AFL Telecommunications
A Fujikura Business

Fiber Optic Sensing Overview

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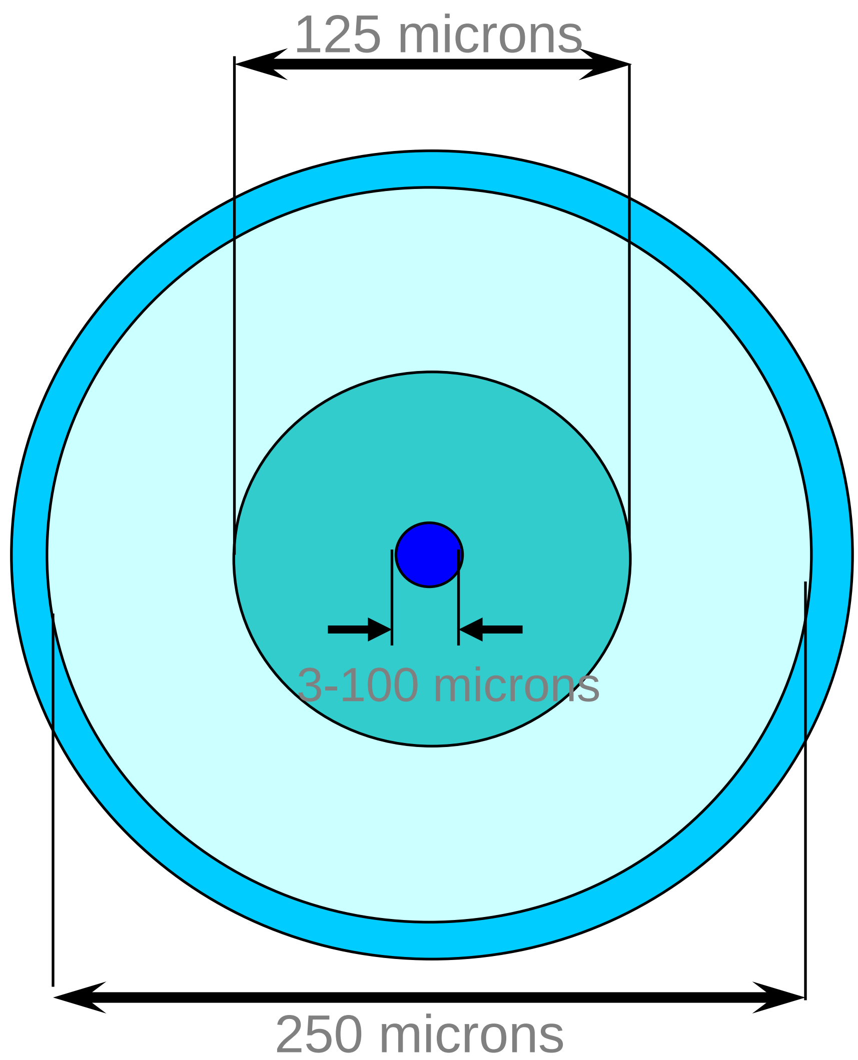
April 30, 2009

"Tsunagu" Technology
Fujikura

Contents

Fiber Structure

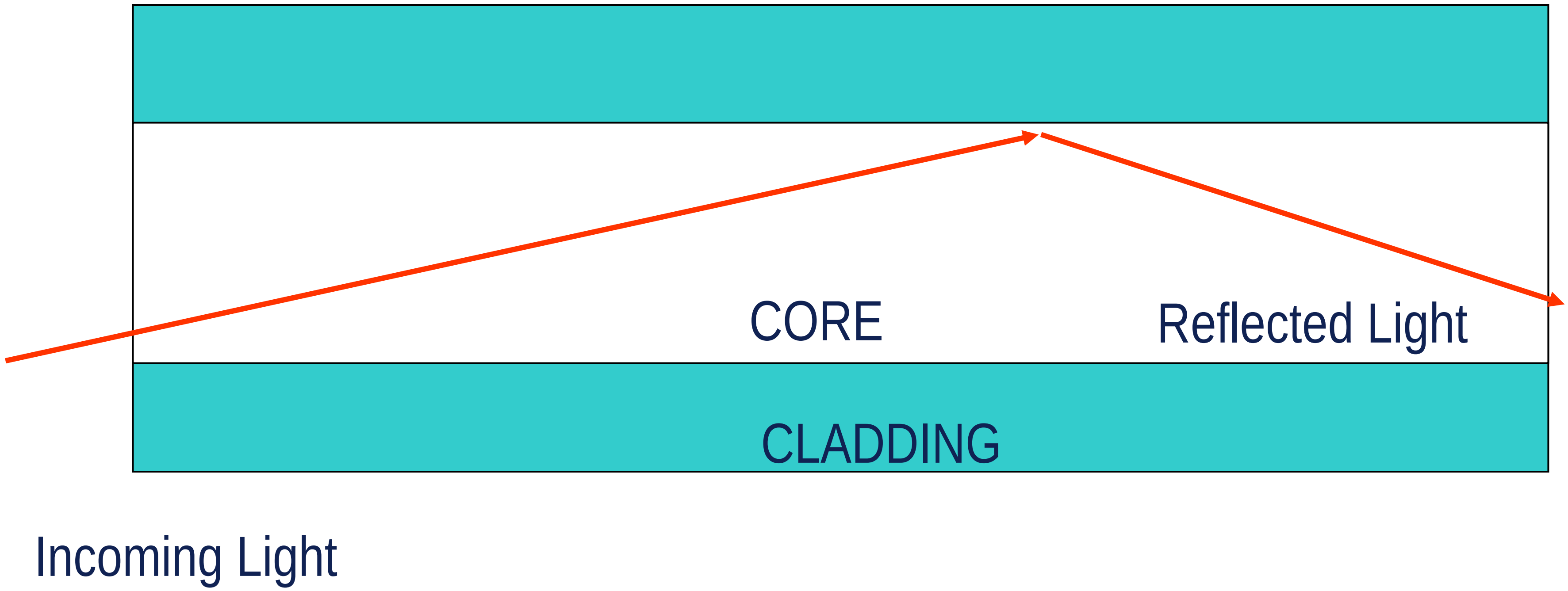
- **Core** - The center of an optical fiber. Contains dopants to change speed of light.
- **Cladding** - Outer layer of glass to contain light. Different refractive index.
- **Coating** - Cushions and protects fibers (Primary Buffer).



Optical Waveguiding

The cladding "holds" the light inside the core. Thus, we can control the direction in which a light signal is propagated. This process is called "Total Internal Reflection."

Total Internal Reflection



Total Internal Reflection is achieved through:

