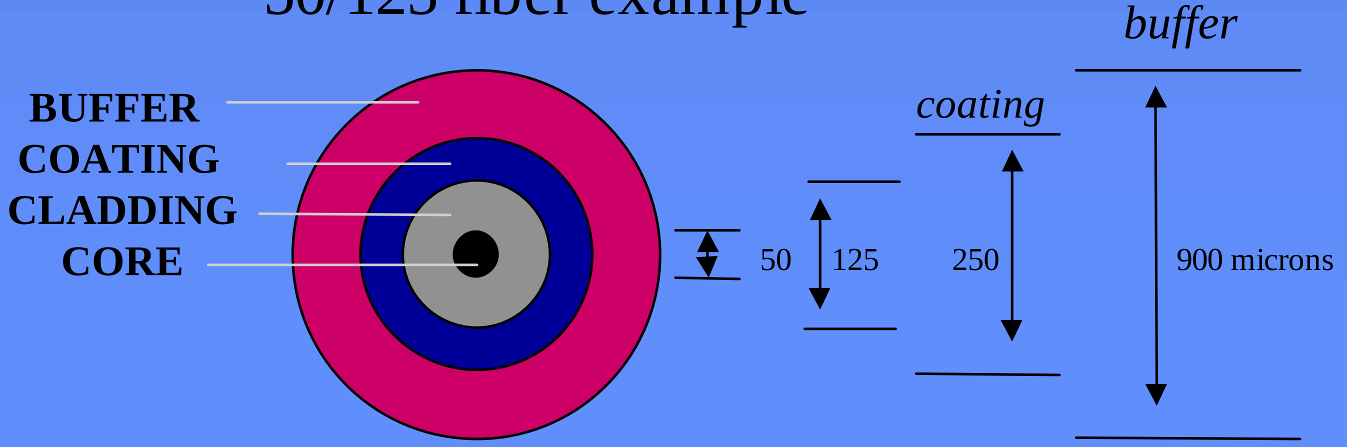


- Protecting the glass from outside elements & stress is important
  - glass cannot stretch
  - glass is flexible but cracks when bent too far
  - optical glass degrades in the presence of moisture
  - it can chip or crack with direct impact
- The next discussion topic: "How do we protect the glass fiber?"

The Coating & Buffer Layers

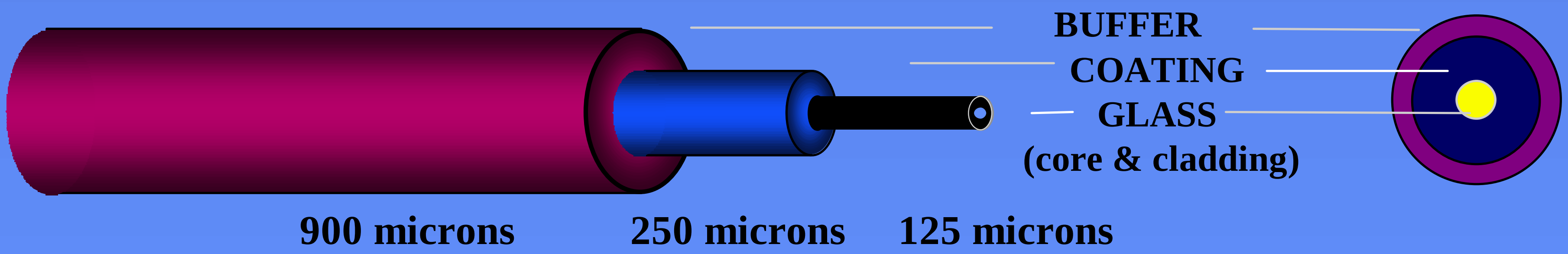


50/125 fiber example



The Buffer Layer

Note: A cable manufacturer will buy coated fiber and buffer it (if necessary) to meet the application requirements



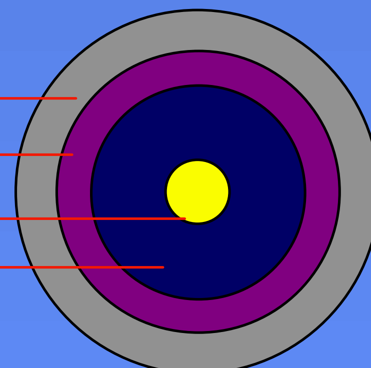
- **Buffer:** Protects fiber from user & installation stress - applied by cable mfr
- **Coating:** Protects fiber from moisture & user stress - applied by glass supplier
- **Glass:** Core & Cladding....Transmits light signal

Protecting glass in cable

Tight Buffered versus Loose Tube

Tight Buffered

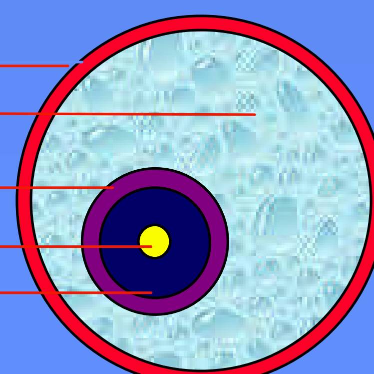
Buffer
Coating
Core
Cladding



95% of all indoor fiber cables are buffered designs

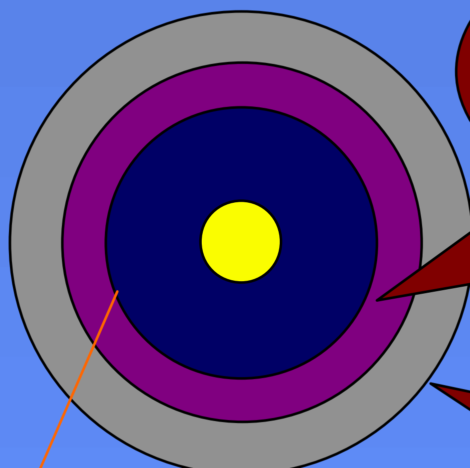
Loose Tube

Buffer Tube
Water Block Gel
Coating
Core
Cladding



Loose Tube commonly used for outdoor applications

Review: Protective Materials over Glass



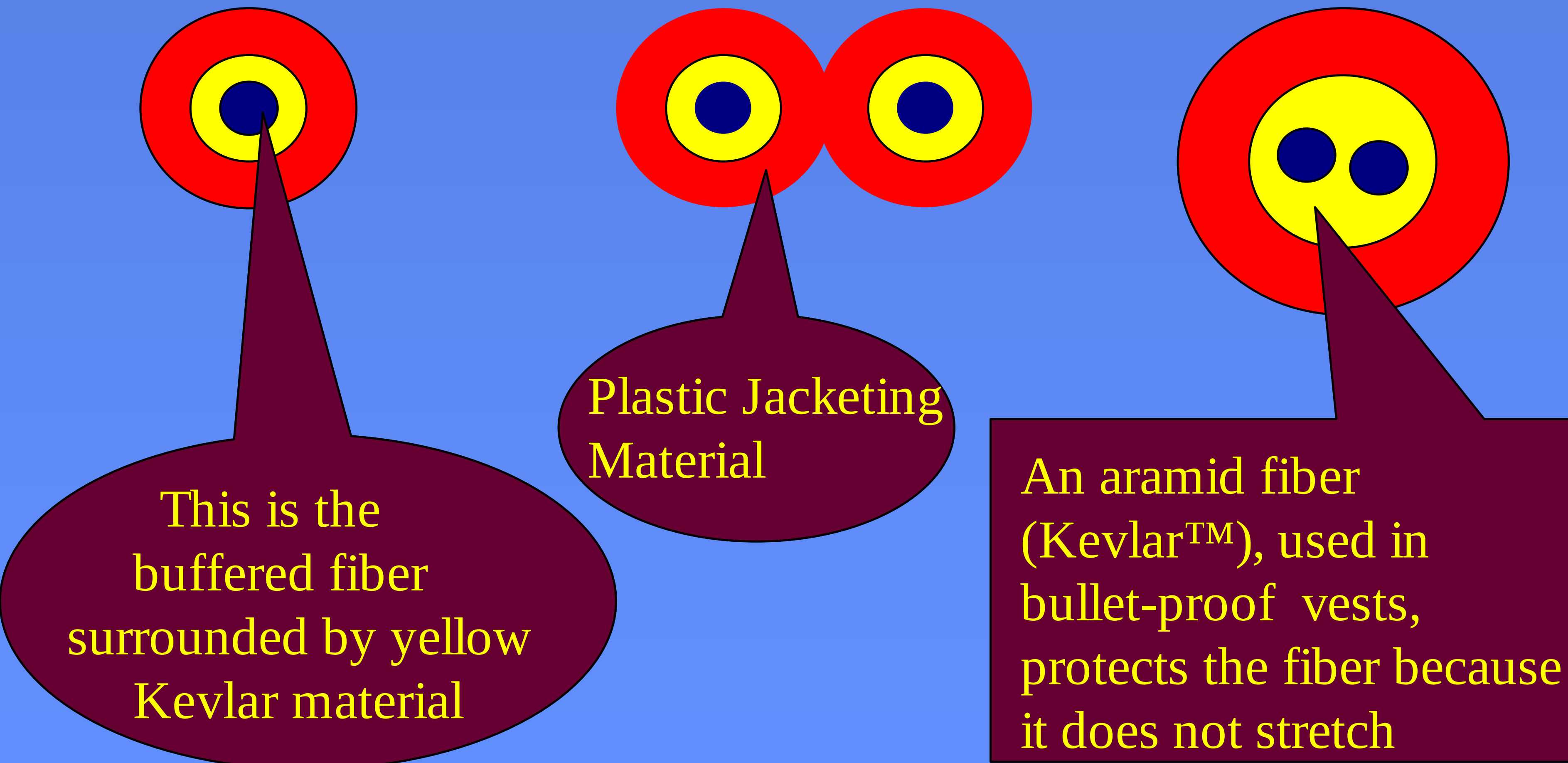
COATING - ACRYLATE -
applied by glass manufacturer
* prevents cracking

BUFFER - flexible plastic
*used for flex protection
*applied by cable supplier
* color coding

Note: core & cladding are both glass and cannot be separated

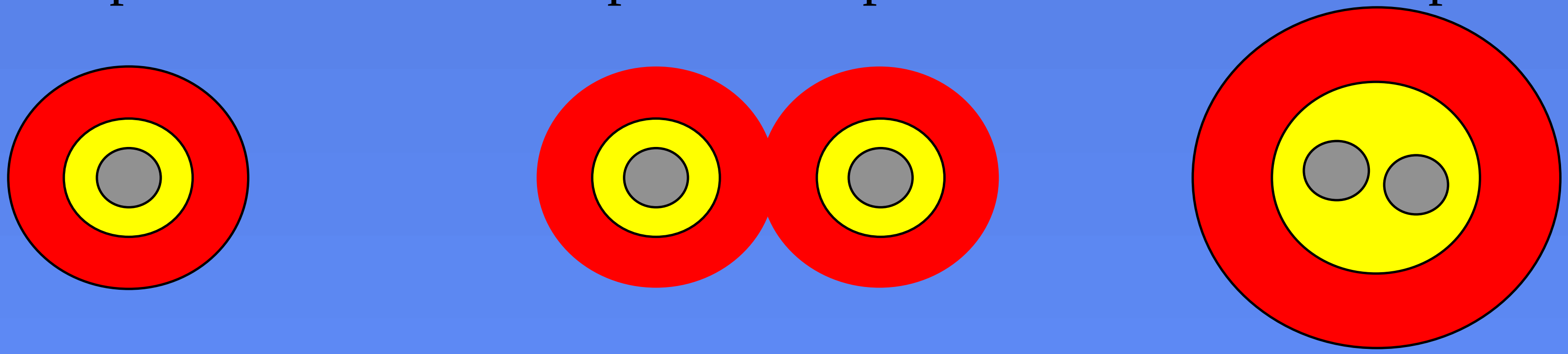
Common Buffered Cable Designs

Simplex | **“Zipcord” Duplex** | **Round Duplex**



Cable design vs glass type - Your choice

Simplex "Zipcord" Duplex Round Duplex

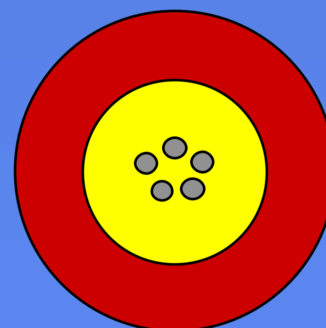


Fiber Type (core/clad)	Wavelength (nanometers)	Min.Bandwidth (MHz-Km)	Attenuation (dB/Km)
50 / 125	850 / 1300	400 / 400	3.0 / 1.3
62.5 / 125	850 / 1300	160 / 500	3.75 / 1.5
8.3 / 125	1300 / 1550	n / a	0.55 / 0.45

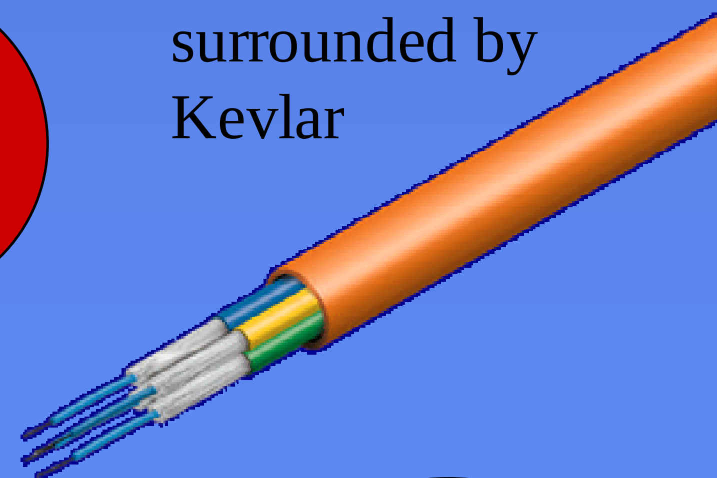
Typically these designs are not used for longer than 100 meters

Indoor cables

- Light duty designs
  - Used for installations with low - medium stress on cable
  - Low cost

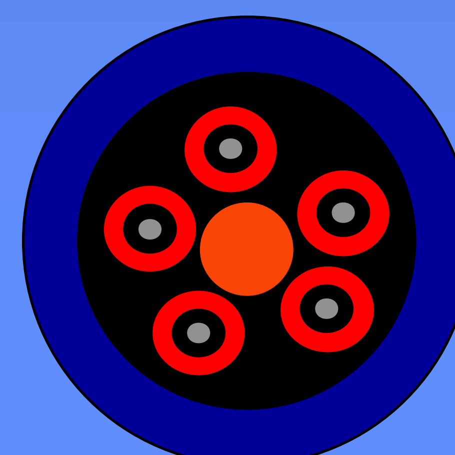


Multiple fibers surrounded by Kevlar



- Heavy duty designs
  - Used for industrial environments or where crush protection / tensile strength is needed

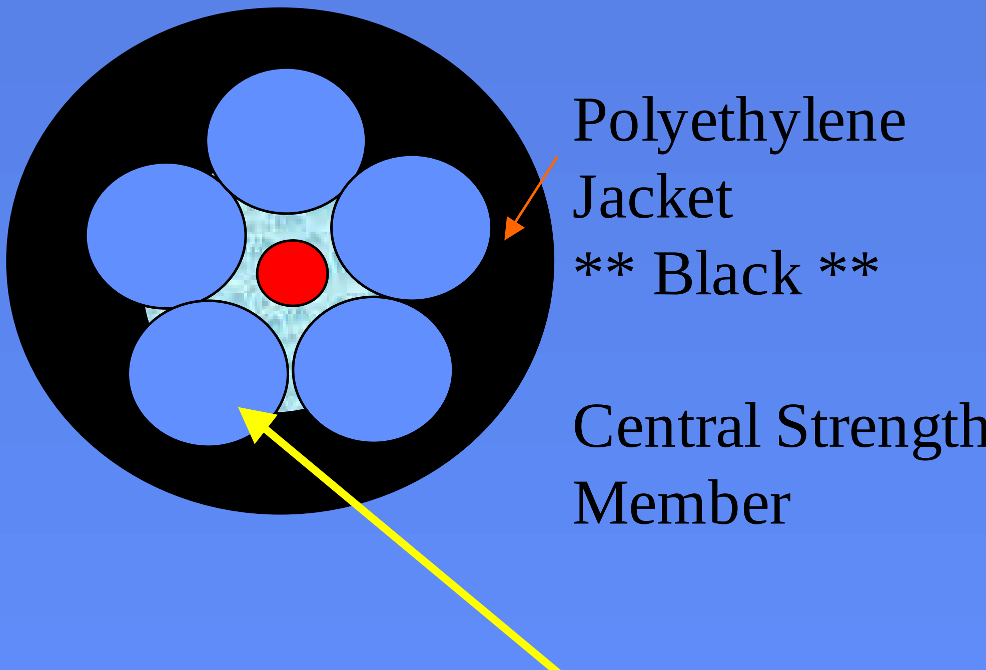
Multiple simplex cables under common jacket