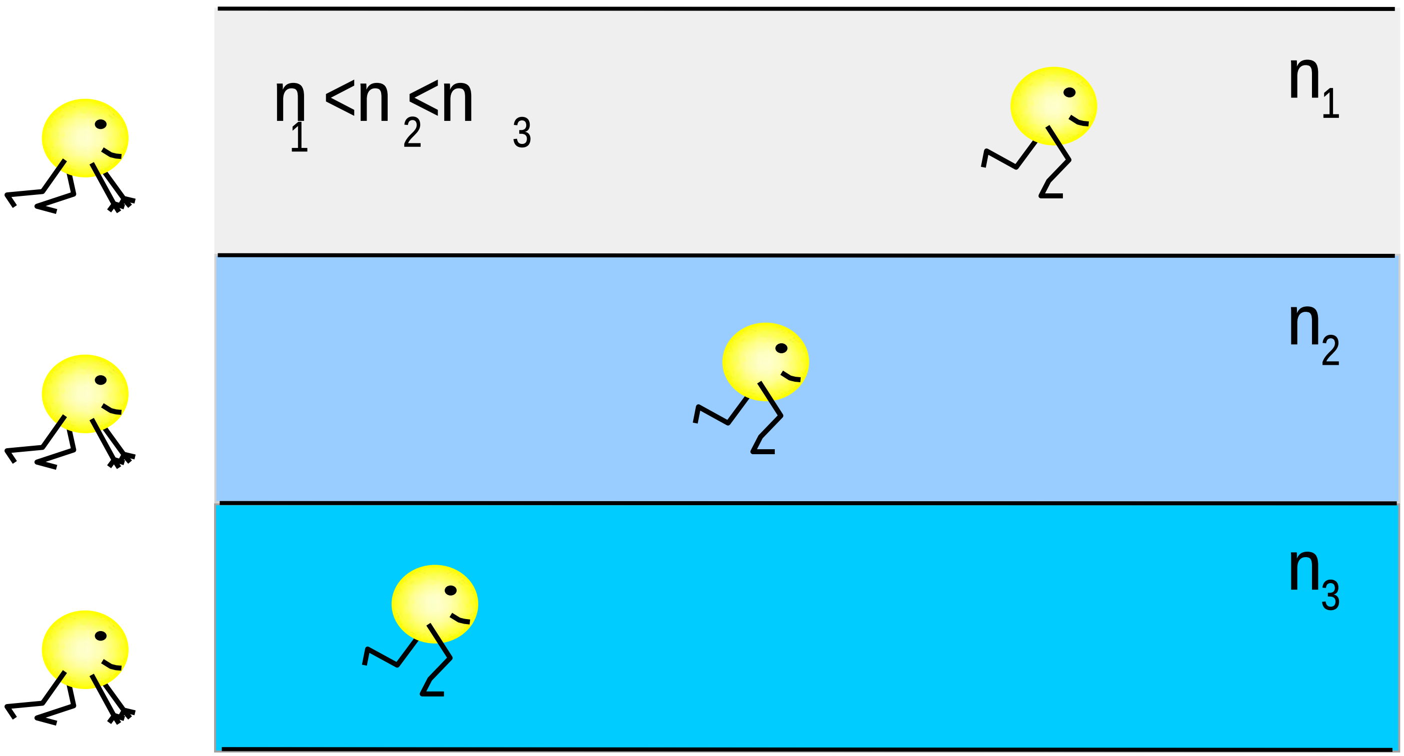
- Keeping the light signal inside the “Critical Angle.”
- The Critical Angle is a function of the “Index of Refraction” between the core and cladding.

Index of Refraction

- **n** is the abbreviation assigned to index of refraction
- The index of refraction (n) is a ratio comparing the speed of light (c) in a vacuum to the speed of light in a medium.
- Optical glass has **n** approximately equal to 1.45

$$n = \frac{C_{vac}}{C_{mat}}$$

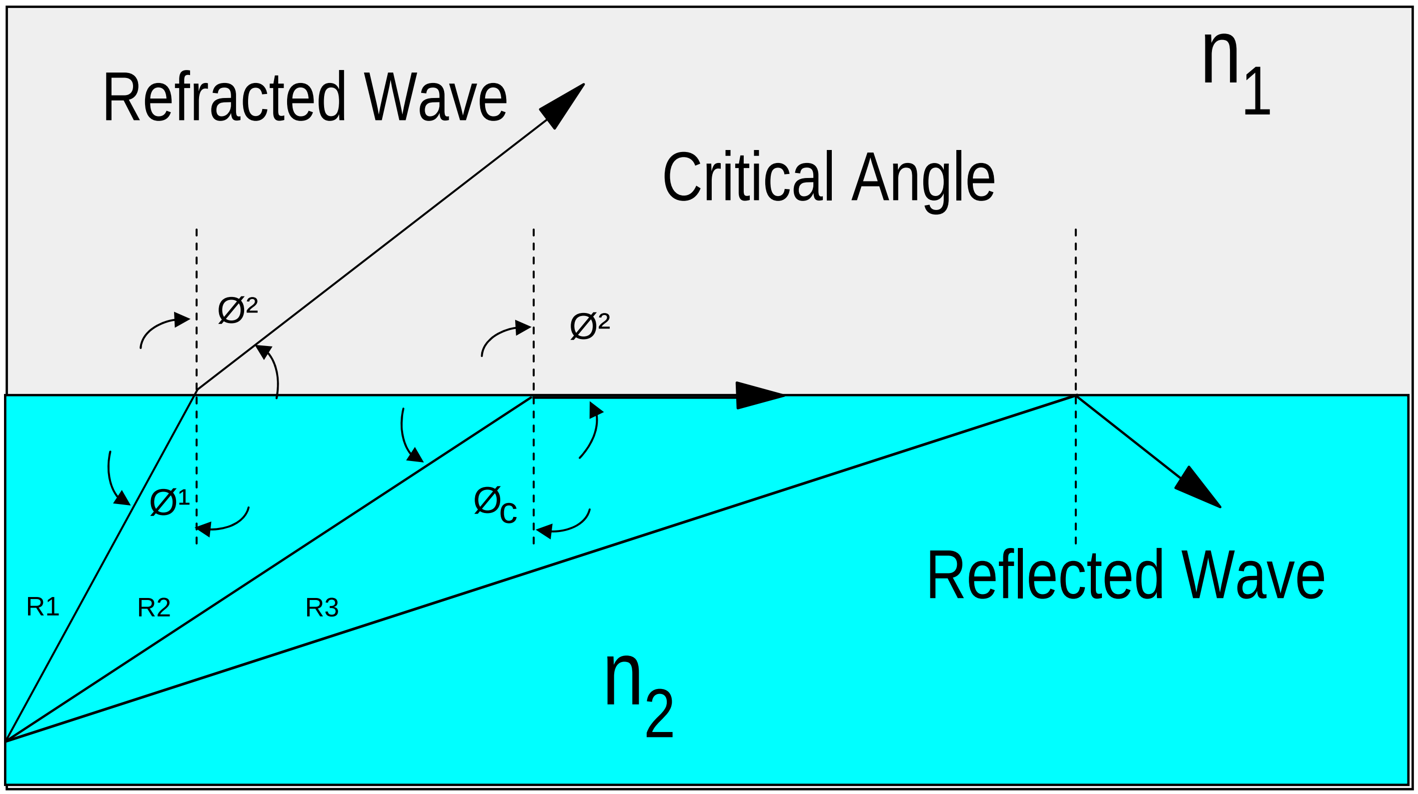
Refractive Index (Optical Density)



The lower the refractive index ("n") the faster the light travels

Light will bend as it travels from a material with one index of refraction ("n") to a material with another "n." The bend increases as the angle of entry decreases. Eventually, the angle is small enough to prevent light from entering the other "n." This is the "Critical Angle."

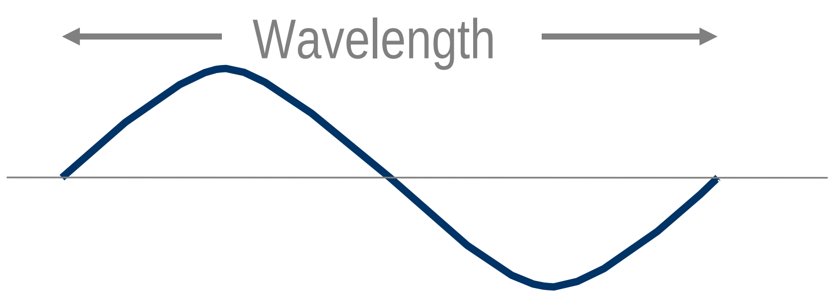
Critical Angle



Snell's Law

Wavelength in Fiber Optic Systems

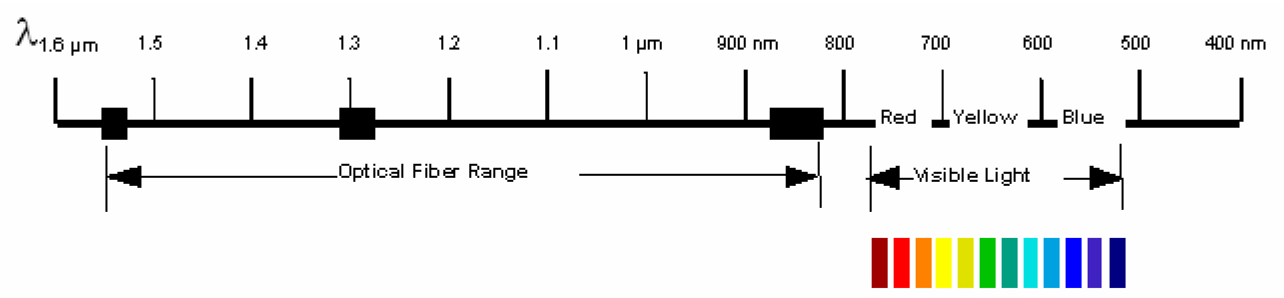
- Wavelength is defined as the distance, in nanometers, between one point on a wave to the corresponding point on the next wave
- A Nanometer = one-billionth of a meter



Standard Wavelengths

- For single mode fiber
  - 1310 nm and 1550 nm
- For multimode fiber
  - 850 nm and 1300 nm

*Note: All transmission wavelengths for optical fiber operate in the infrared spectrum of light. Thus, the light is not visible.



Attenuation ...

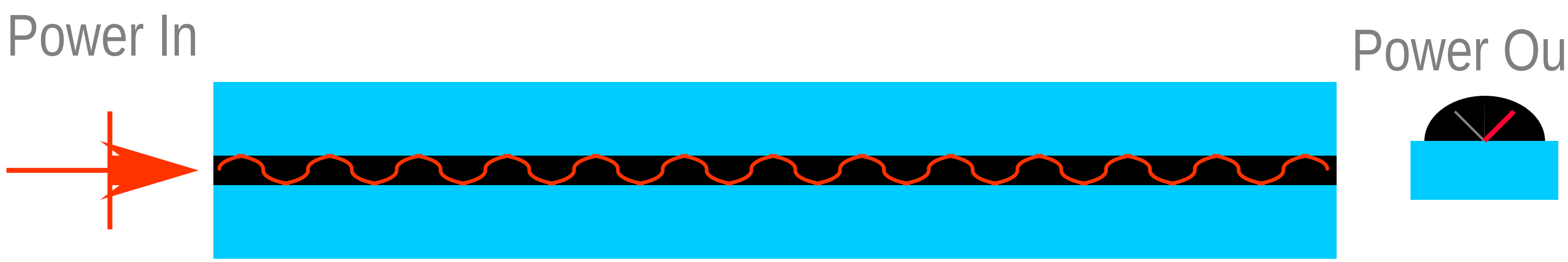
is the decrease in optical power

- Measured in decibels (dB)
- Limits the distance the signal travels
- Some attenuation is inherent in glass
- Some attenuation can be induced by people and the environment

Attenuation

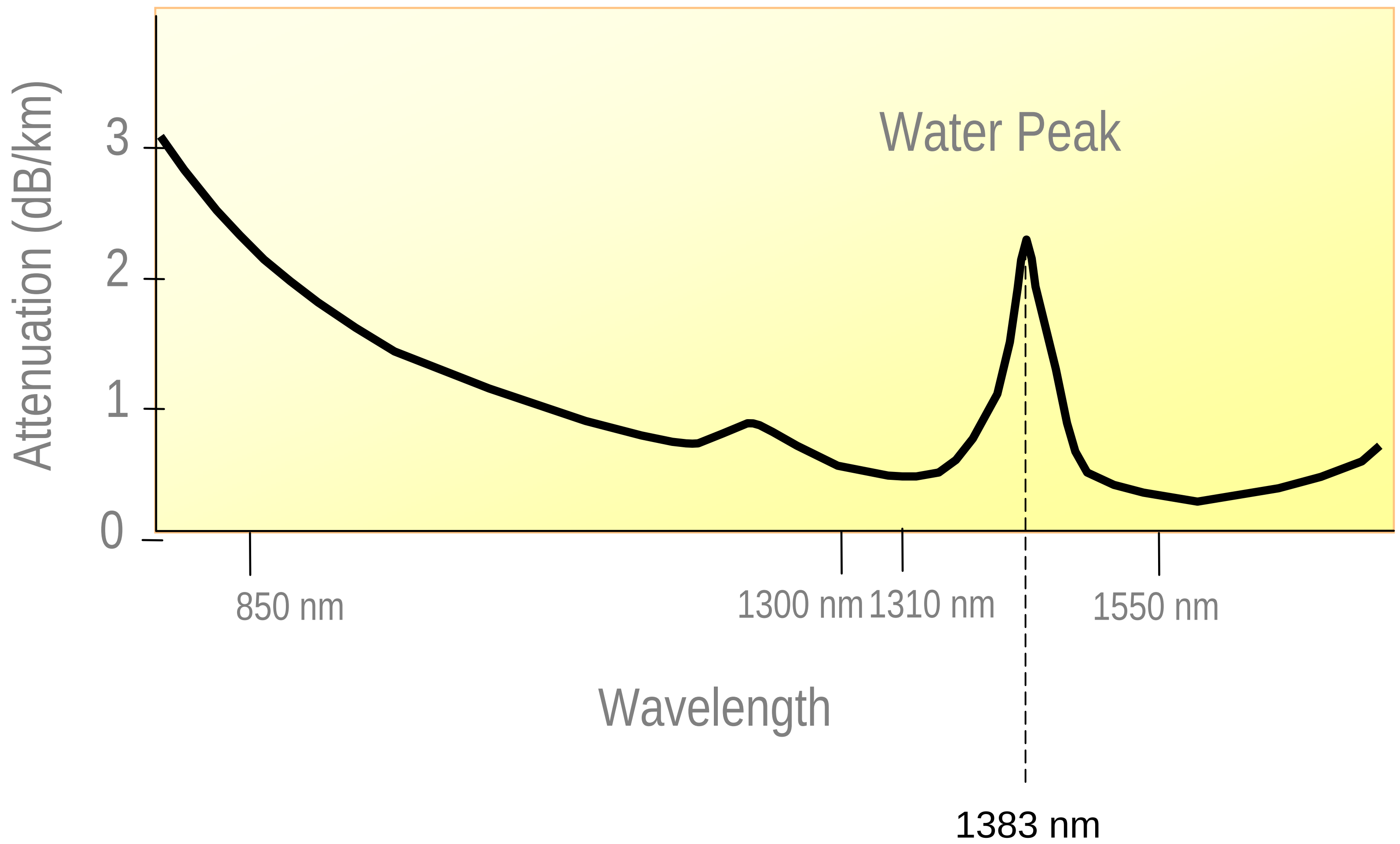
Attenuation

$$\text{Attenuation in decibels (dB)} = -10 \log \frac{\text{Power Out}}{\text{Power In}}$$