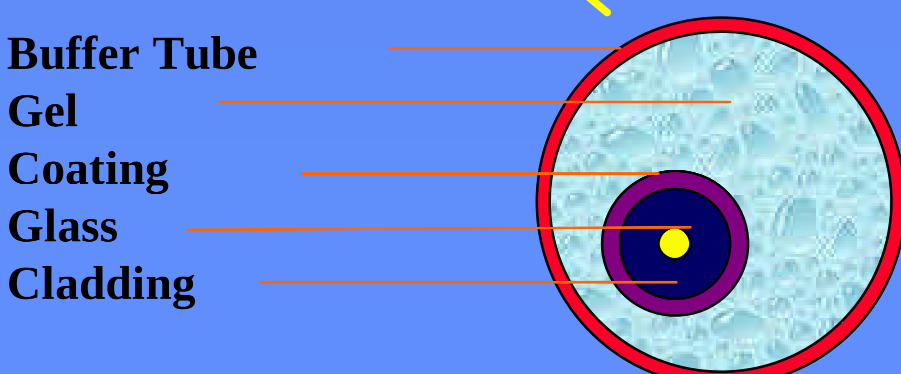
Indoor Cables
Flammability & Smoke

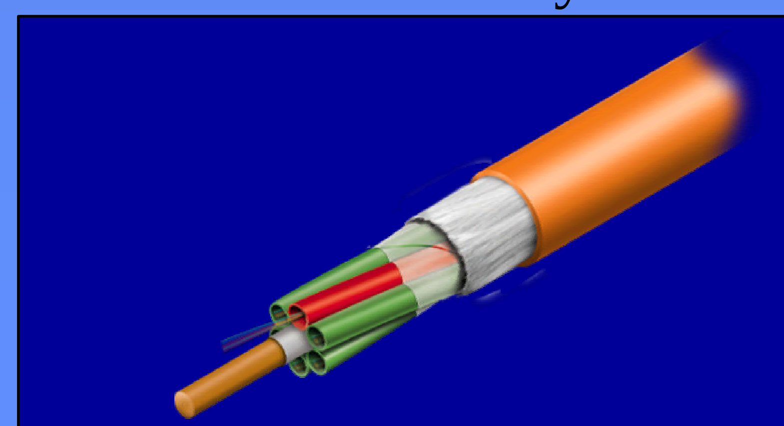
- Riser (UL)
  - OFNR means Optical Fiber with Non-Conducting Members, passes UL Riser flame test
- Plenum (UL)
  - OFNP means Optical Fiber with Non-Conducting Members, passes UL Plenum flame test
- Low Smoke, Zero Halogen
  - LSZH designs meeting OFNR are now available

Outdoor Fiber Cable - Loose Tube



- Outdoor cable uses gel or tapes to prevent water from reaching fiber
- Multiple fibers can be put in each buffer tube
- Polyethylene jacket is used with carbon black coloring to resist ultraviolet rays of sun

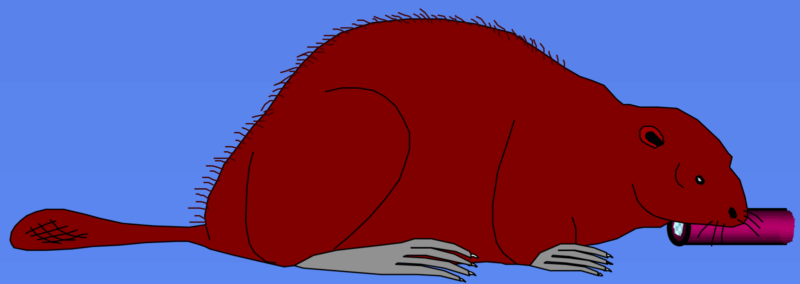


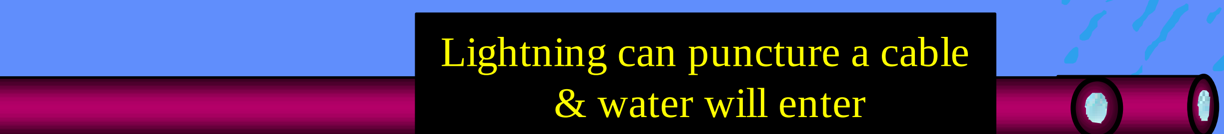


Outdoor Fiber Cable

Other design considerations

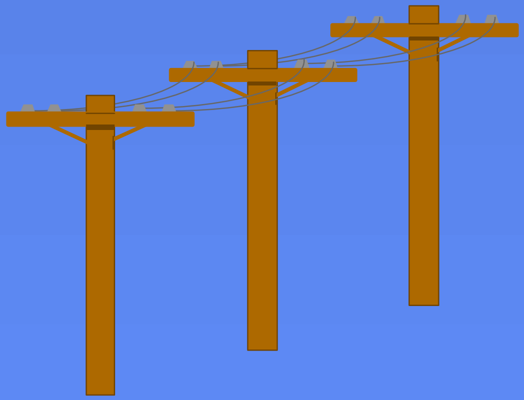
- Metal armouring is used to prevent rodents from puncturing the inner tubes of cable
- In regions with high lightning activity, there are metal-free (all dielectric) cable designs



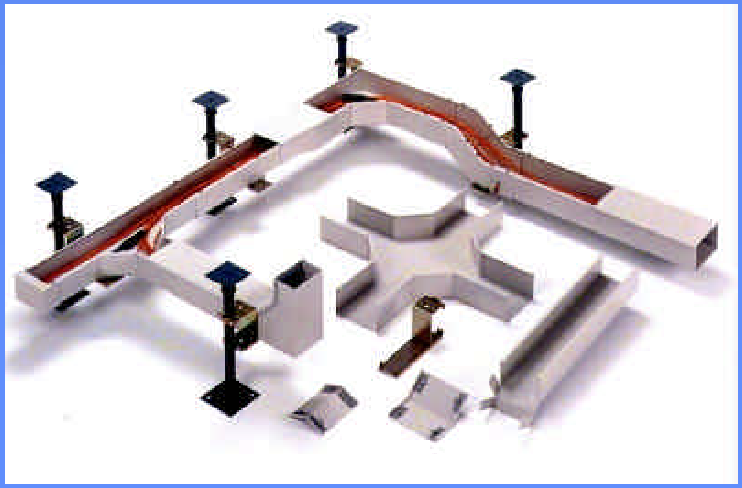


Outdoor Fiber Cable

Other design considerations



- To suspend between telephone poles, fiber cable can be attached to messenger wire or have messenger wire built-in
- If a site will not see temperature extremes, indoor cable can be used in duct or tray system



Hybrid Cables

Singlemode & Multimode

- **Future need for single mode fiber.**

  The ATM Forum, Technical Committee, 622.08 Mbps Physical Layer Specification, af-phy-0046.000, January, 1996, specifies single-mode fiber must be used for links greater than 500 meters.

- **Following table was developed by TIA Fiber Optic Division, Lan Section, Premise Fiber Technology Recommendations and provides the recommended fiber types for a wide range of standard LANs. Updated 6/97.**

FOLS Fiber Recommendations

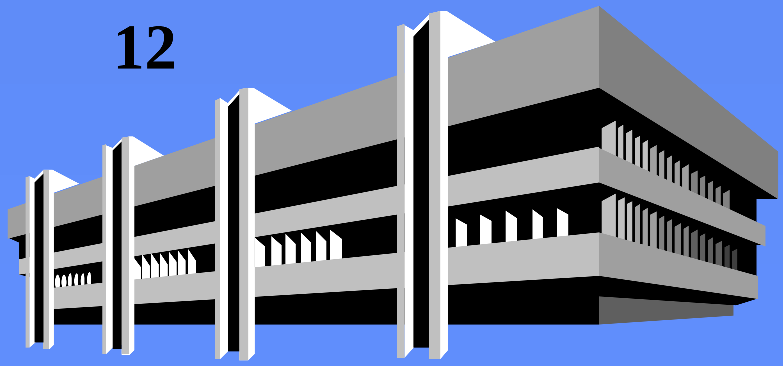
Application	Mbaud	Fiber Type
10 BaseF	20	MM
Token Ring	32	MM
100 VG	120	MM
100BaseF	125	MM
FDDI	125	MM
FibreChannel	133	MM
FibreChannel	266	SM
FibreChannel	531	SM
FibreChannel	1062	SM
SONET-ATM	52	MM
SONET-ATM	155	MM
SONET-ATM	622	SM

Multimode = 62.5/125 TIA/EIA 568a & ISO11801 optical glass

Singlemode= 8/125 Standard Singlemode

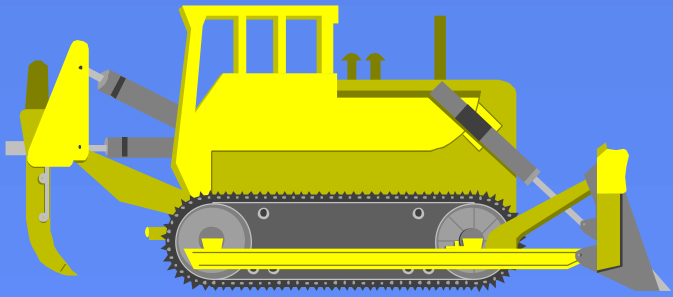
Campus Sites
Recommended Fiber Configurations

No. of Total Fibers	Multimode	Singlemode
18	12	6
24	18	6
24	12	12
30	24	6
36	24	12
60	48	12



Additional Fiber Count Planning

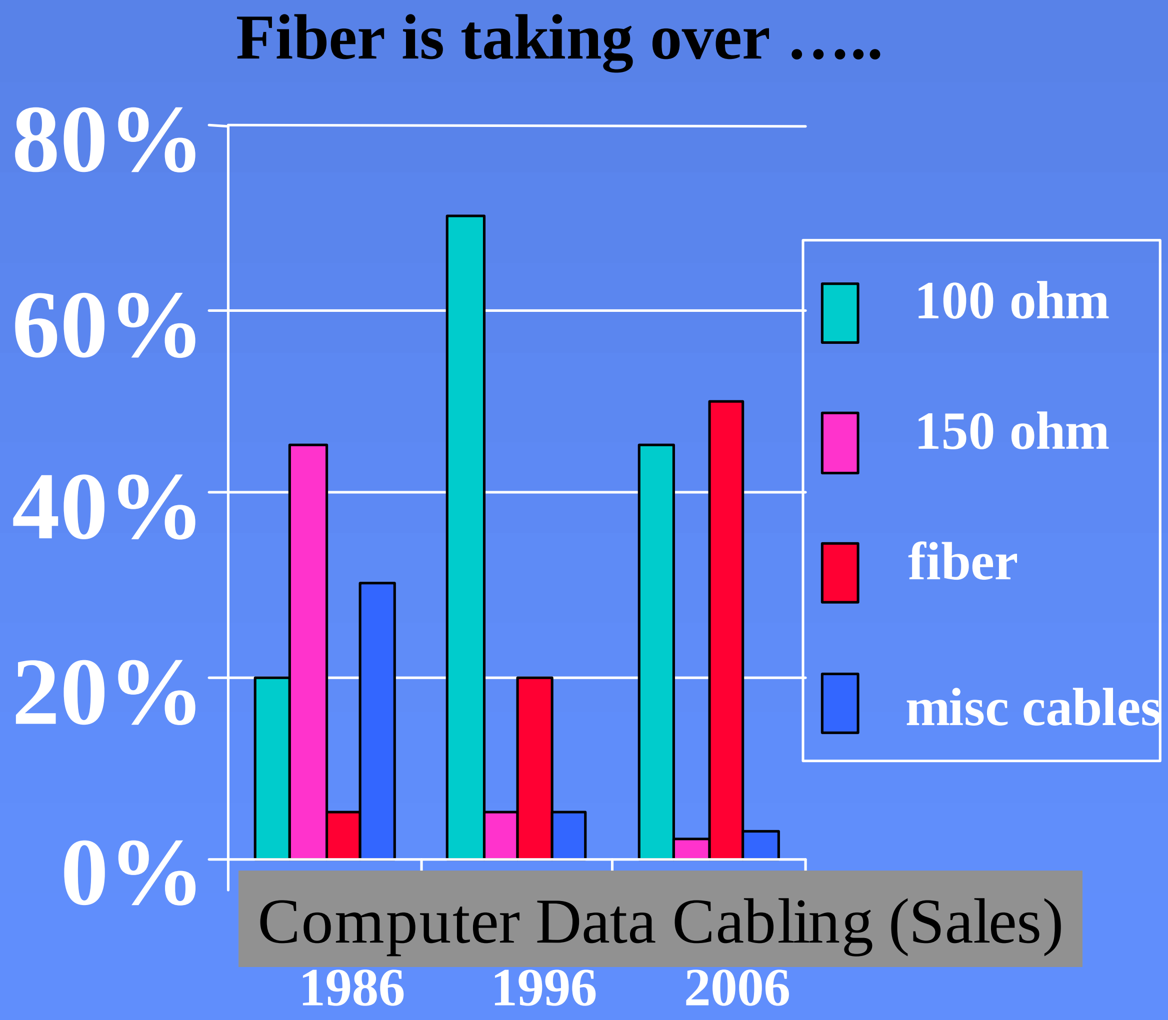
- Campus Backbones should be planned with a significant growth factor because of expense in installing additional cable.
  - Heavy machinery
  - Outdoor conduit / pathways



- Redundancy.
- Recommend that hybrid cables of singlemode and multimode fiber be included in the interbuilding cable plant.

Fiber Future

- Remember two key points about outdoor fiber
  - Plan your fiber counts for the future
  - Put in multimode & singlemode
- Indoor fiber
  - War is waged between 50, 62.5 and singlemode



The computer industry is going where no one has gone before in low cost, high-speed optical communications.

Understanding optical cabling technology direction is the key to future-proofing your designs.

End of Part 1

Optical Fiber Basics

Connectors & Termination

Class 2a

Solutions
for a small planet

Optical Fiber Termination Process Overview

- The following procedure is for the ST connector using standard epoxy cure.
- Although termination methods vary, all connectors share optical fiber connection fundamentals….
- We will explore these fundamentals after the overview.

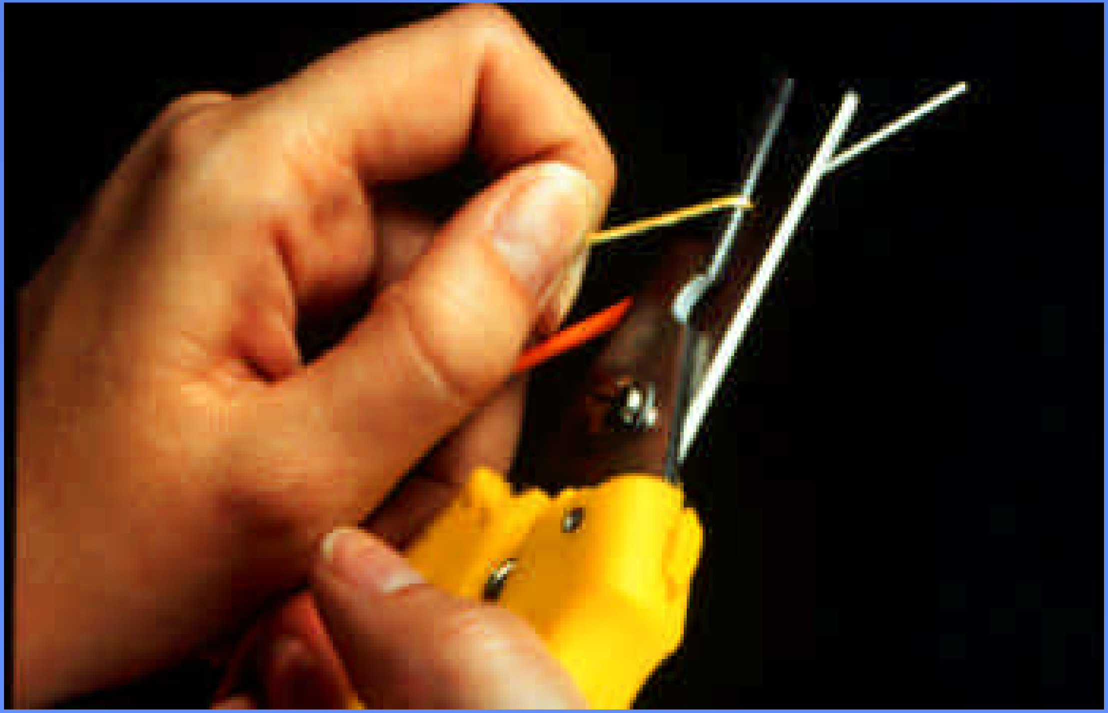
ST Termination
Standard Epoxy Method

1. **Place strain relief and crimp sleeve on cable or on subunit.**

ST Termination

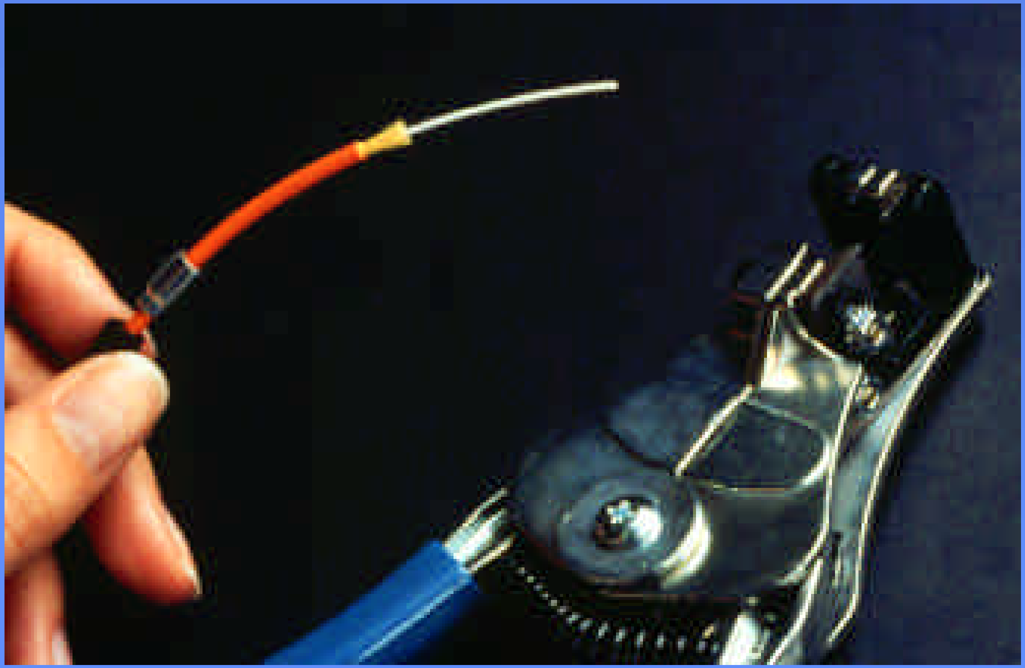
2. Strip off approximately 2 - 3 inches (4 - 6 cm) of the outer jacket.