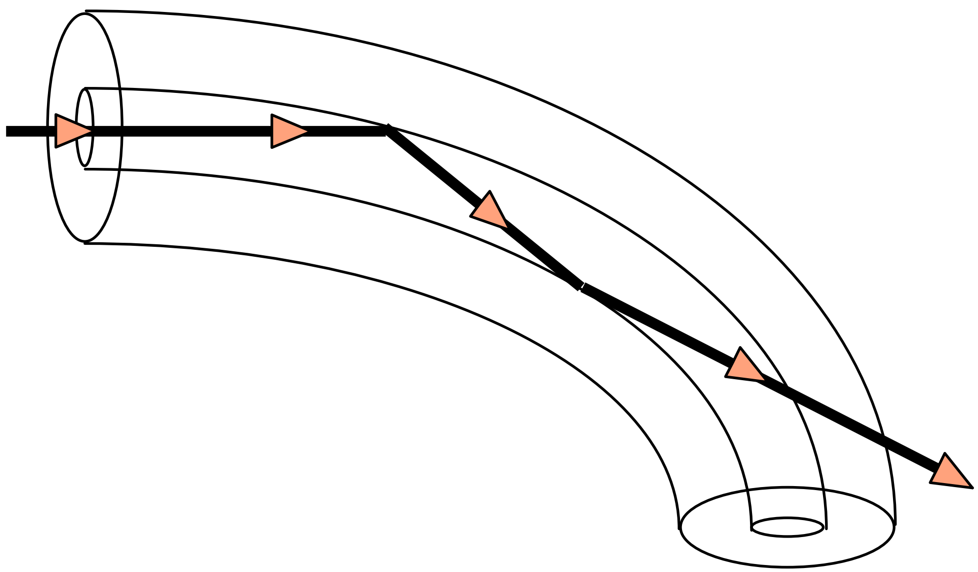


dB	Power Through
0.3	93 %
0.4	91 %
3.0	50 %

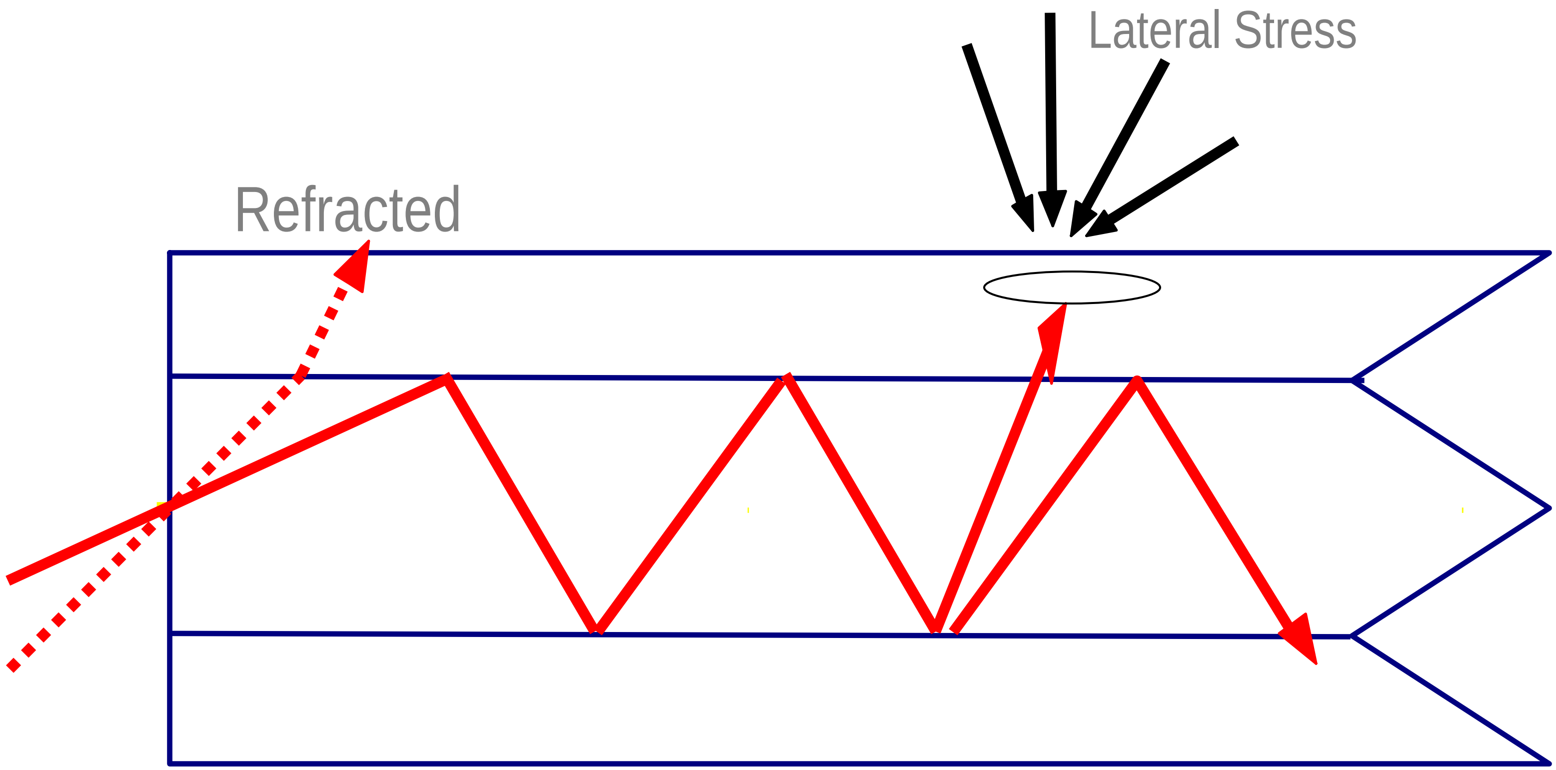
Intrinsic Attenuation



Extrinsic Attenuation
“Macrobend”

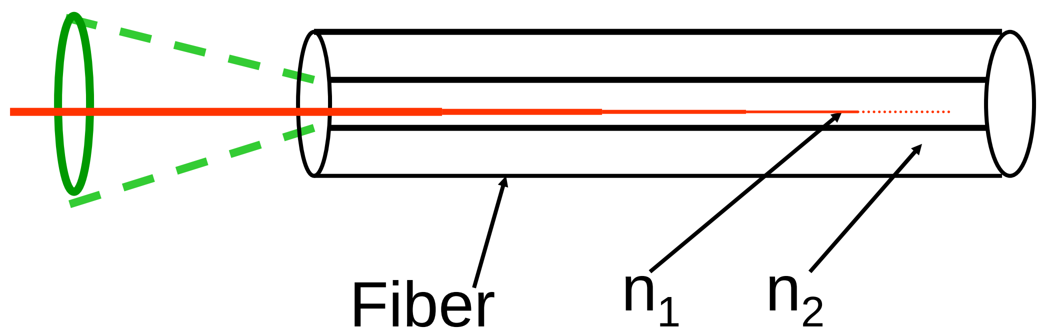


Extrinsic Attenuation "Microbend"