ST Termination



3. Twist the Kevlar strength member, cut off excess leaving a short piece meeting the dimensions given on assembly chart

ST Termination



4. Fiber subunit prepared.

ST Termination

5. **Using an assembly template, mark the buffer at the appropriate place for stripping.**

   This same template was used to determine length of Kevlar.

ST Termination

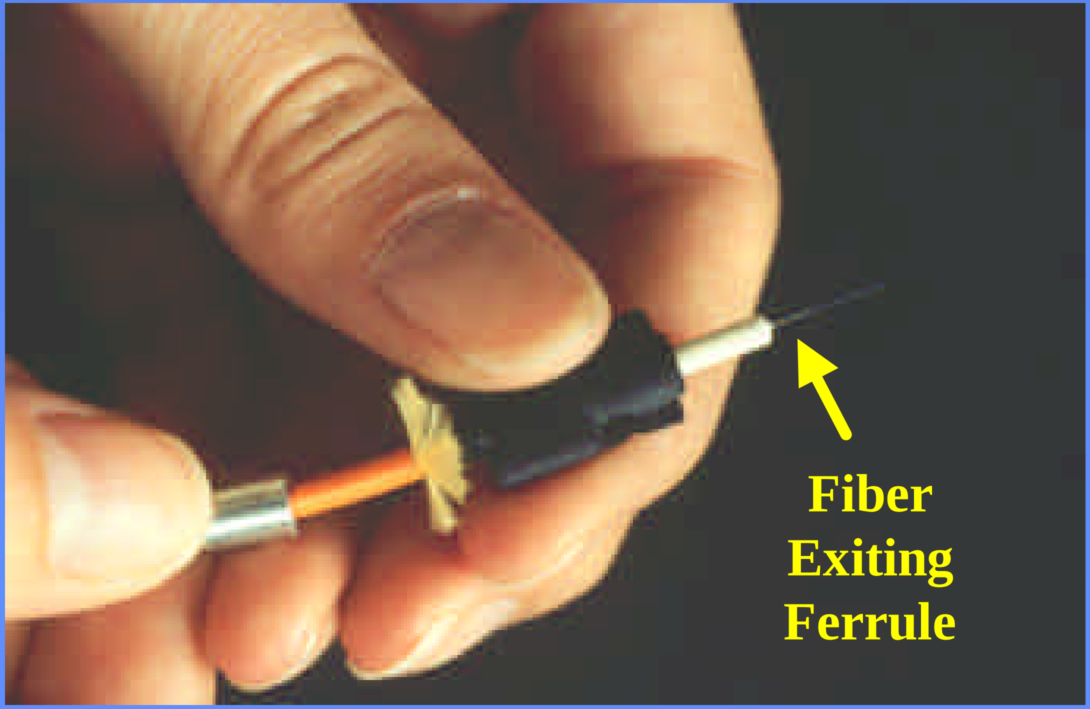
6. Strip off appropriate length of buffer from fiber.

ST Termination

7. Load connector body with epoxy.

8. Epoxy will need to be heat, UV or air cured following glass insertion (see step 9)

ST Termination



9. Immediately fit the connector over the fiber and seat it against the buffer.

ST Termination

10. Crimp the sleeve over the back body of the connector capturing the Kevlar.

ST Termination

11. Grasp the fiber with a swab and pull it off flush with the ferrule, following scribe procedure (not shown).

Scribing is the process of putting a scratch in the side of a glass fiber so that it snaps / cracks off cleanly following cure.

ST Termination

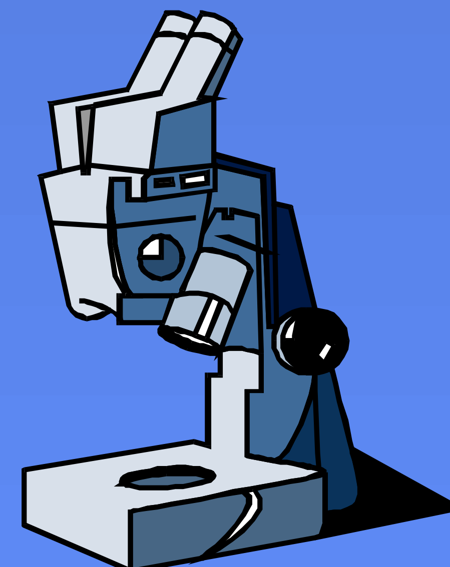
12. Holding a piece of lapping paper in your hand, grind the ferrule in a figure 8, a few times to get the sharp edges off.

ST Termination

13. Using a polishing puck, polish each connector on lapping paper.

14. Inspect each connector using a hand held inspection microscope.

Visual Inspection

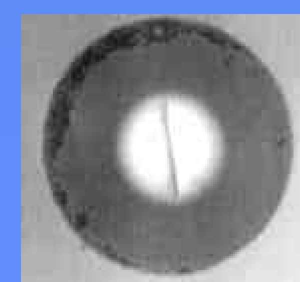


– Once the termination is complete,
– the connector should be visually
– inspected using a microscope.

- This is what you don't want to see!

Chip in glass

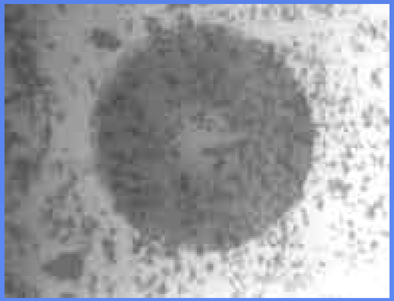
Chip in glass



Crack in core

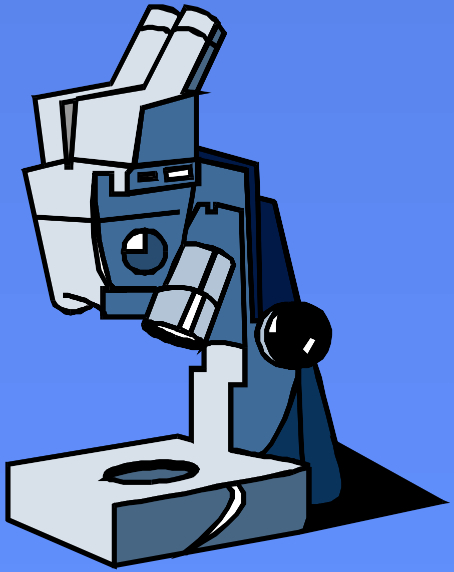
Visual Inspection

Other things to look for after polishing the end face

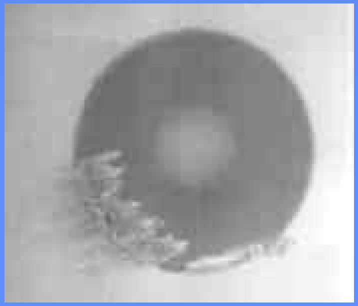


Dirt

Epoxy on end face

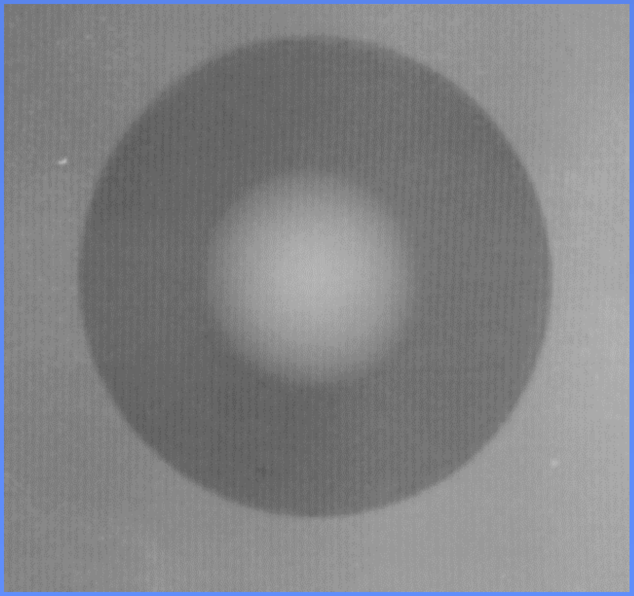


Scratch in core



Epoxy on end face

Polish Inspection

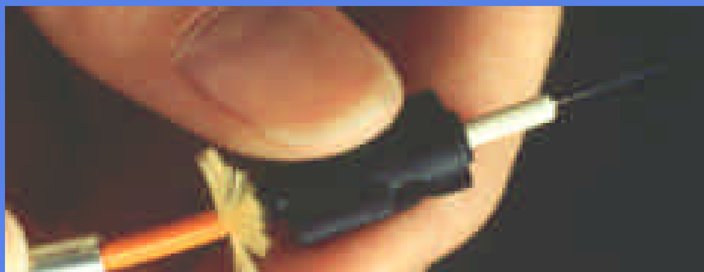


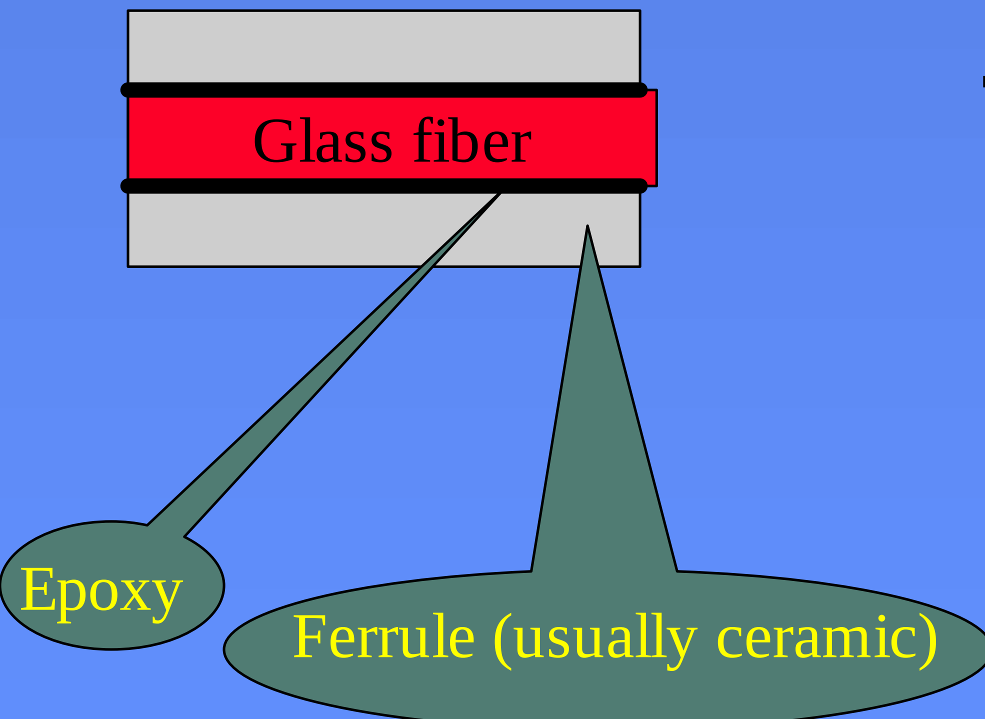
Good Polish!
Notice the light in the core versus no light in the cladding

Core size is 50% of total (62.5 /125)

Fiber Connectors

Basic Concepts

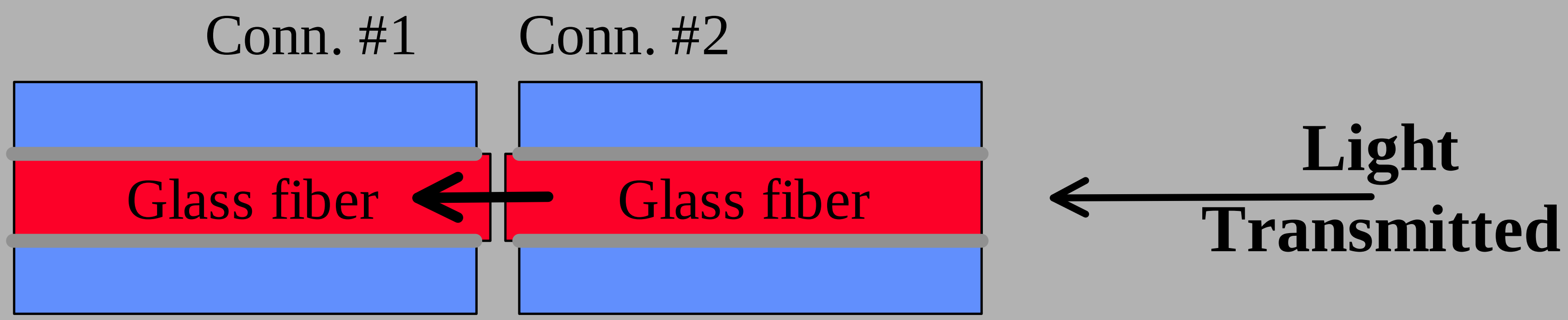




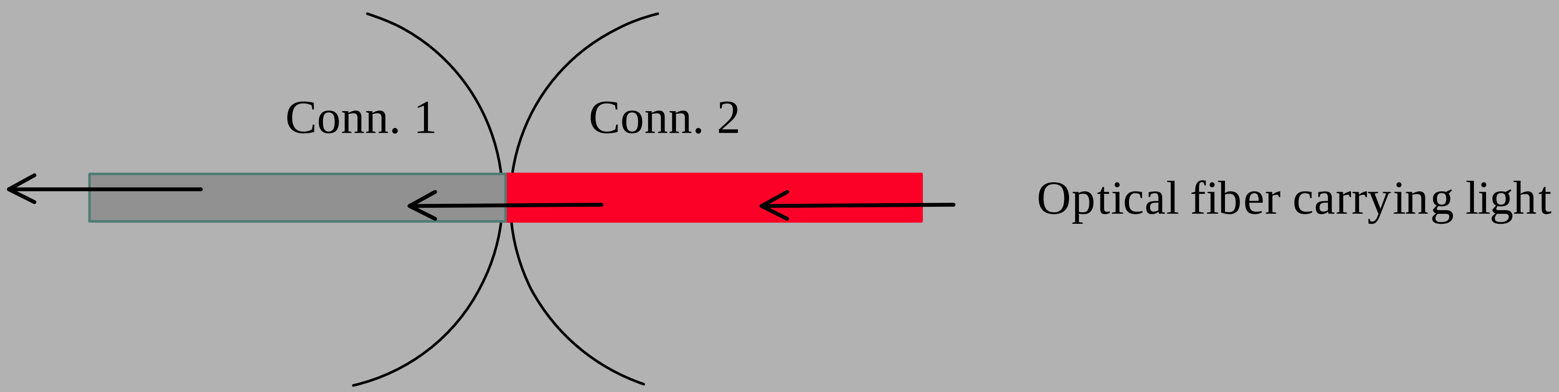
The glass fiber is bonded with epoxy to the ferrule which protects the glass tip after it is polished.

Ceramic & glass have similar temperature expansion coefficients

Fiber Connectors- Basic Concepts

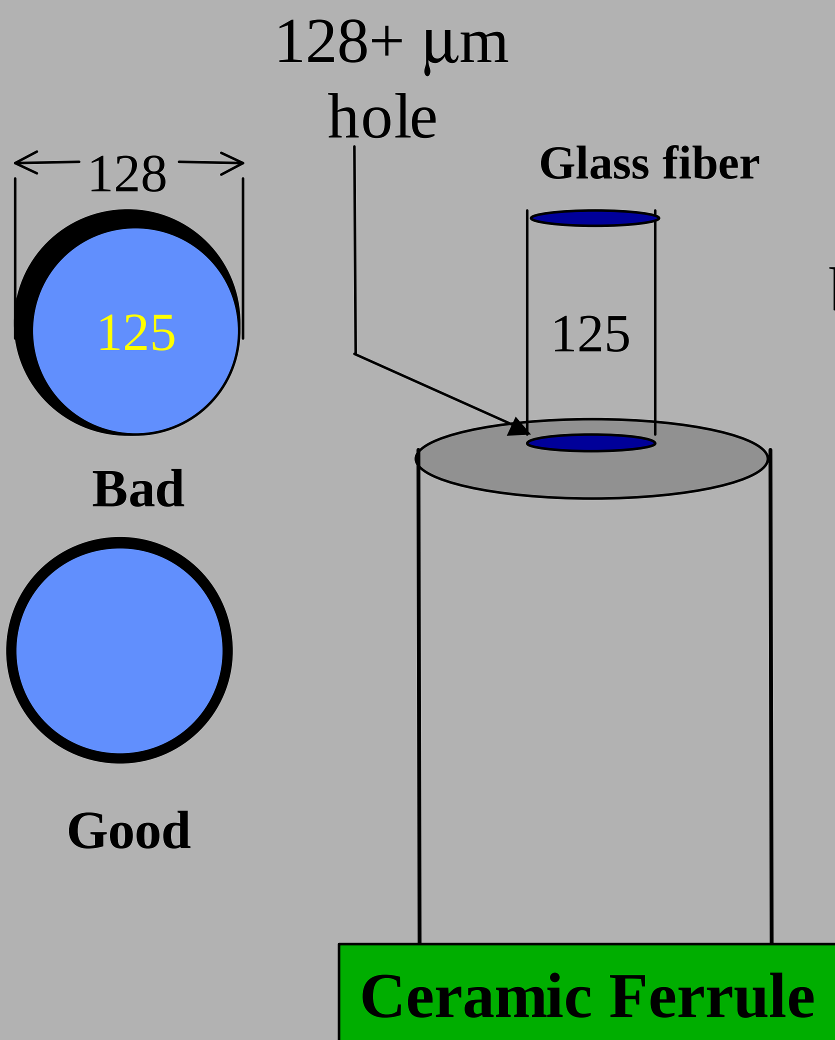


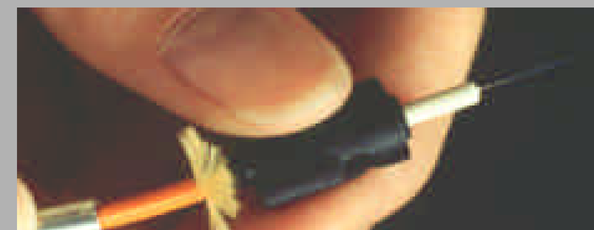
The 2 ferrule tips touch to ensure light passes through



Typically, the ferrule tips are rounded in a Physical Contact (PC) finish

Fiber Optic Connector Basics





The ferrule hole must
be large enough for 125µm glass fiber
and the surrounding epoxy.