Photon Interaction With Optical Fiber Elements

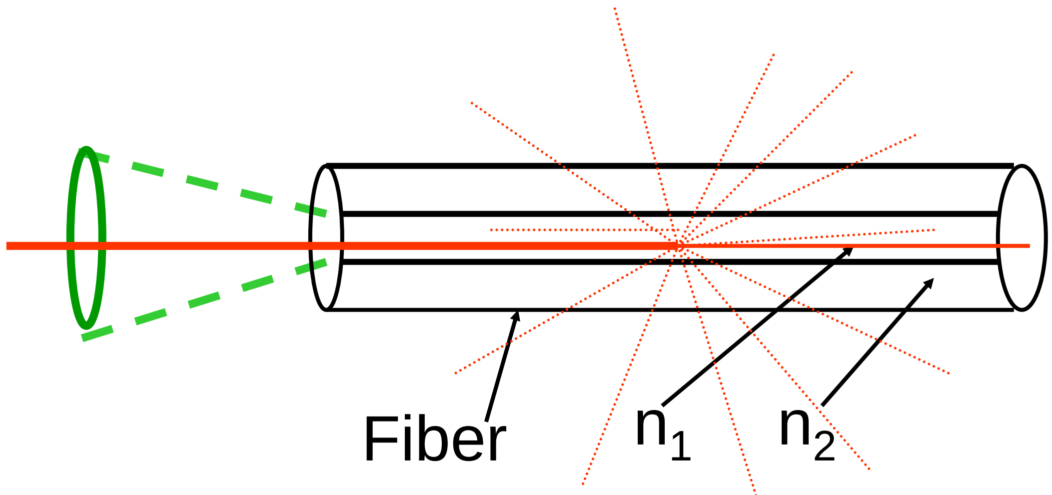
-Absorption



Photon Interaction With Optical Fiber Elements

-Absorption

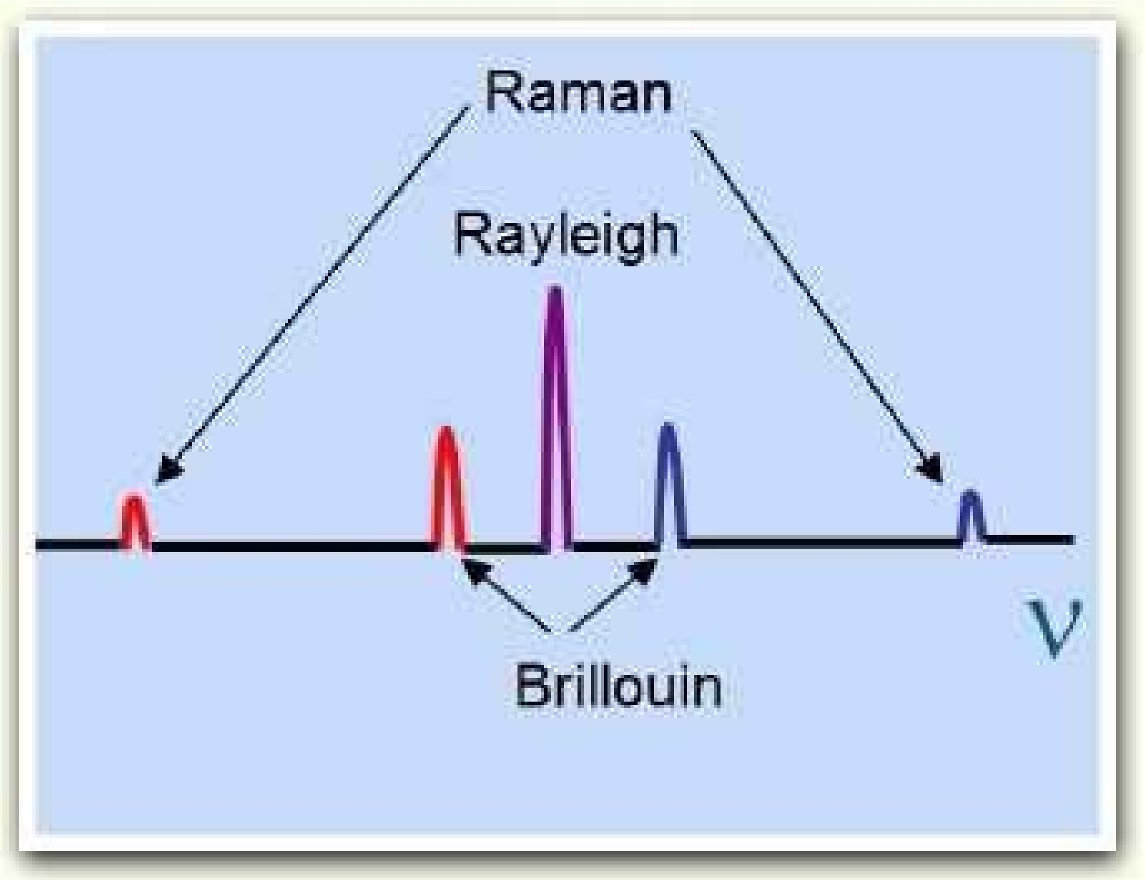
-Scattering



Scattering

- Rayleigh Scattering
  - Elastic scattering - same energy level and wavelength as incident light
  - Commonly used to analyze optical parameters via OTDR
- Brillouin Scattering
  - Inelastic Scattering
  - Shift in wavelength based on acoustic vibrations of molecules in the glass structure
  - Sensitive to temperature and strain
- Raman Scattering
  - Inelastic Scattering
  - Shift in wavelength and intensity based on thermally induced molecular vibrations

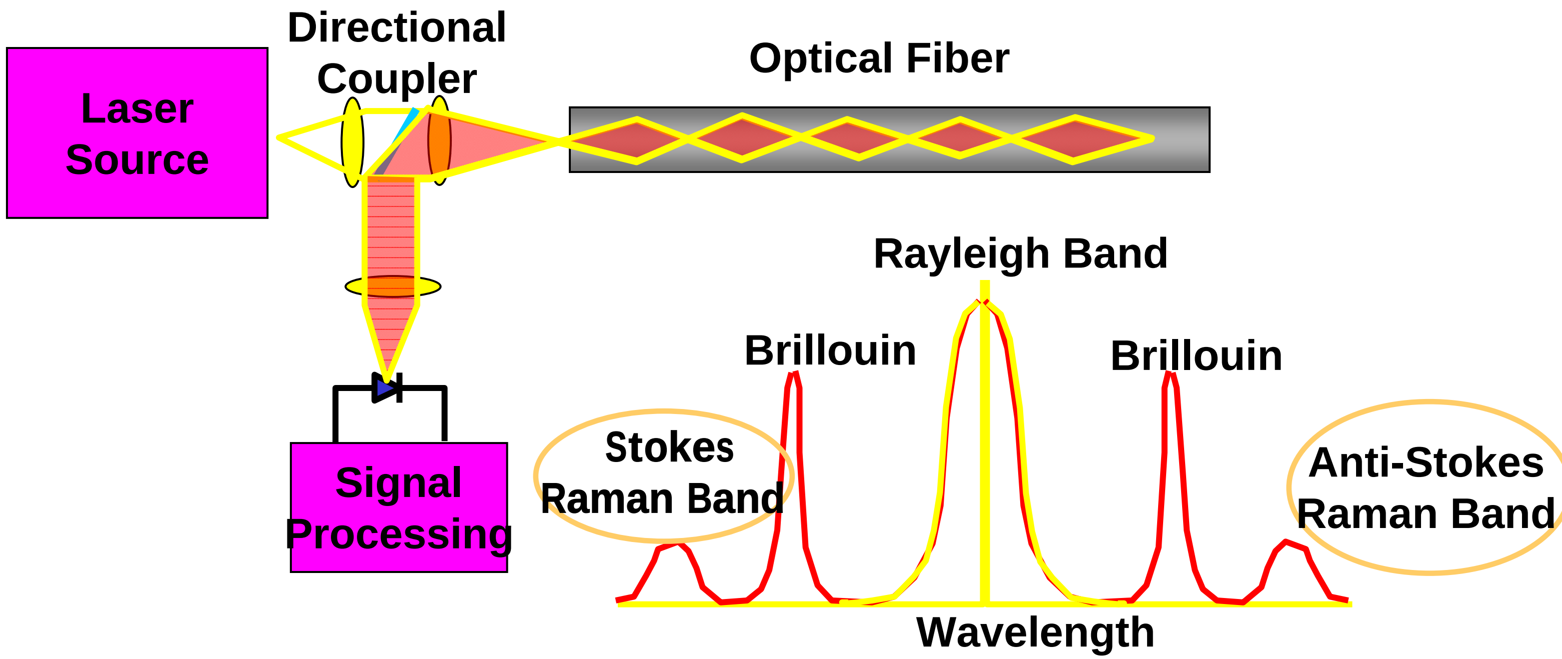
Typical Reflection Spectrum



Raman Effect, Stokes/Anti Stokes

- Based on energy exchange between incident photons and molecules in the glass structure.
- If the molecule absorbs energy stokes scattering occurs at a lower wavelength.
- If the molecule loses energy anti-stokes scattering occurs at a higher wavelength. This exchange can be induced by changes in temperature.

DTS Principles of Operation



Advantages of Optical Sensing

- Passive optical fibers are immune to the effects of EMI and RFI
- Less vulnerable to lightning
- Commercialized cable designs make it suitable for use in a variety of harsh environments
- Optical sensing enables distributed measurements which means temperature can be monitored all along the length of the optical fiber.