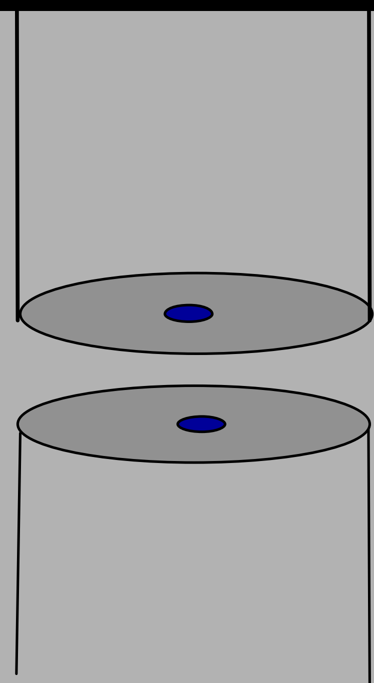
If the hole is too big, then the fibers
may be offset from each other.

Typical hole sizes:
Multimode: 126 - 130
Singlemode: 125 - 126.5

Fiber Optic Connector Basics

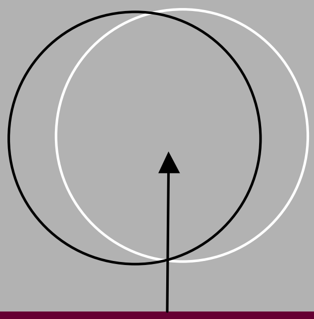
In singlemode glass, the core is only about 10 microns in diameter

If the alignment between the fiber cores is off even 1 or 2 microns, it may reduce launch power by 25%



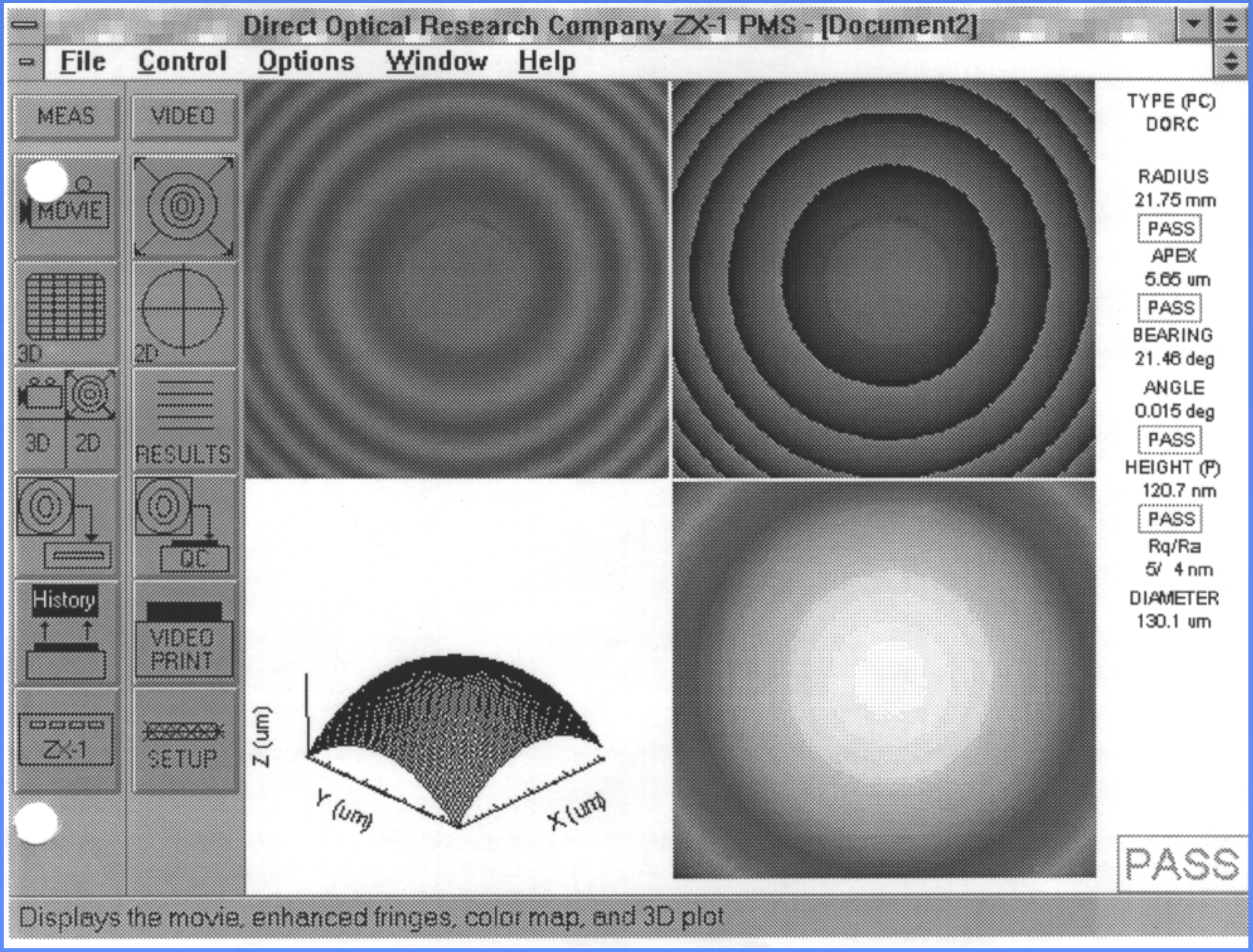
125 µm glass with 10 µm core

Singlemode cores with 2 micron offset



Remaining area of light transmission

Factory Analysis of Connector Endface



Radius

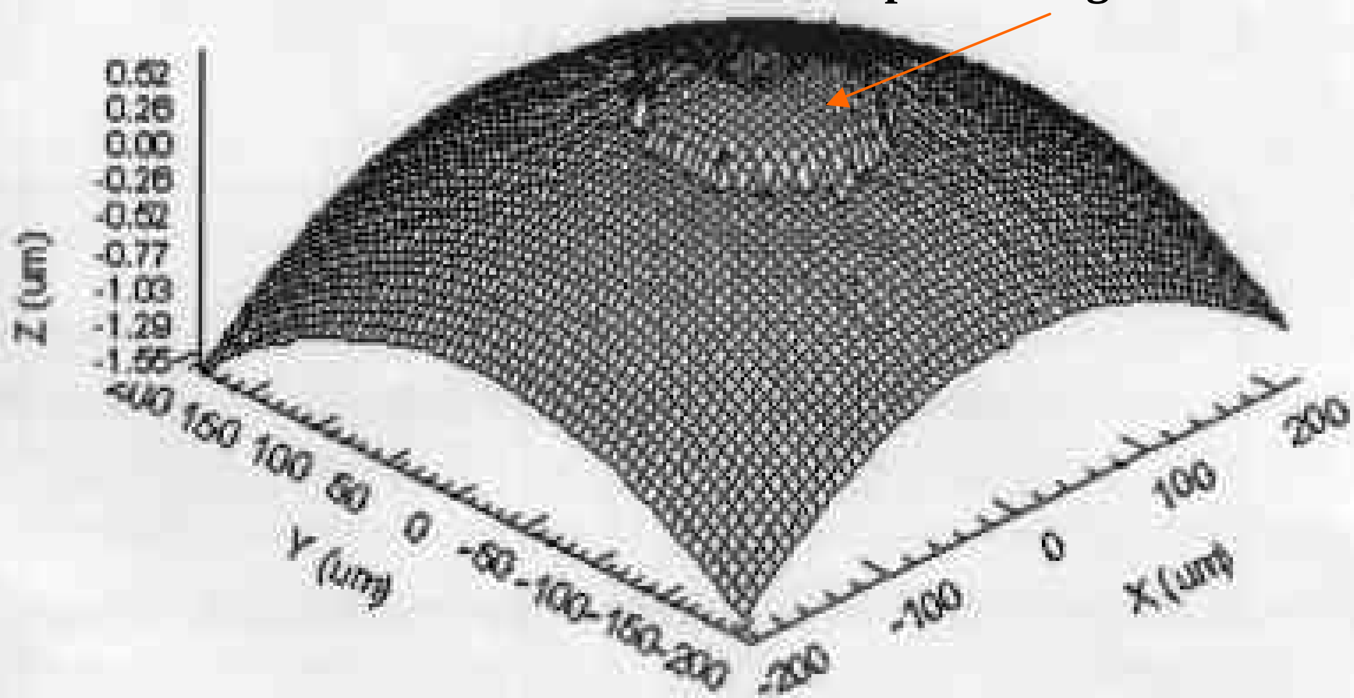
Apex

Height

Fiber Height

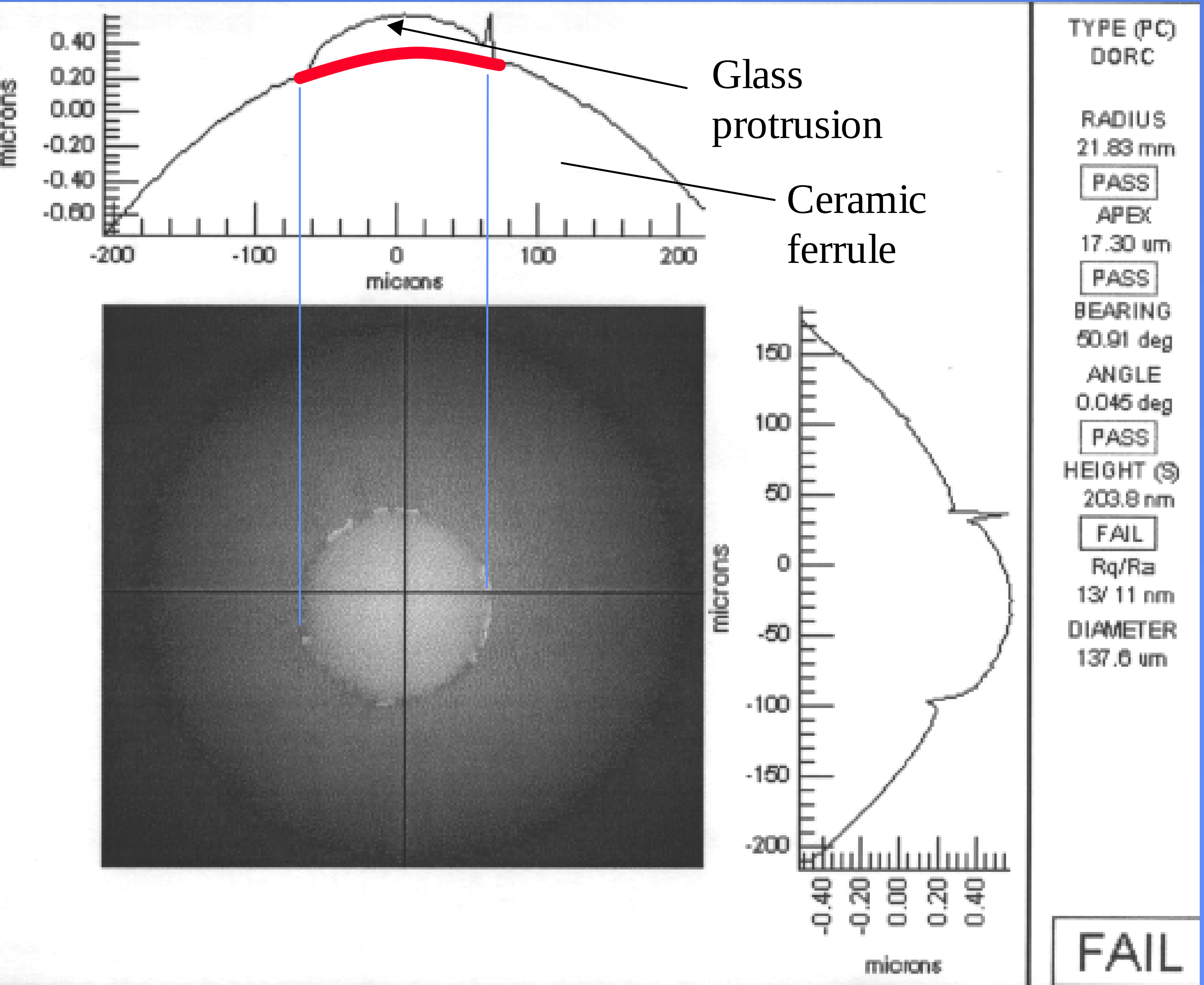
The amount the fiber protrudes from the ferrule surface

Glass protruding 203 nm

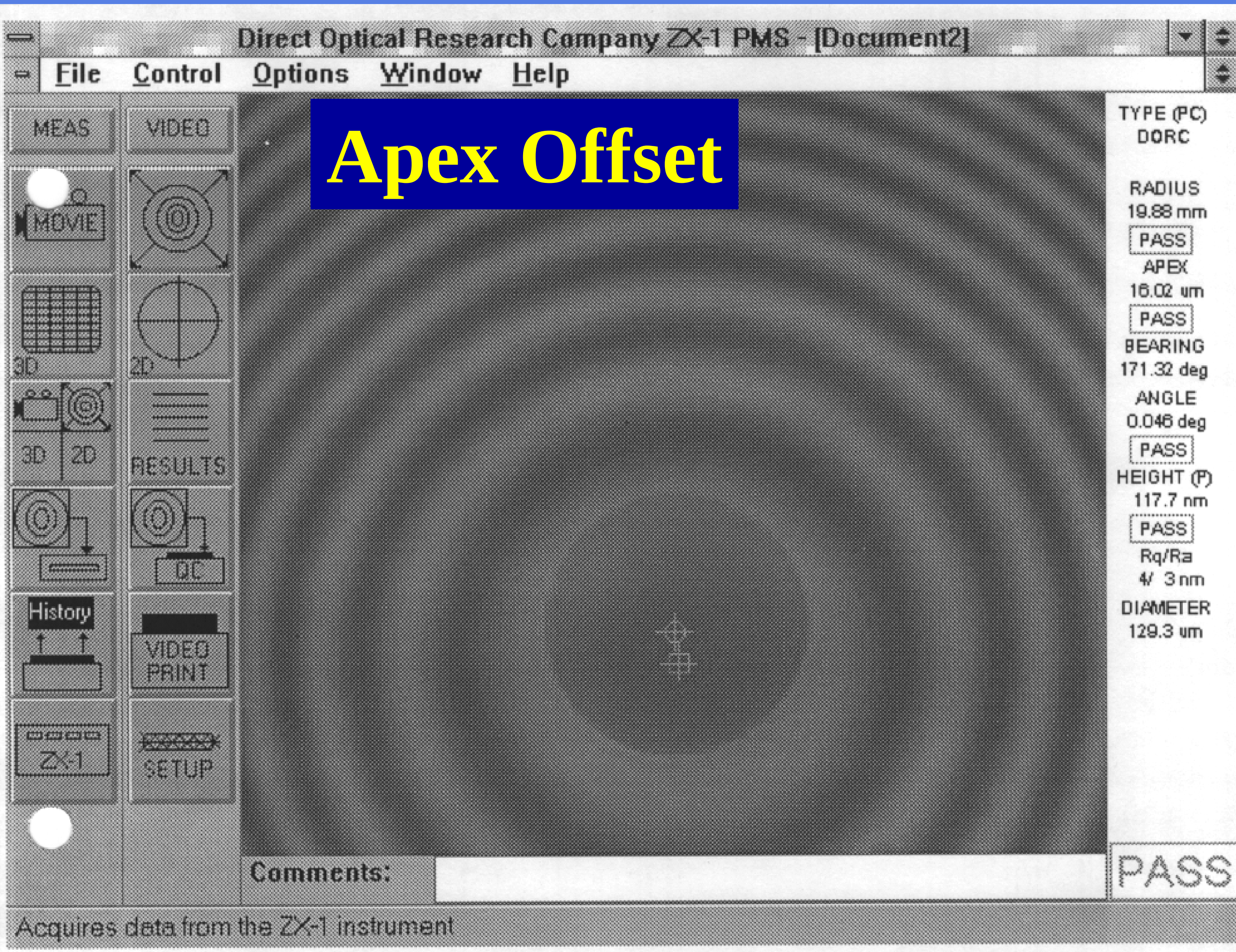


RADIUS
21.83 mm
PASS
APEX
17.30 um
PASS
BEARING
50.91 deg
ANGLE
0.045 deg
PASS
HEIGHT (S)
203.8 nm
FAIL
Rq/Ra
13/ 11 nm
DIAMETER
137.6 um

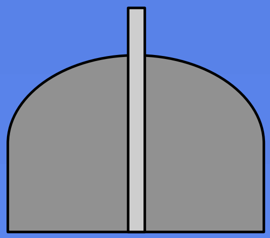
Fiber Height

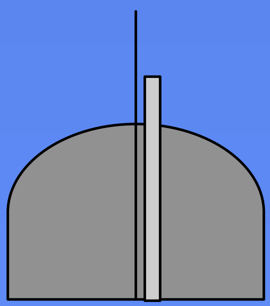


Apex Offset



Perfect apex

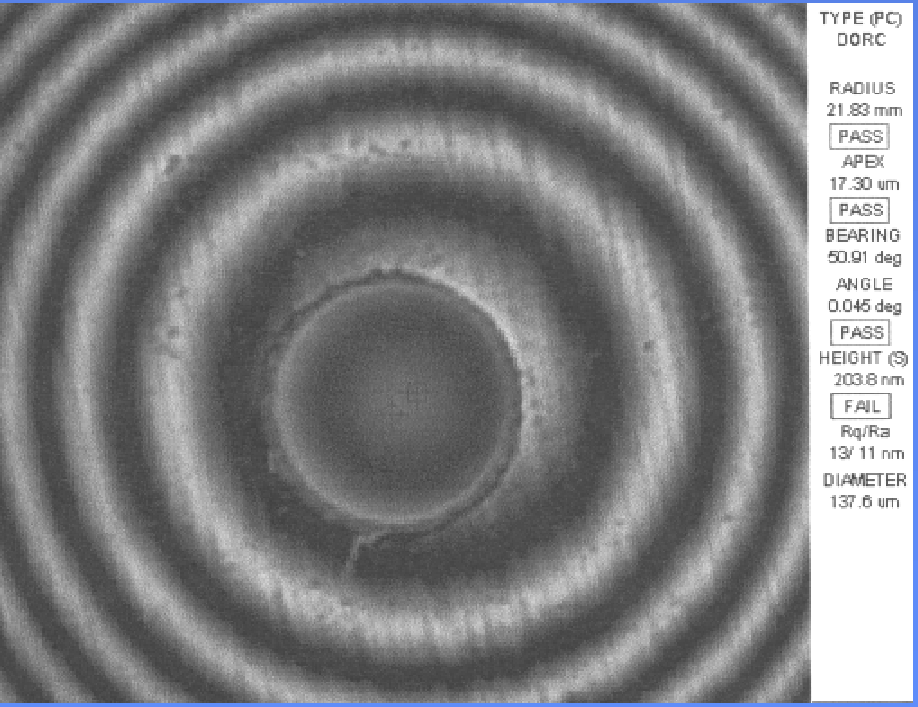


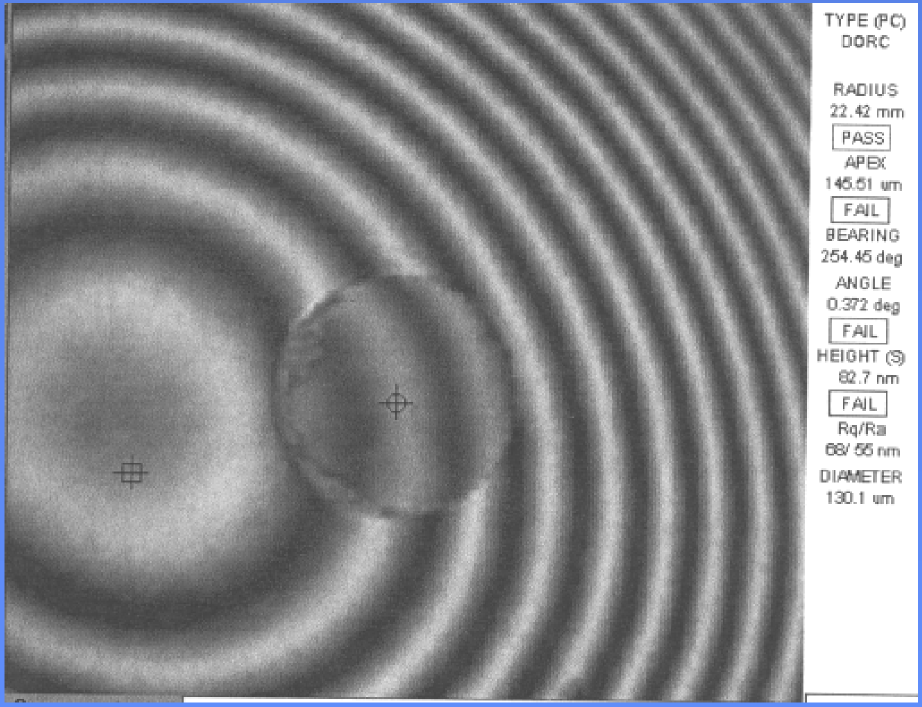


Offset apex

distance from center of glass to the center of ferrule dome

Apex Offset

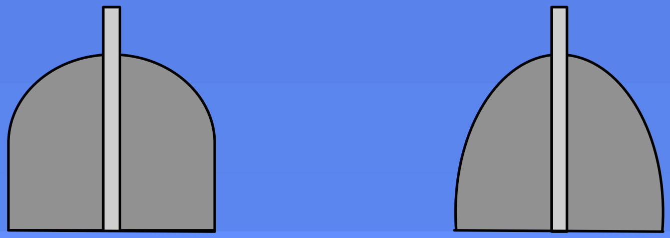




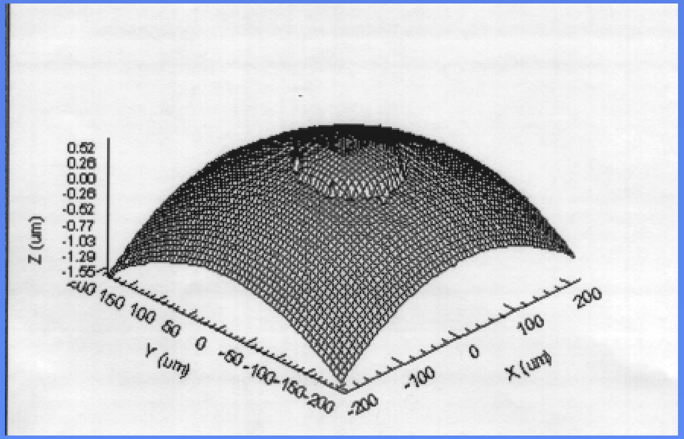
Not perfect but good

Bad

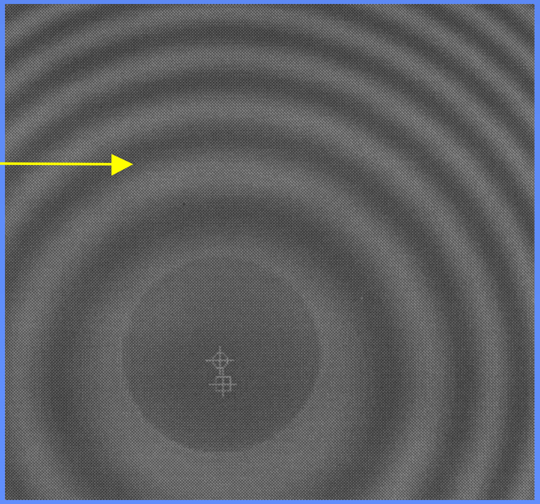
End Face Radius



End faces with different radii of curvature



Consider the interferometric rings of this ferrule like a topographic map



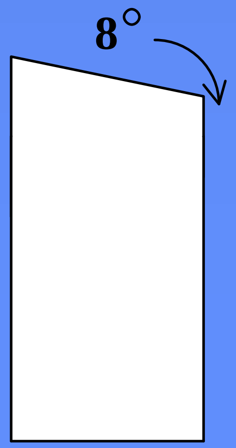
Connection / Splice Loss

Type	Fiber Core (A) (microns)	Fiber Core (B) (microns)	Mean Loss (dB)
Connector	62.5	62.5	0.40
Connector	50	50	0.40
Connector	9	9	0.35
Connector	62.5	50	2.10
Connector	50	62.5	0.00
Mechanical Splice	62.5	62.5	0.15
Mechanical Splice	50	50	0.15
Mechanical Splice	9	9	0.15
Fusion Splice	62.5	62.5	0.40
Fusion Splice	50	50	0.40
Fusion Splice	9	9	0.40

- **Following successful termination, a typical mated pair will have the loss values shown above**

Back-Reflection

- For singlemode connectors, a back-reflection measurement is important
- Most lasers will not perform well with connectors exhibiting high back-reflection
- Singlemode connector back-reflection could be grouped in 3 categories:
  - PC finish: -28 to -40 dB
  - Super PC: -41 to - 55 dB
  - 8 degree angle: -56 dB and beyond



Summary of Connectorization Concepts

- All connectors share these fundamentals
  - Tolerances of connector holes
    - singlemode needs to be much tighter than multimode
  - End-face of fiber must have no defects in the core after polishing
  - The end-face of fiber must meet certain requirements for:
    - radius
    - fiber protrusion
    - apex (offset)
  - The end result after proper connectorization should be good loss and reflection values

End of Class 2a

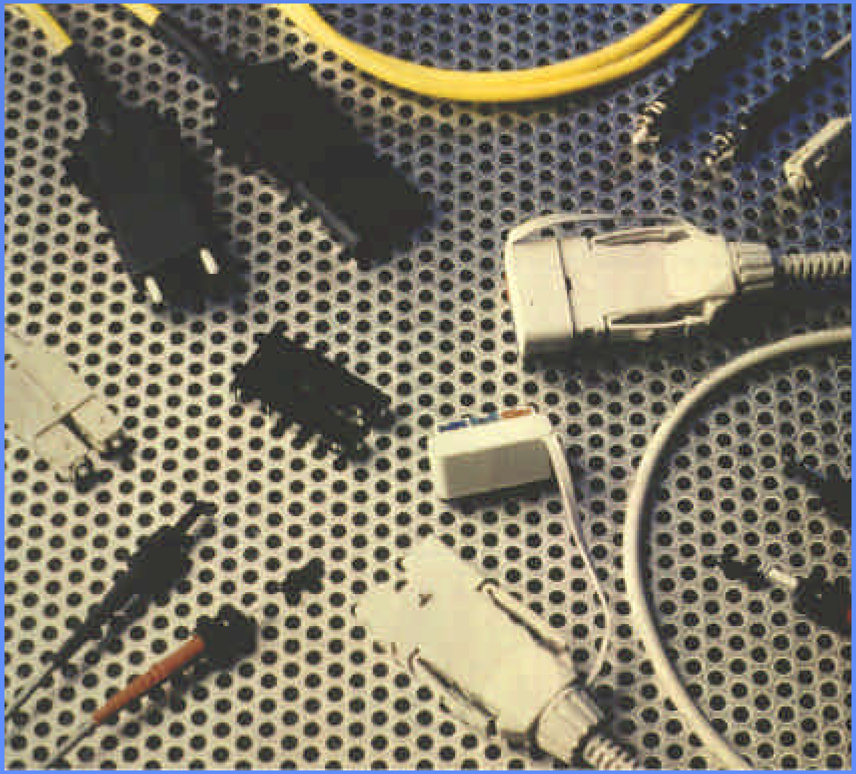
Connectors and Termination

Connectors & Termination

Class 2b

Solutions
for a small planet

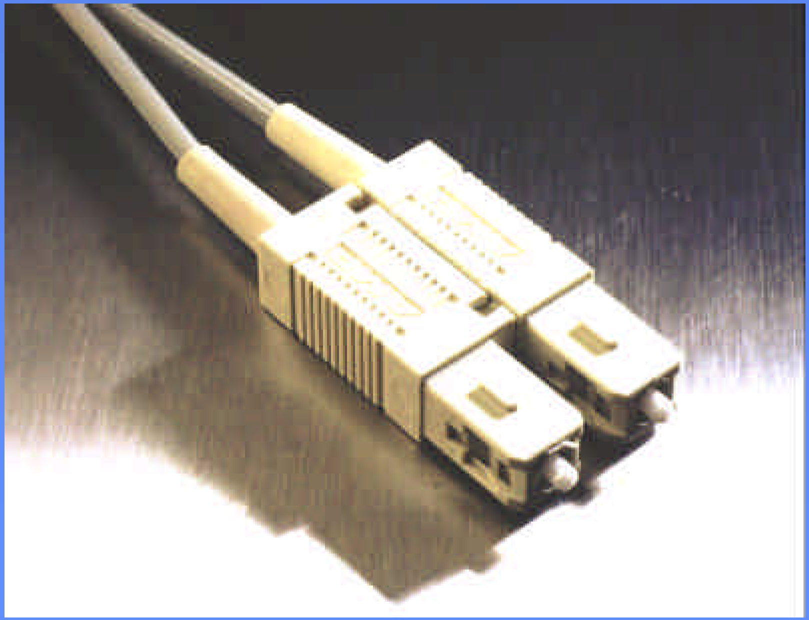
Available Connector Types



- IBM uses all major connector styles
  - FDDI
  - Duplex SC
  - ST Style
  - FC
  - ESCON
  - MT / MTP / MPO

Fiber Optic Connectors

Duplex SC Connector

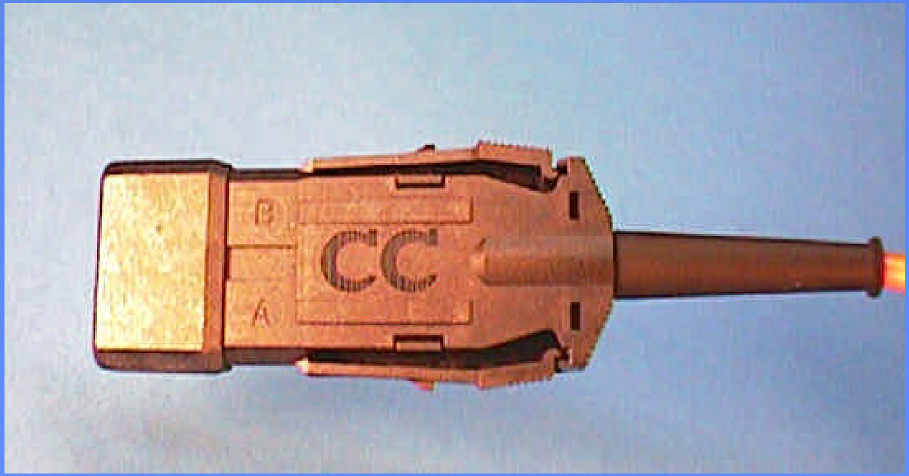


- Duplex SC:
  - Recommended by TIA 568 & IS0 11801 for new wiring
  - Specified by Gigabit Ethernet, FibreChannel, ATM & Low cost FDDI
  - Functionally better than ST
    - » duplex capable
    - » PUSH / PULL
- SC: "Subscriber Connection"

Fiber Optic Connectors
ST Style Connector

- The ST Connector has been the favorite of installers for years
- Pros: Low cost, simple design, readily available
- Cons: Not available in duplex form, requires bayonet rotation to disengage, easy to damage
- ST: “Subscriber Termination”

Fiber Optic Connectors
ESCON™ Connector

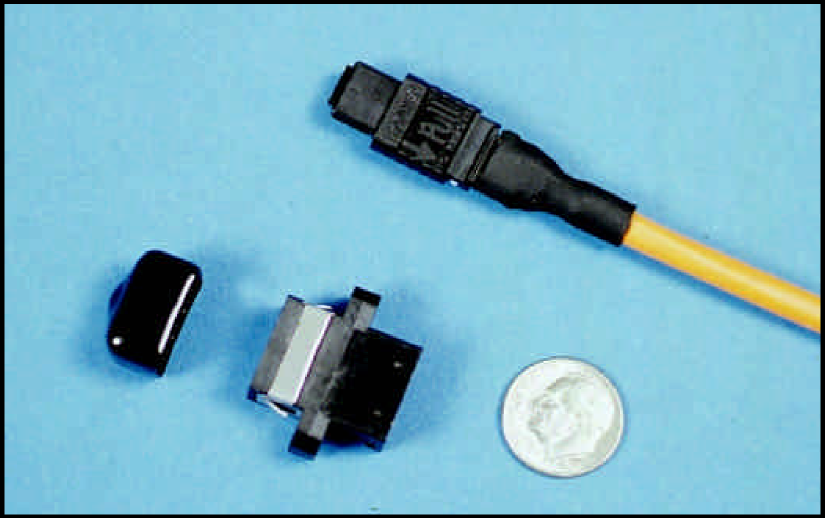


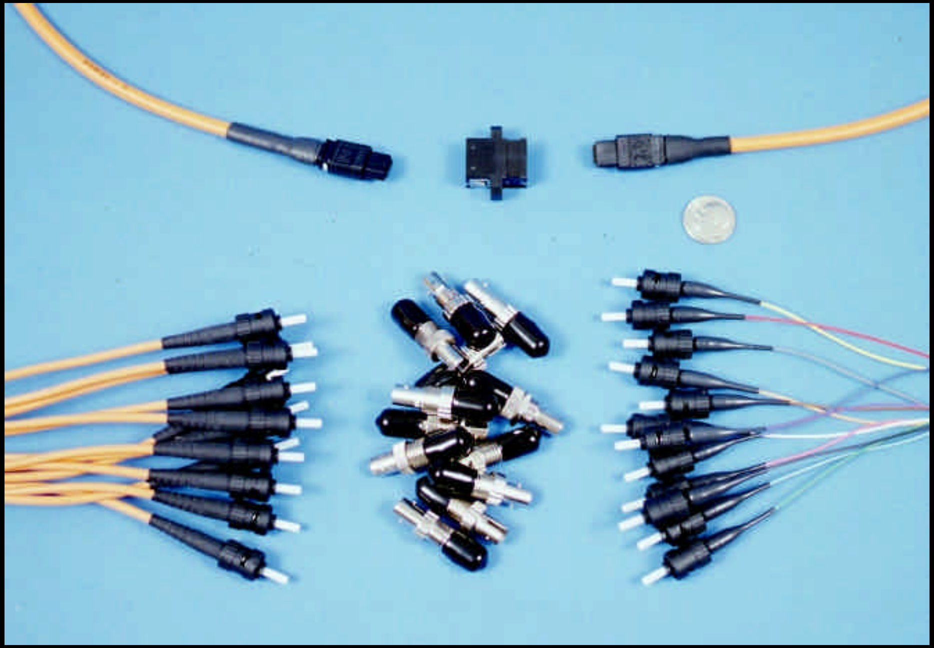
- Developed by IBM for use in high reliability Enterprise System mainframe Connections
- The most stringently tested duplex fiber connector available
- IBM qualified manufacturers:
  - Computer Crafts, Siemens & AMP