Cable Design Considerations

Application

- Underwater / Sub-Sea
- Aerial
- Duct
- Direct Buried
- Downhole
- Building
- Tunnels / Sewers
- Surface

Cable Design Considerations

Environmental Considerations

- Temperature
- Pressure
- Hydrogen Sulfide
- Corrosive Agents
- Strain
- Tension
- Compression
- Electrical
- Chemical
- Dynamic / Static
- Rodent

Cable Design Considerations

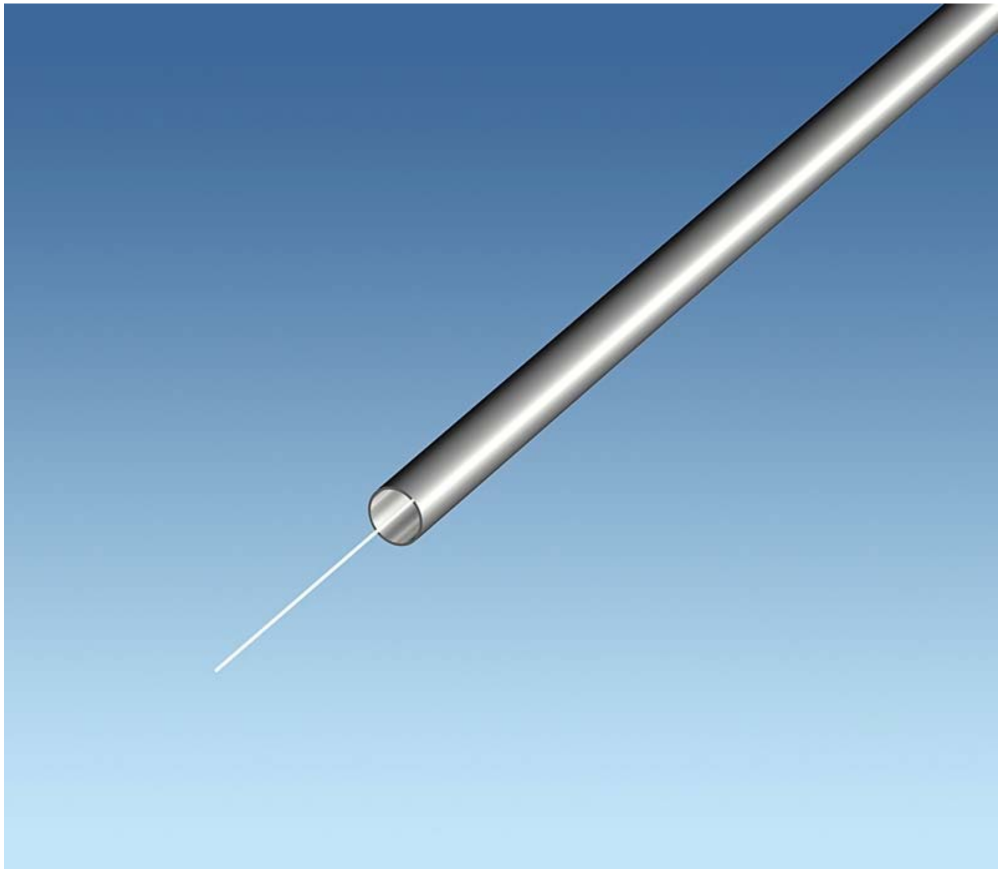
Customer Performance Requirements

- Optical loss budget
- Fiber type / count
- Cable OD / weight
- Metallic vs. Dielectric
- Fiber strain window
- Deployment / ease of installation
- Price and delivery

Hermetically Sealed Stainless Steel Tubes

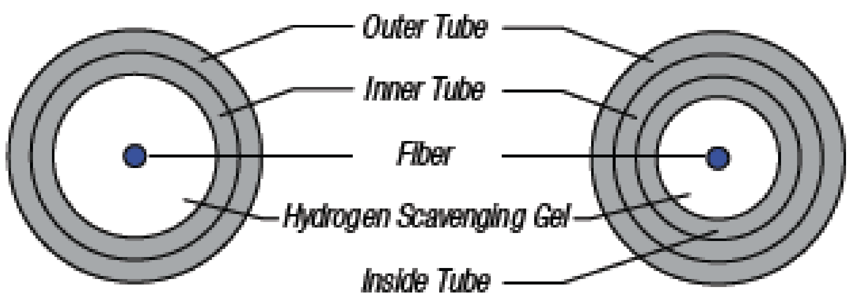
Requirements and Capabilities

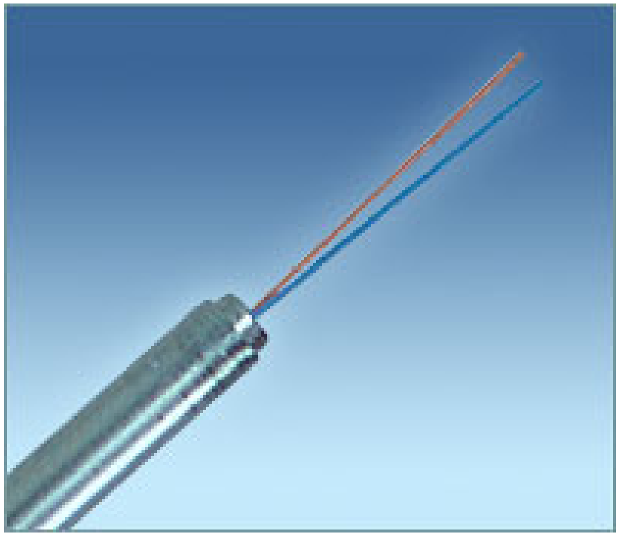
- Stainless Steel Tube (SST)
- 1 to 72 fiber
- Hydrogen Scavenging gel
- 1.1mm to 3.8mm Diameters
- Tube thickness
  - Tube in Tube
    - Patent Pending
- Special metals
- Clean tube option
- lengths up to 50 km



AFL Product Solutions

- Double and Triple Tubes (Patent Pending)



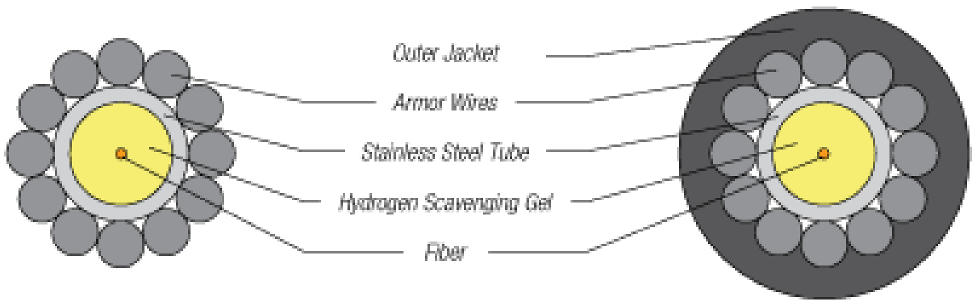


- Suitable for installation in:
  - Tunnels,
  - Roadways
  - Runways
  - Gasifiers
  - Any Industrial Application

Crush resistance, temperature resistance, and quick thermal response in a small yet very robust package.

AFL Product Solutions

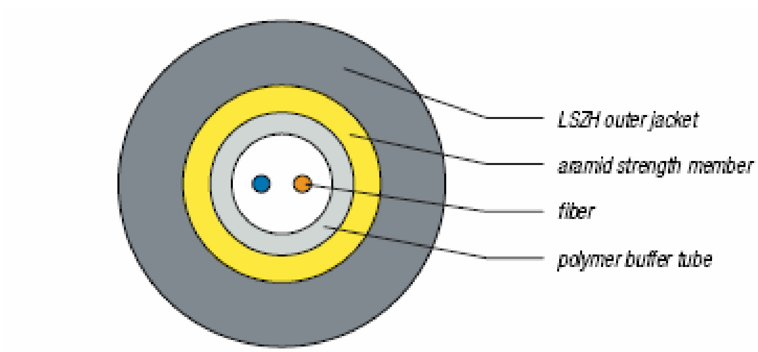
- Armored Metal Tubes

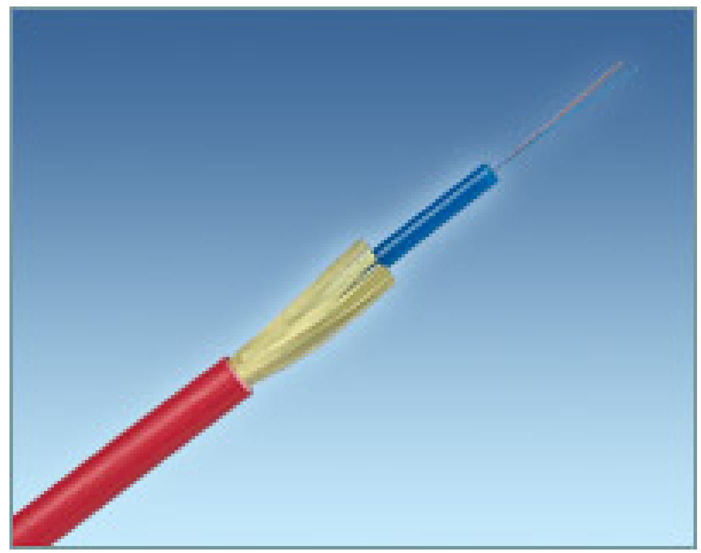


- Small Diameter .083 inches (2.12mm)
- Mechanically Robust
- Flexible
- Virtually chemically inert (316SS tubes and wires)
- Optional jacket for improved handle ability