Fiber Optic Connectors
FC Style Connector

- The FC Connector has been widely used by the telephone and Cable TV industries
- Used almost exclusively for singlemode applications
- Uses a rotating "screw-in" attachment method
- FC: "Fiber Connector"

IBM





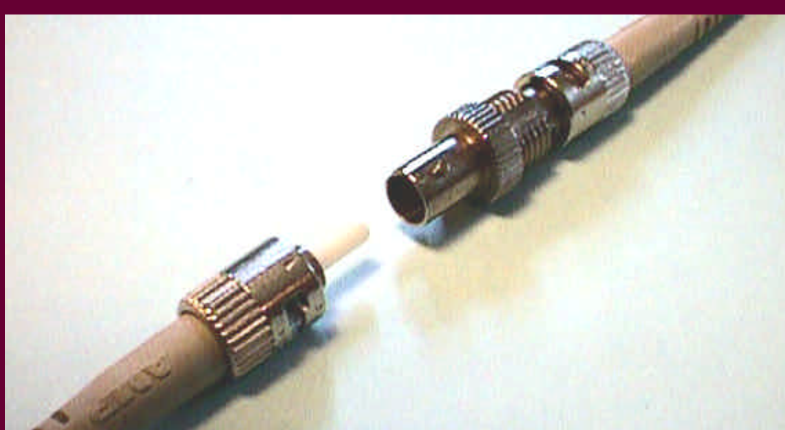
12 fiber systems - new vs old

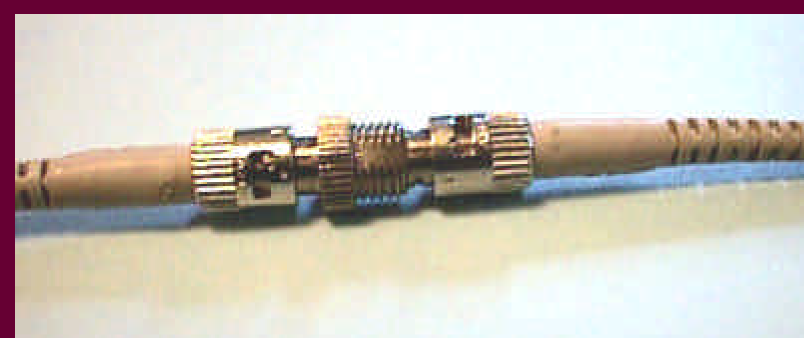
MTP Connector

- **The MTP Connector is a multifiber connector**
  - **2, 4, 8, 12 fibers available**
- **Developed by NTT in Japan**
- **Licensed to several companies**
  - **USConec**
  - **Fujikura**
  - **Furukawa**
  - **Sumitomo**
- **MTP: Multifiber Terminated Push-on**

Fiber Optics is an all-male world

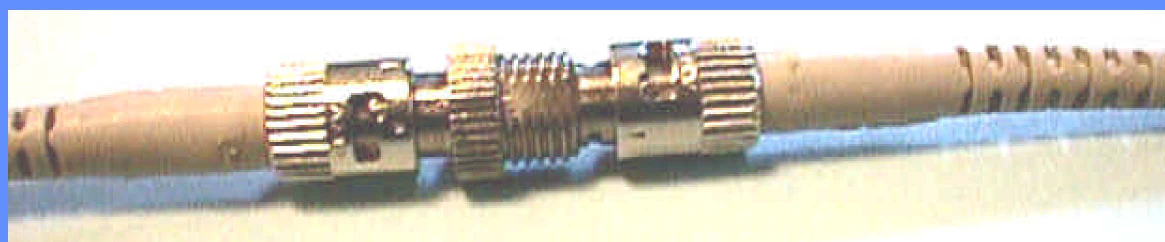
ST Male Plug   Coupler   ST Male Plug



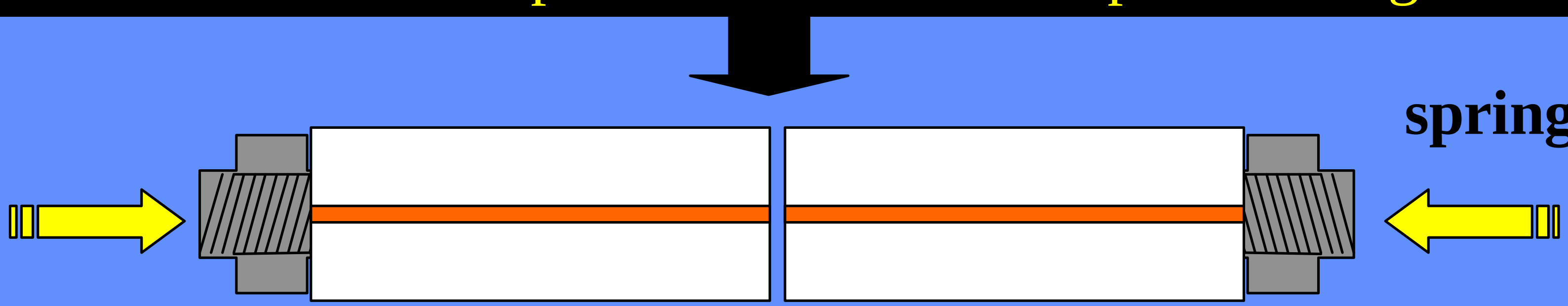


Couplers

A passive device that connects two male plugs



Look inside the coupler. This is what the tips are doing.

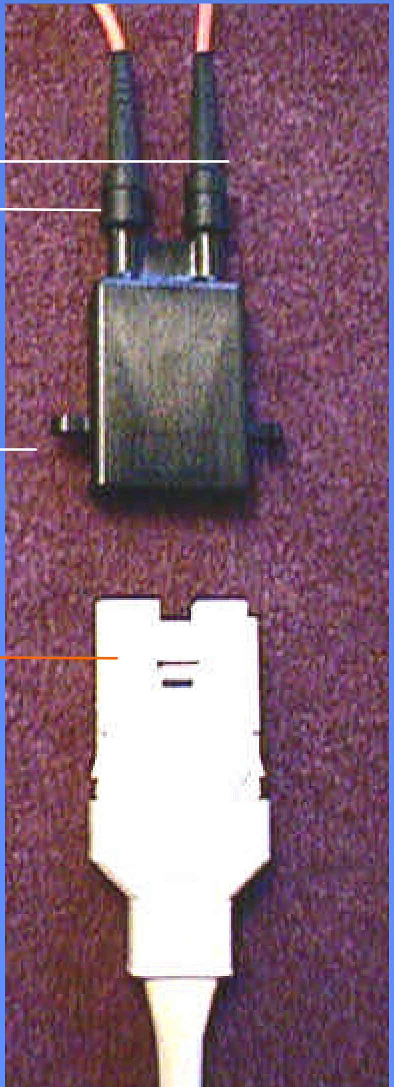


The ferrule tips are in contact. Some connector designs use springs to ensure that the ends touch but do not receive excessive force.

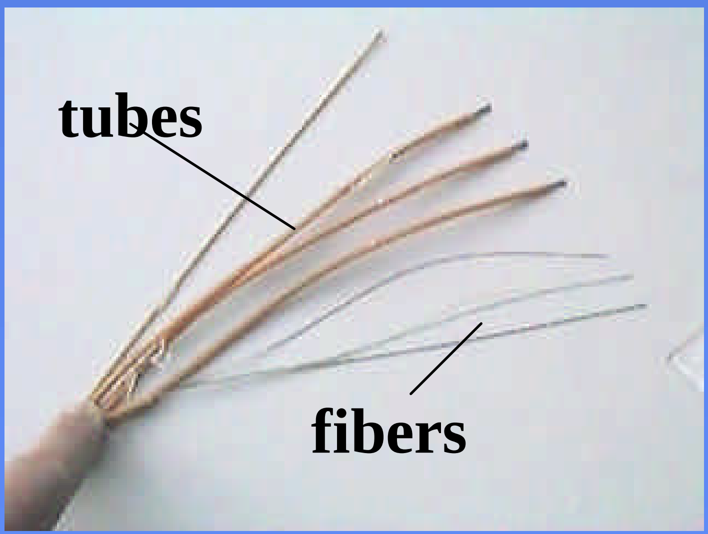
Adapters

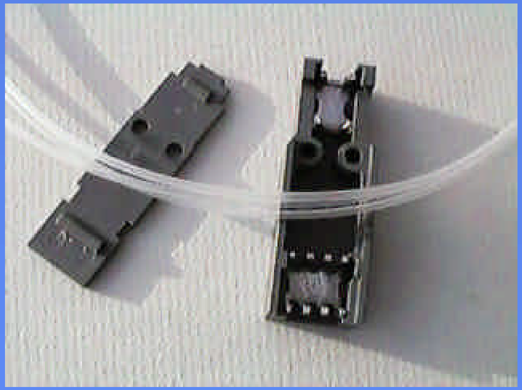
An adapter is a passive device that connects two different styles of connectors

In this example, a duplex connector (FDDI) will adapt to 2 simplex ST connectors



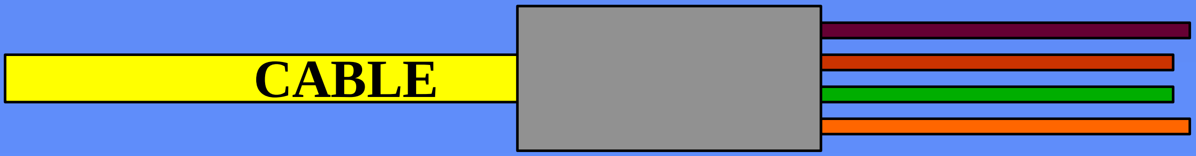
Breakout Kits





Fanout tubing &
Fanout shroud

Loose tube cable with exposed tubes and exposed fibers.

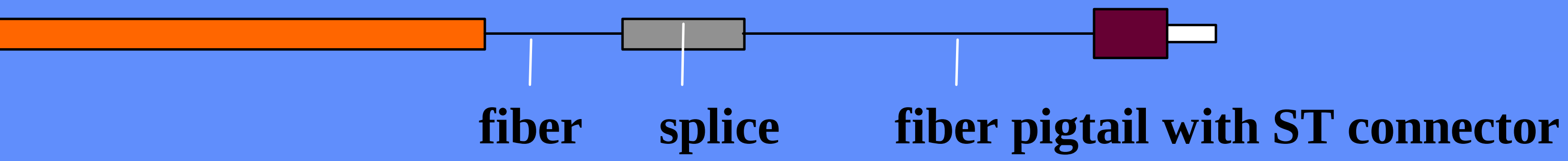


Fan-out shroud

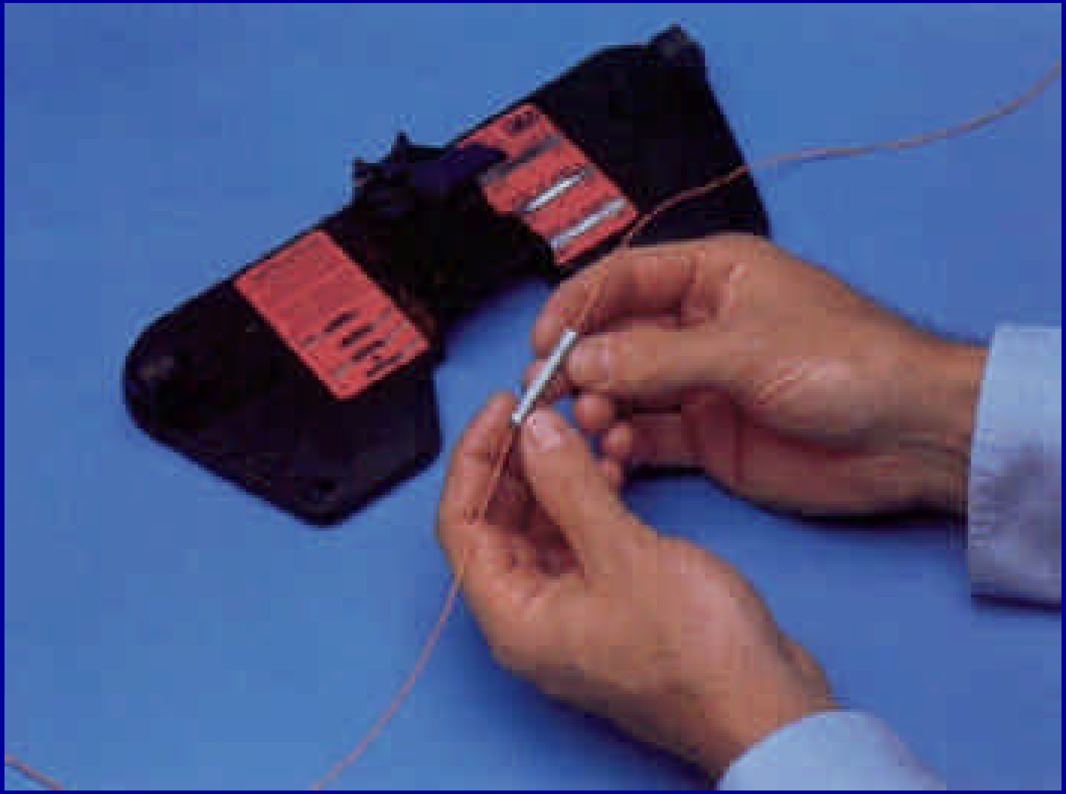
Fan-out tubing with fiber inside

Splicing

- There are 2 basic methods of splicing:
  - fusion
  - mechanical
- Splicing requires only a "cleaved" glass end
  - minimal stripping tools and a precision cleaver
- Splicing applications:
  - repairing damaged sections of glass
  - termination method that requires no polishing
    - » connector pigtails are purchased from assembly factories



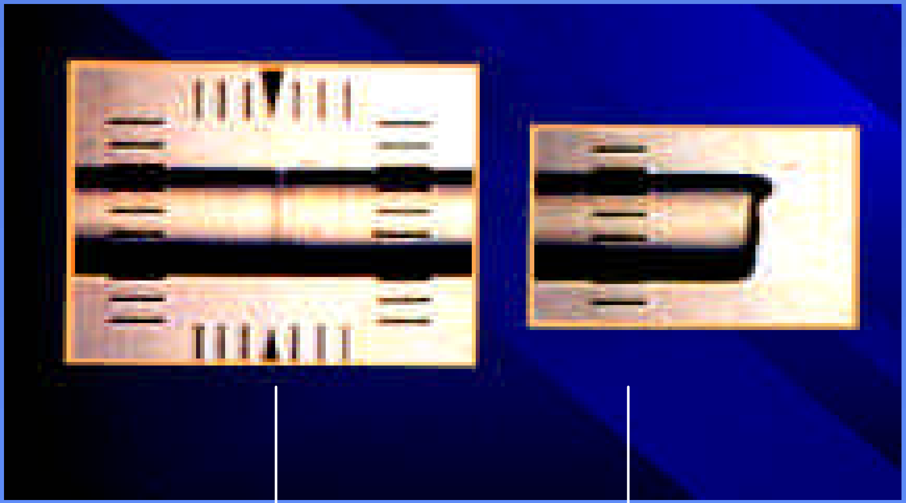
Mechanical Splicing



A mechanical splice with installation tool

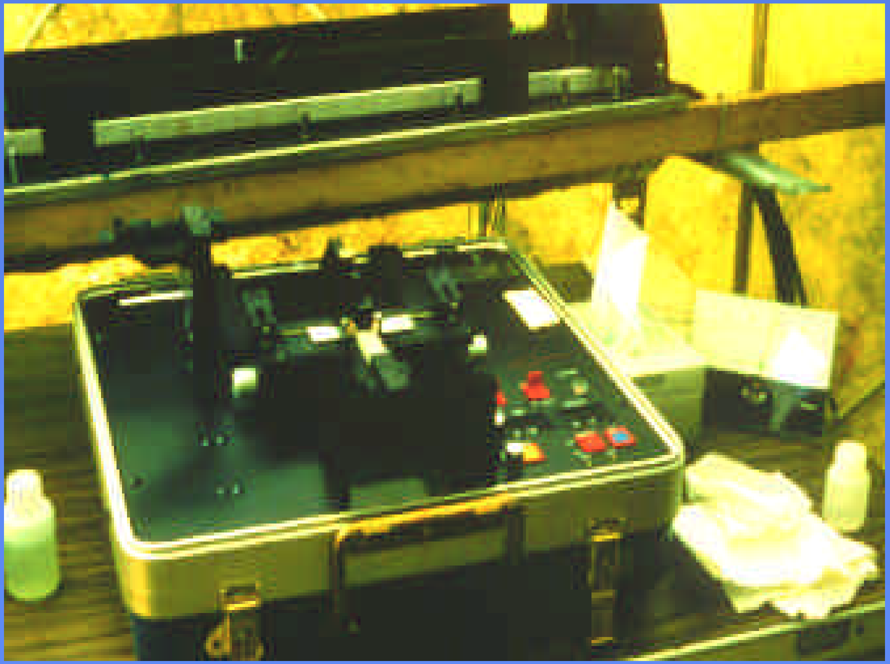
Methods of Splicing

Fusion Splicing



Ready to Fuse

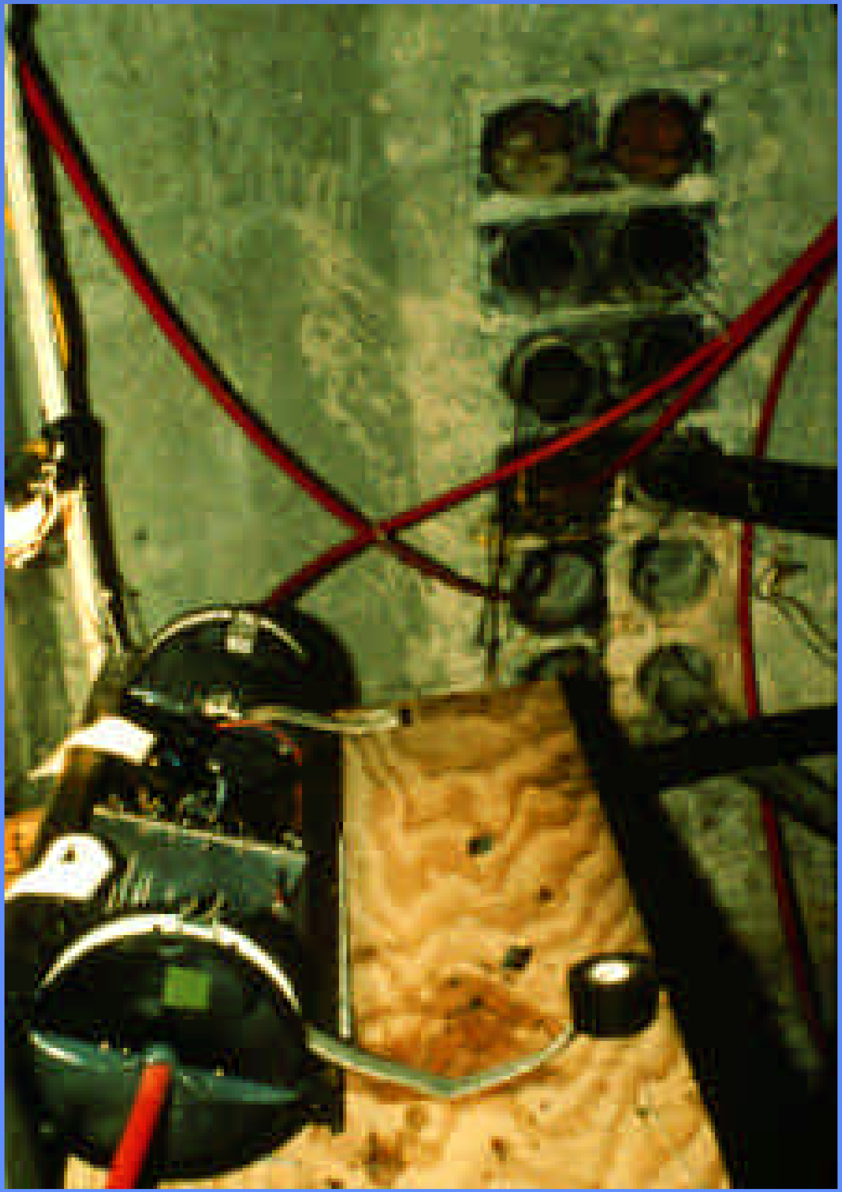
One side with improper cleave



Fusion splicer set up in the field.

Fiber as seen through viewer of fusion splicer

This is an older manual unit.



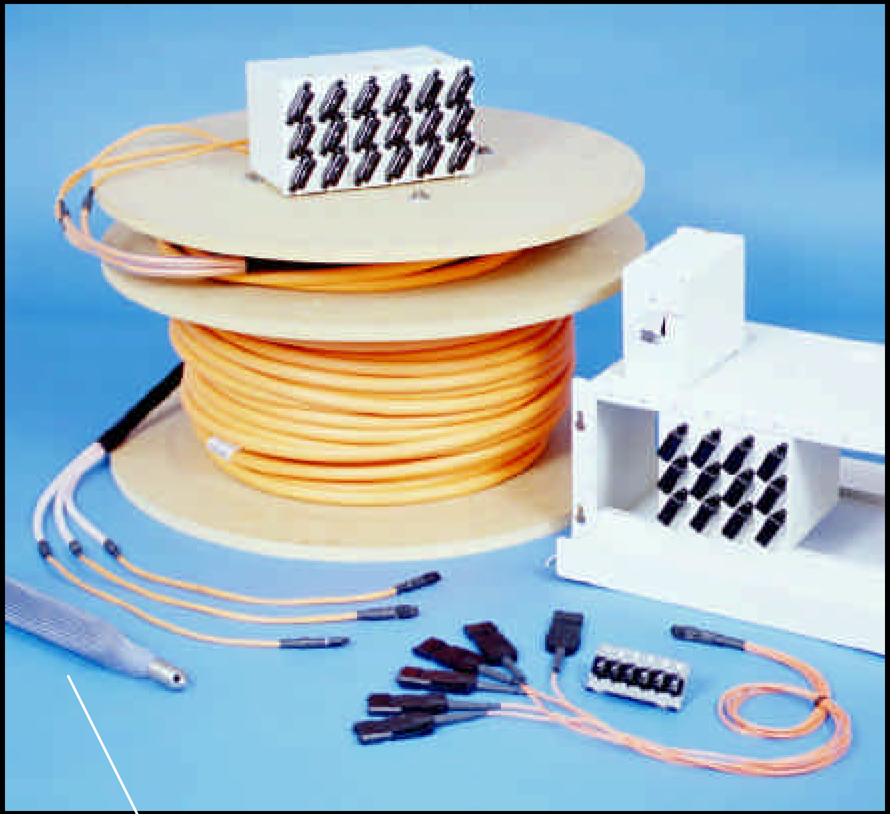
Splicing

Splice case in underground cable vault.

Case will be closed then filled with a re-enterable filling compound.

Most splicing is done in difficult environments or where installation time is limited (eg. repairs)

Factory Termination



Pulling sleeve

- Many mainframe computer users request preterminated fiber solutions for reliability reasons
- Many installers use factory assembled cables to avoid working with the bare fiber
  - New ultra-small multifiber connectors available
  - Availability of pulling sleeves
  - New furcation / fan-out designs

Next Generation Connectors

- Several new designs on the market
- Industry standards groups are reviewing designs
- New connectors are developed for:
  - lower cost
  - size and installation like an RJ45 connector
- The new designs:
  - MT-RJ
    - » 2 fiber connector based on MT
  - Mini-MTP
    - » 2 fiber connector based on MT
  - Volition VF-45
    - » 2 fiber connector developed by 3M….with a male & female!
  - SC-DC
    - » 2 fiber connector similar to SC
  - LC
    - » developed by Lucent

This is the end of Class 2b

Fiber Optic

Connectors & Termination

Optical Fiber Cabling System

Design, Installation & Testing

Class 3

Solutions for a small world

What is a decibel (dB)?

A measure of the power entering the fiber versus the power leaving the fiber.

$$dB = 10 \, LOG \left[\frac{\text{Power out}}{\text{Power in}} \right]$$

$$dBm = 10 \, LOG \left[\frac{\text{Power out}}{1 \text{ mWatt}} \right]$$

Measurements of Light Power versus Power Budgets

Power Loss	dB Loss
50 %	-3 dB
75 %	-6 dB
87.5 %	-9 dB
90 %	-10 dB
99 %	-20 dB
99.9 %	-30 dB

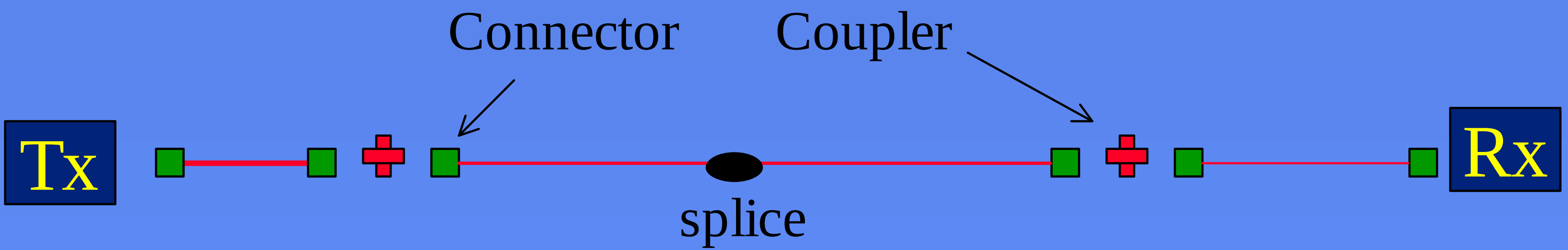
Power Budget Examples:

Application:	Budget:
ESCON (mm)	8 dB
FDDI	11 dB
ATM (mm)	7 dB

Most applications need at least 10% of the launched light to function properly as a link

Fiber Optic Links

The elements of the link



To predict the attenuation (loss) we have from the transmitter (Tx) to the receiver (Rx), we add:

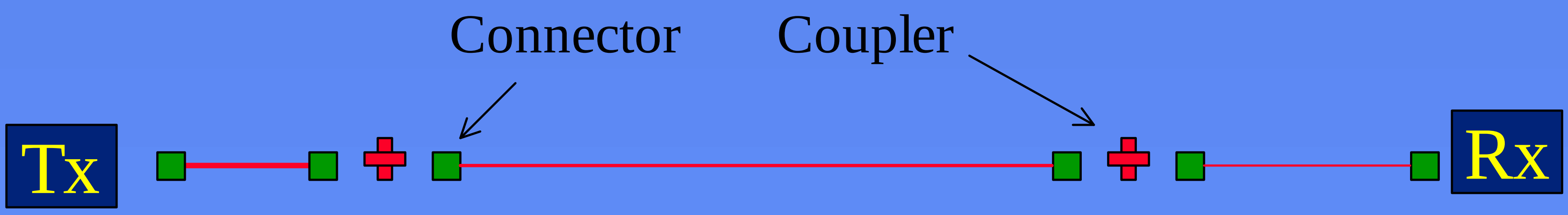
cable loss + connector loss + splice loss = link loss

Link Testing - Connector Attenuation

Assumption:

Attenuation per connector pair: 0.4 dB mean

Formula: connector attn (dB) = number pairs * connector loss (dB)



Question: What is the total connectorattenuation?

Answer: 3 pairs (6 conns.) X 0.4 dB loss per pair = 1.2 dB

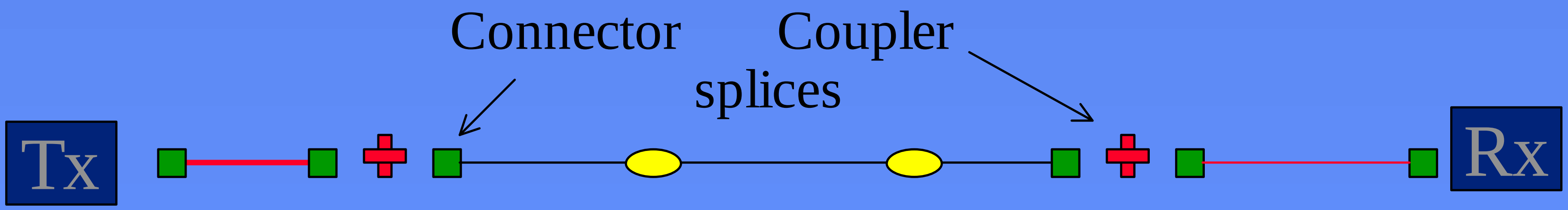
Note: some transceivers assume one pair in power budget

Fiber Optic Testing

Assumption: Loss per Mechanical Splice

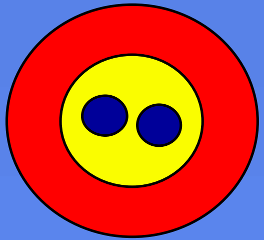
0.15 dB mean

splice attn (dB) = number splices * splice loss (dB)



2 splices X 0.15 dB/splice = 0.3 dB splice loss

Fiber Optic Testing - Cable Attenuation



Attenuation coefficient 62.5/125 um

3.75 dB/km max. @ 850 nm

1.5 dB/km max. @ 1300 nm

Attenuation Coefficient singlemode indoor

1.0 dB/km max.@ 1310 nm and 1550 nm

Formula: cable attn (dB)=attn coefficient (dB/km)*length (km)

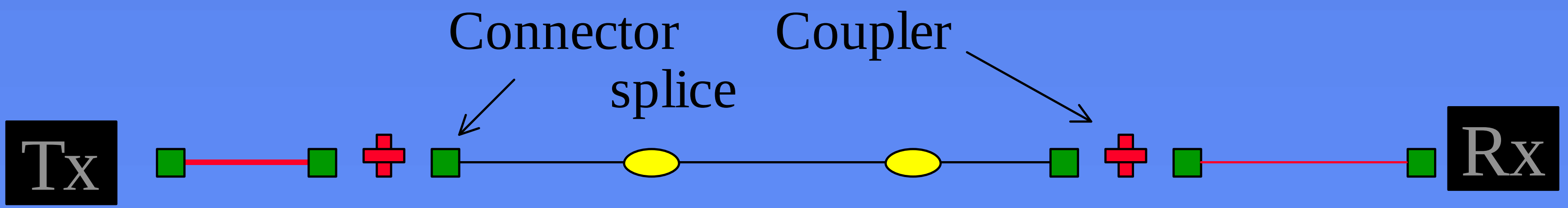
Example: What is cable loss for 10 Km of 62.5/125 cable at 1300 nm window?

Answer: 10 Km * 1.5dB/Km = 15 dB

The Big Test

Calculate the link loss from the information given

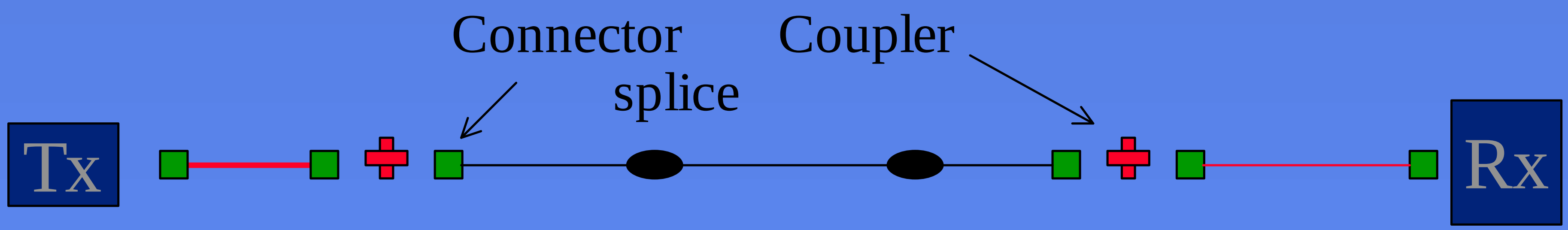
Link Loss = Cable Attn + Connector Attn + Splice Attn



Assuming 62.5 /125 glass attenuation is 3.75 dB/Km @ 850 nm, what is the total link loss @ 850 nm wavelength if the cable length is 2 Km?

Connector loss is 0.4/pr. & mech. splice is 0.15 dB/splice

Link Example



Assuming 62.5 /125 glass is 3.75dB / Km @ 850 nm, what is the total link loss @ 850 nm wavelength if the cable length is 2 Km?

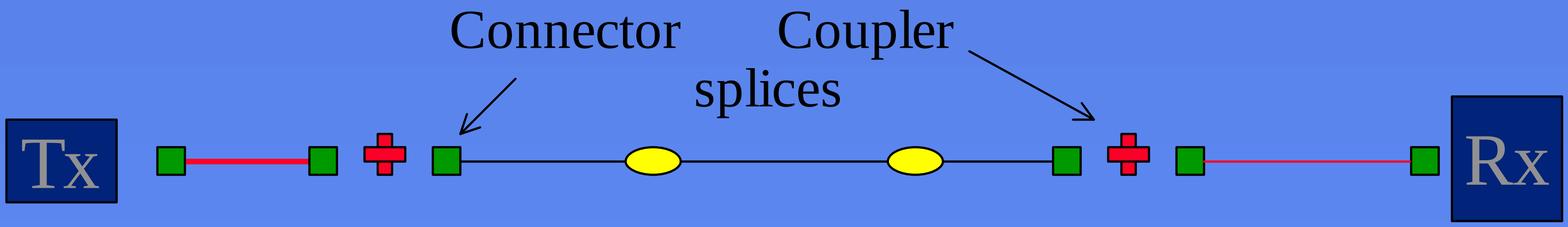
Answer:

Cable ……3.75 X 2 = 7.5 dB
Connectors 3 X .4 = 1.2 dB
Splices……..2 X .15 = .3 dB

Total: 9.0 dB

Application Example - FDDI

FDDI has a power budget of 11 dB at 1300 nm.



For this link, assume 1.5 dB/km cable attenuation @ 1300 nm & a cable length of 2 Km.

What is the total link loss?   3 dB for cable, 1.2 for connectors, 0.3 for splices = 4.5 dB total loss + 1 dB “allowance” = 5.5 dB planned loss

A loss allowance of 1 dB is added for system degradation over life use. This example shows a cabling margin of 11 dB - 5.5 dB = 5.5 dB

Link Loss Calculation

- **There are a number of different methods:**
  - Worst case analysis
  - Mean & variance analysis
  - Typical + allowances for system degradation
- This presentation is simply to demonstrate the concept

A good methodology can be found in Chapter 13 of *The Handbook of Fiber Optic Data Communication*

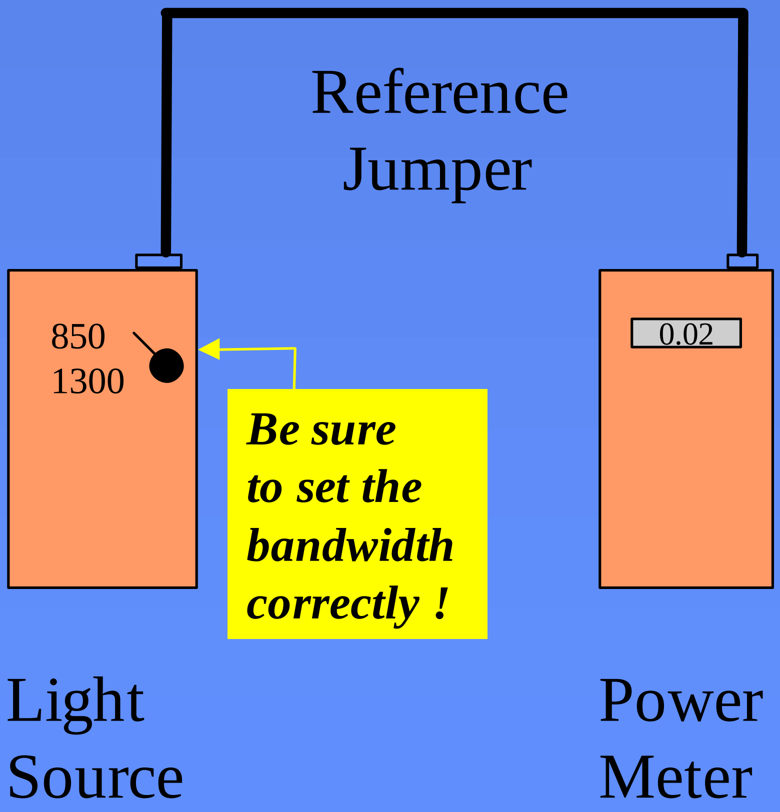
Optical Fiber Testing

Single Reference Jumper Method

Described in ANSI/TIA/EIA-526-14A, Method A.