AFL Product Solutions

- LSZH Distributed Temperature Sensing Cable





- Cost effective solution compared with metal tube alternatives
- LSZH Jacket for indoor use applications
- UV stabilizers for outdoor use
- Small diameter
- Flexible
- High tensile strength

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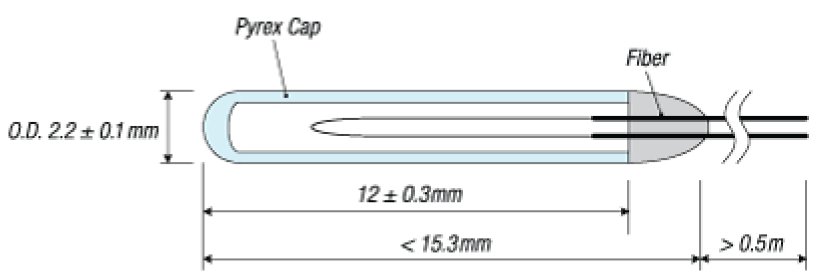
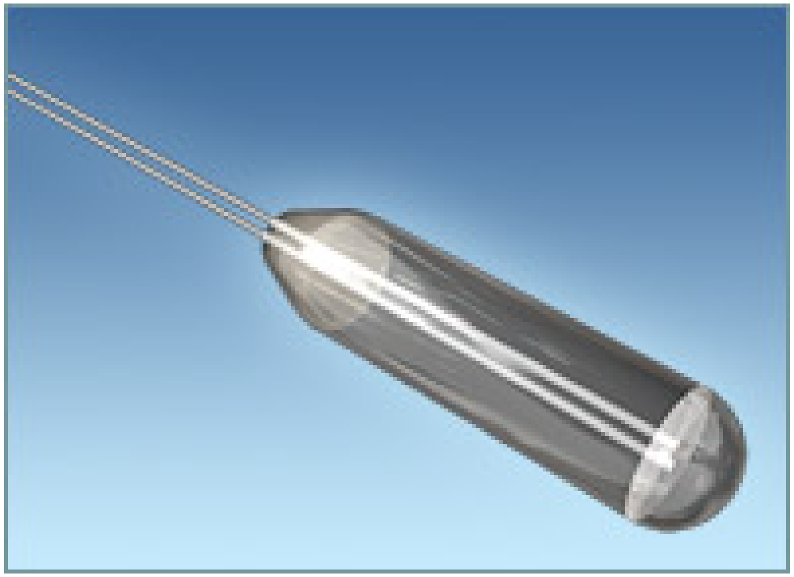
AFL Product Solutions

- Mini Bend Double Ended System





•Low insertion loss	<0.1dB
•Small diameter	2.2mm
•Short length	8.0mm
•Temperature	232C @500hrs
•Fiber Type	50um Carbon/Poly

Fiber Types Available

- < 85^{o}C
  - Acrylate – SM, MM
    - Fujikura, Corning, others
  - Acrylate Bend Insensitive - SM
    - Fujikura
- < 200^{o}C
  - Silicone/PFA – SM, MM, Pure silica SM
    - Fujikura
- < 300^{o}C
  - Polyimide, Carbon – SM, MM, Pure Silica SM
    - OFS, Verrillon, Ceramoptic, Fujikura
- < 700^{o}C
  - Metallized
    - FiberGuide

Cable Splicing

FSM 18S

SpliceMate™
A Mate You Can Trust

FSM 60 With Fuse Connect Capability

Cable Splicing

- Fusion Splicing Overview
- Fusion splicers use a high voltage electric arc
  - Do not use the splicer where explosive gasses are present

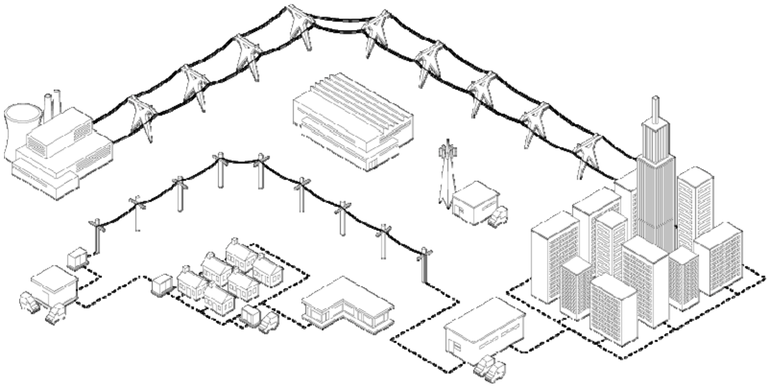
- Never view a fiber end without first determining there is no active Laser or LED

- After removing the coating from an optical fiber the exposed glass is sharp and can puncture the skin
  - Be aware of exposed glass
  - Dispose fiber scraps to keep work area free of potential hazards

- Follow your company's safety procedures

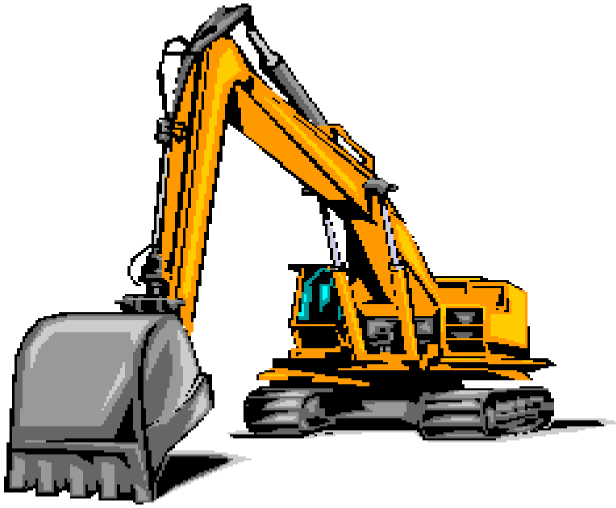
Why Splice?

- Join two or more fibers for continuous light path



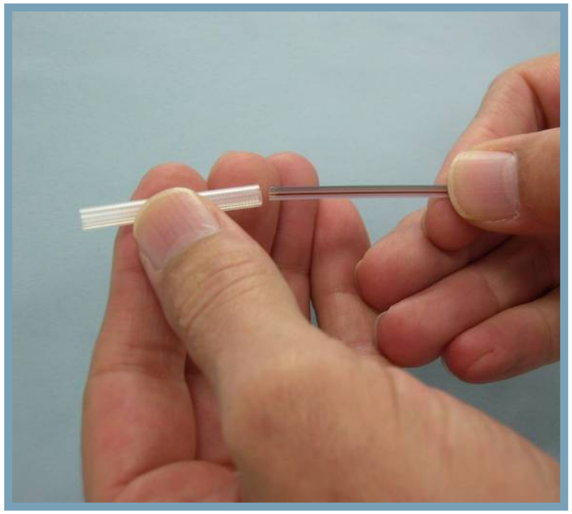
- May be required because of:
  - Length of system
  - Cable plant layout
  - System Restoration

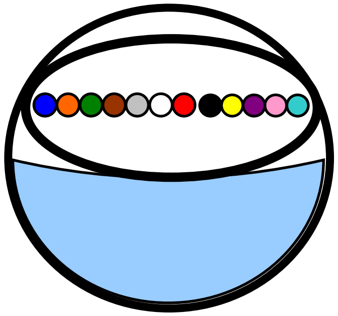
- Fusion splice loss can be as low as .01dB compared to connector loss that can be as great as .25dB
- ORL >60dB with fusion splice
- Mechanical splice insertion loss and ORL can fluctuate with ambient conditions