1. Insert one jumper of known good quality between the light source and the power meter.

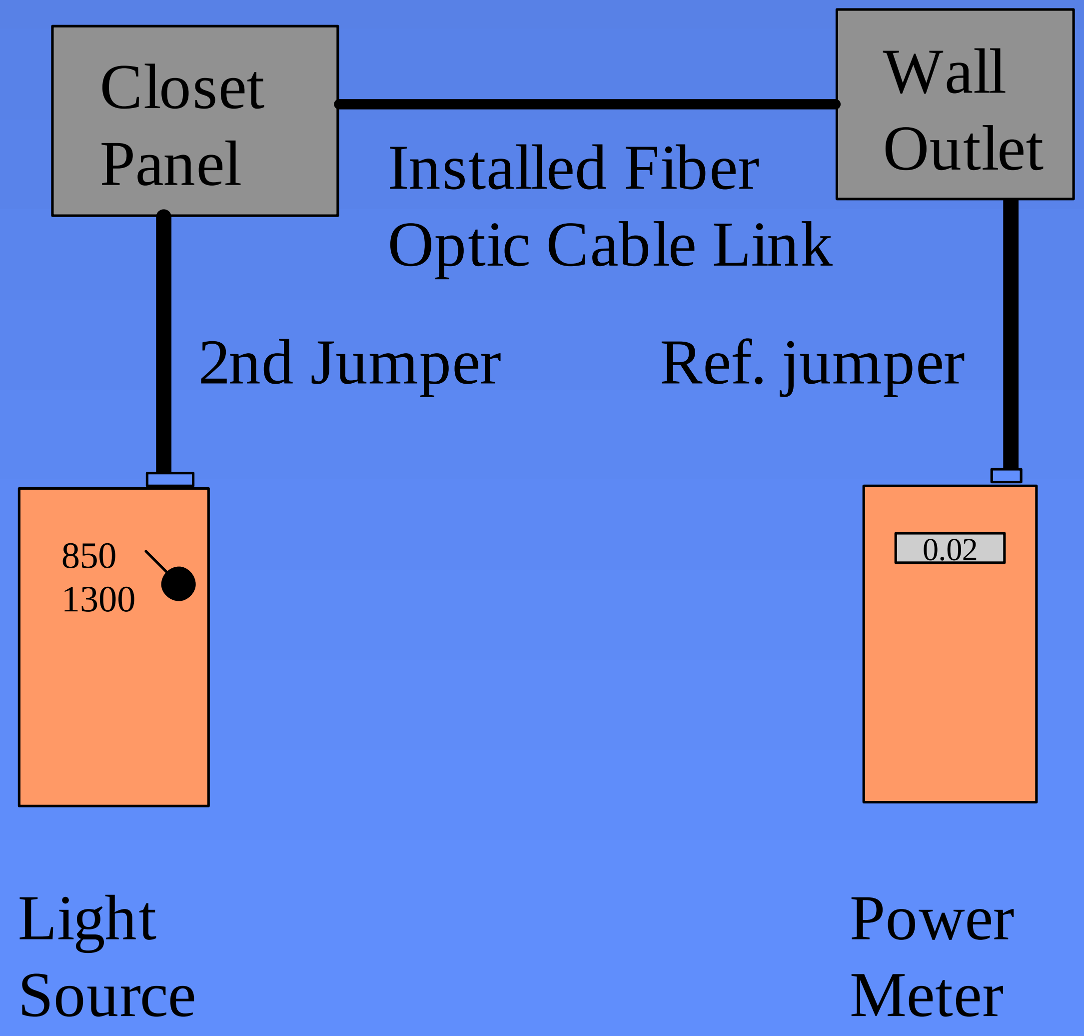
2. Note the reading or zero the meter.



Optical Fiber Testing

Single Reference Jumper Method

3. Disconnect jumper from power meter.
4. Connect light source with jumper to one end of link.
5. Connect power meter with a second jumper.
6. Activate source and meter.
7. Record readings.



Fiber Optic Testing

Typical Optical Fiber Test Equipment:
light sources, power meters, OTDRs

Fiber Link Troubleshooting

OTDR (Optical Time Domain Reflectometer)

Results include:

*** Length**

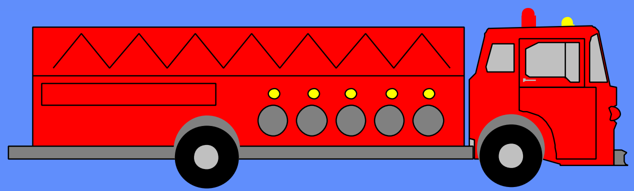
*** Attenuation**

*** Splice Losses**

*** Stress Points**

OTDR Testing is detailed in the EIA / TIA Standard FOTP-61 (455-61)

OTDRs are primarily used for emergencies / troubleshooting



OTDR Testing

Spikes are reflections due to connectors or splices.

Standard OTDR trace showing power loss vs distance with a sharp decline at transition point

A Very Brief Overview of Optical Cabling Installation Practices

Cable installation

Cable tensile strength

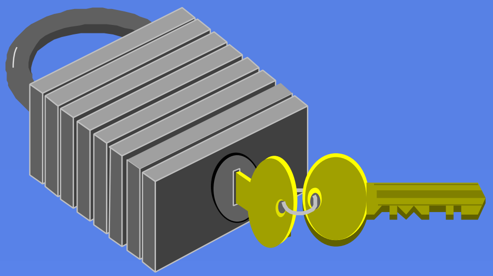
Pulling techniques

Pulling eyes

Minimum Bend Radius

Long Term vs Short Term tensile loads

Enclosures & Outlets



Fiber Optic Installation Guide

When pulling cable, the load must be applied to all parts of the cable.

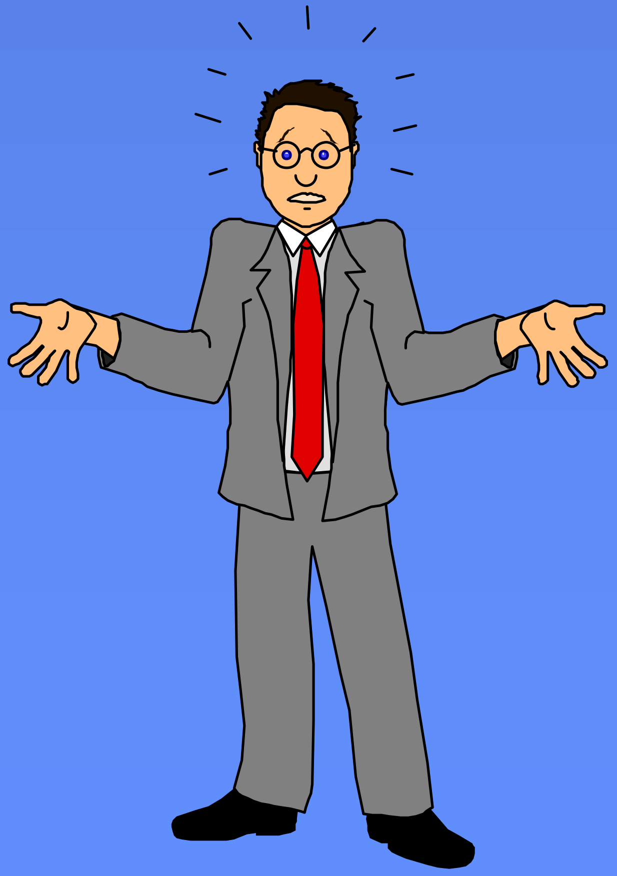
Some types of indoor cable require special installation procedures

Failure to lock the cable components together during installation can lead to elongation of the jacket material or glass failure

Plastic can stretch 200-500% while Kevlar / aramid fiber and optical glass will not stretch. Kevlar is there to pull on with the jacket to protect the optical glass.

Pop Quiz (Just like in school)

- **Which cable has the highest tensile pulling strength?**
  - **Unshielded twisted pair copper, 4 pair, 24 AWG**
  - **Unshielded twisted pair, 25 pair, 24 AWG**
  - **Fiber optic, 2 fiber (duplex) round**



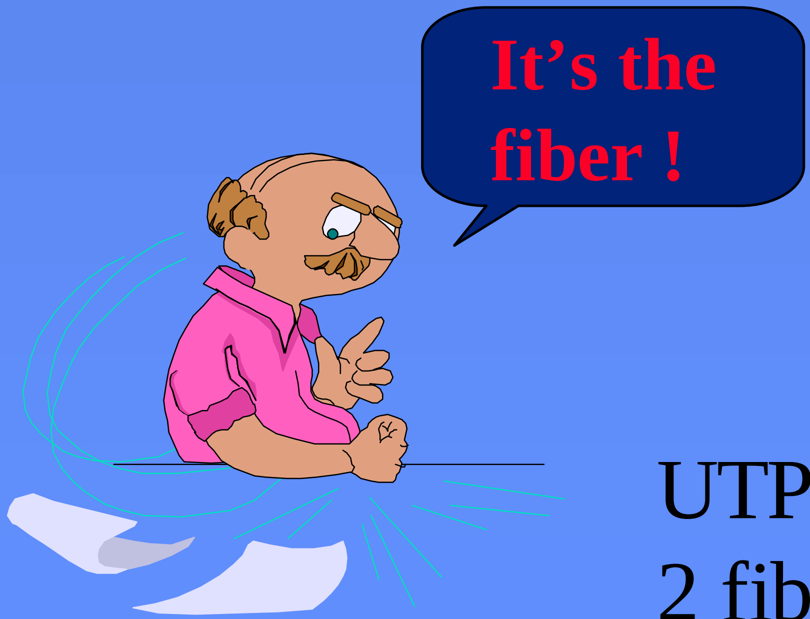
Tensile Strength
Pop Quiz Answers

Typical 2 fiber cable is

6 X stronger than Category 5

UTP cable

and 1.5 X stronger than 25 pair PowerSum cable



UTP: 100 - 250 Newtons

2 fiber cable: 900 - 1100 Newtons

Fiber Optic Cable- Pulling Eye

1. Strip off 14 to 16 inches (35 to 40 cm) of the outer jacket of the cable.
2. Bend the fibers back onto the cable and tape in place using electrician's tape.

Fiber Optic Cable - Pulling Eye

3. Twist the Kevlar to facilitate handling then bring back over the cable forming a loop.

4. Continue taping the fibers and the Kevlar past the end of the cable jacket.

Pulling Grip Installation

1. To install a split mesh pulling grip first strip 6 to 8 inches (15 to 20 cm) of the outer jacket of the cable.

Pulling Grip Installation

2. Apply friction tape over 6 to 8 inches of the outer jacket and continue over the stripped portion.

3. Compress the split mesh grip and slip over the cable end. squeeze the grip down onto the friction tape.

Pulling Grip Installation

4. Apply electrician's tape over the cable.

5. When pulling cable with a split mesh grip install a swivel between the grip and the rope.

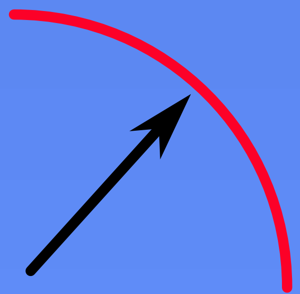
Fiber Optic Installation - Bend Radius

Minimum Bend Radius:

1. **Installation Bend Radius**
   (under high pulling stress or "loaded")
2. **Long Term Bend Radius**
   (after installation or "installed")

Bending the cable below the minimum bend radius can:

1. **Damage the cable jacket.**
2. **Shorten the life of the fiber or break the glass**



Note: cable manufacturers have different methods of calculating loads and radii.

Tensile Loads & Bend Radius
Basic Rules

- Don’t bend a cable sharply when installing
- The tighter you bend the cable when storing it away, the higher the chance of glass failure in the future
- Easy equations for standard tight buffered cable designs:

Minimum installed bend radius = ~10X dia. of cable

Max. pulling bend radius = ~1.5X installed bend radius

Max. pulling tensile load = ~2.5X to 3X installed load

Load and Bend Values

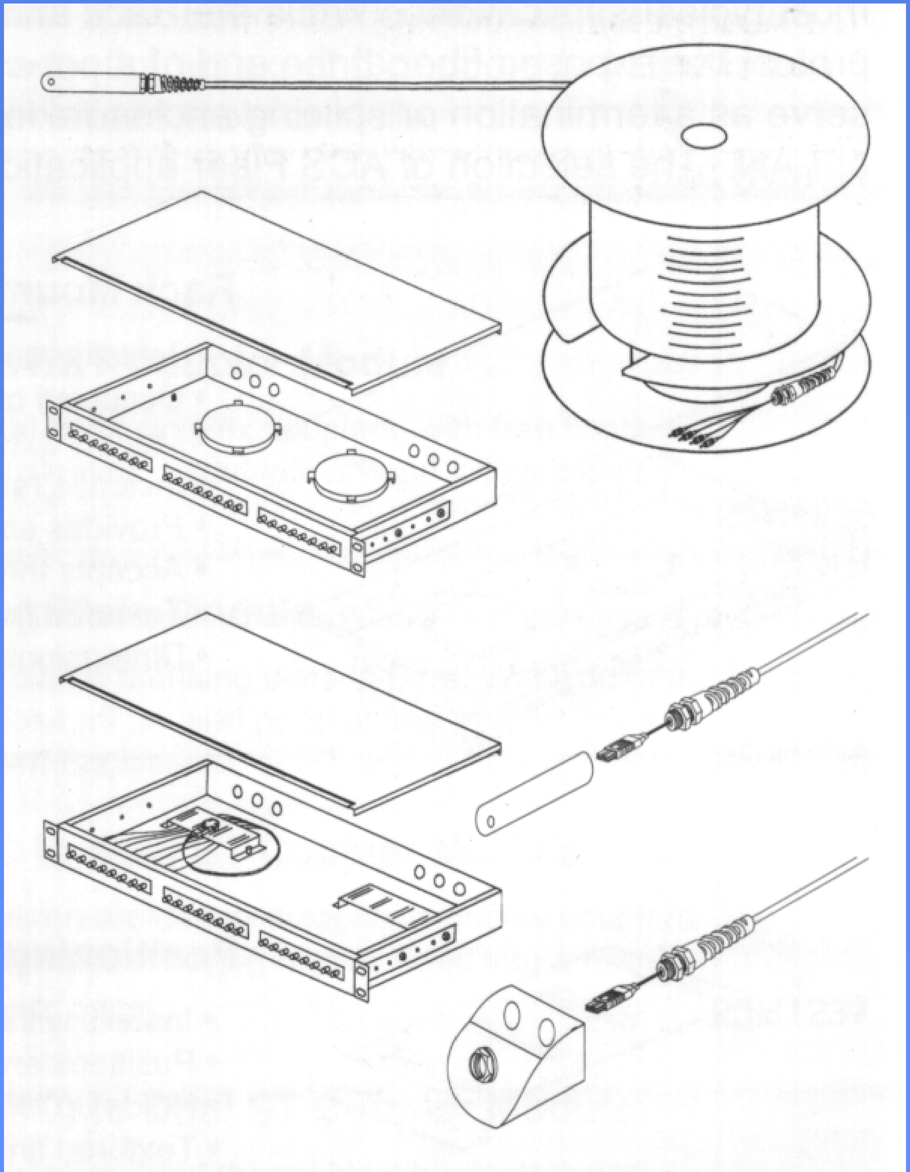
Maximum tensile load depends on cable series and fiber count..specified by cable supplier

Example: 12 fiber mm riser cable..7 mm diameter

	Short term or "loaded"	Long term or "installed"
Maximum tensile load	**405 lbs (1800 N)**	**135 lbs (600 N)**
Min. Installation bend radius	**4.1 in. (10.5 cm)**	**2.8 in. (7 cm)**

Enclosures

- many styles & fiber counts available
  - » counts as high as 144 are common
- grouped usually in 3 styles:
  - » termination enclosures
  - » splice enclosures
  - » combination enclosures



Outlets

- **Outlets are available for fiber to the desk applications**
- **When there is insufficient room for fiber storage in the wall, surface mount multimedia outlets are used**

End of Class 3

Solutions for a small world

Classes 1, 2a / 2b and 3 were intended as an introduction to optical fiber communications. No prior knowledge of optics is assumed.

The time required for presentation of these classes is 6 hours given a technically oriented audience with interest in optics communication.

This presentation is not intended to be a sales & marketing tool. It is a teaching tool. Specific supplier detail has been intentionally avoided to prevent teaching bias. Although it has been examined by many industry experts, I can not list them all here for fear of offending those I forgot. Those with input to this course material will know who they are.

Questions & Comments should be referred to Joseph Iamartino @ worldnet.att.net