Fiber Preparation

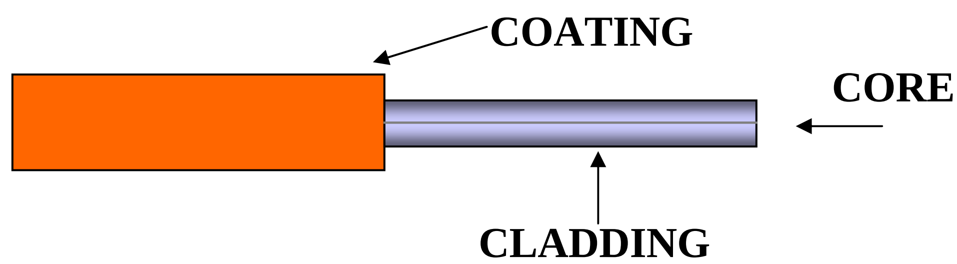
- Splice Protection Sleeve
  - Place a clean splice protection sleeve on one of the fibers to be spliced
  - In the case of ribbon splicing the glass rod of the FP-05 splice protection sleeve will be placed on the bottom of the tube heater





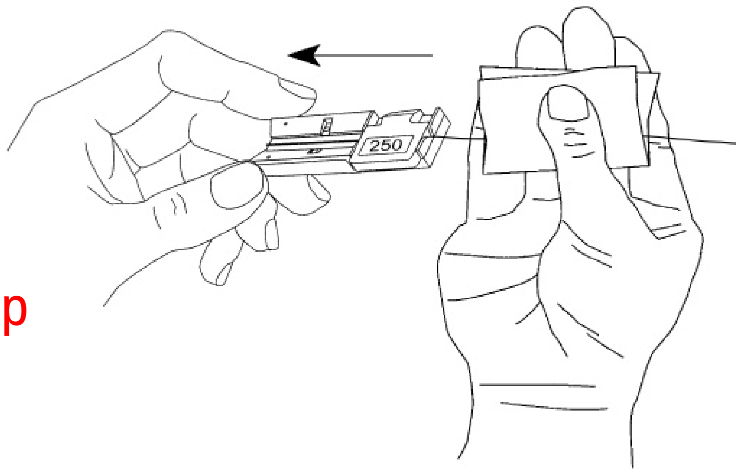
Fiber Preparation

- Stripping The Fiber
  - 250um coating
    - Use mechanical tool
    - Possible to strip a long length with a single pass
  - 900 buffer
    - Use mechanical tool
    - May need to make several passes stripping ¼” each pass
  - Ribbon
    - Requires a thermal stripping tool
    - Strip 30mm or about 1 ¼”



Fiber Preparation

- Cleaning The Fiber
  - Multiple wipes with a lint-free tissue lightly moistened with high-purity isopropyl alcohol (99% purity alcohol recommended)
  - Critical for splicing quality and splice strength

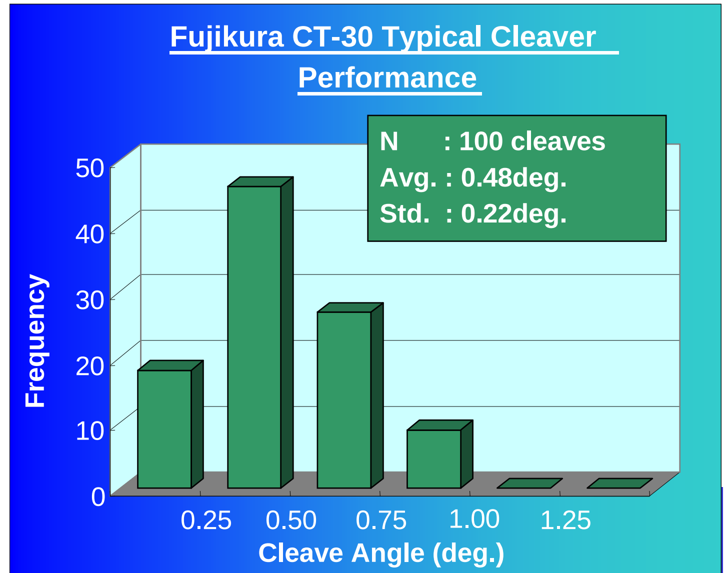


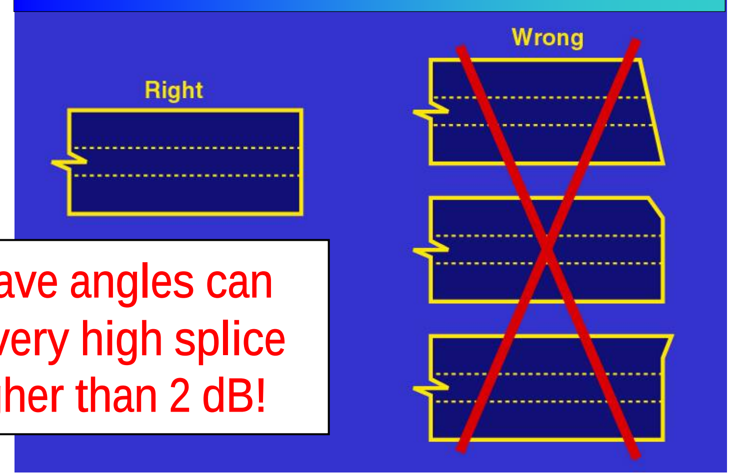
NEVER clean the fiber again after cleaving or you will contaminate the cleaved fiber end!

DO NOT expect the splicer cleaning arc to help clean the fiber. It is only intended to vaporize remaining alcohol so the splicer's optical system can properly observe the fiber image.

Fiber Preparation

- Cleaving The Fiber
  - Produces square fiber endface.
  - Critical for splice quality
  - The last step before splicing





Poor cleave angles can result in very high splice loss, higher than 2 dB!

The Splicing Process

- How does a splicer work
  - Aligning the fiber
    - Can be fixed V-groove or profile alignment
    - Goal is to perfectly match up cores
  - Heating the fiber
    - High-voltage electrical arc
    - Fibers melted and pushed together
    - A good splice depends on:
      - Adequate clamping in the V-grooves
      - Fusion time – how long fibers are heated
      - Fusion current/arc power – how hot the arc is
      - Fiber feed – how much and how fast are the fibers pushed together

PAS Splicer Types

- Core alignment
  - Core alignment is possible using high resolution cameras to view an image pattern created by differences of index of refraction
  - V-grooves move in order to precisely align the fiber cores
    - Present in FJK FSM-60S field platform
- Fixed V-Groove
  - Left / right V-grooves are fixed in position, but precisely aligned
  - Fibers placed in precision V-grooves
    - Present in Fujikura FSM-18S and mass fusion splicers

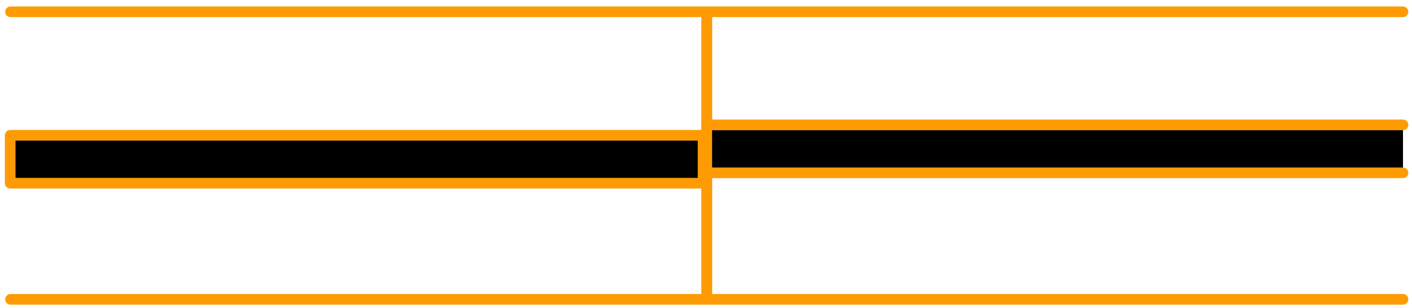
Core Alignment vs. Fixed V-Groove

Fixed V-groove type splicers have two major limitations compared to core-alignment PAS splicers:

1. Their lower resolution optical systems cannot detect the position of the fiber core.

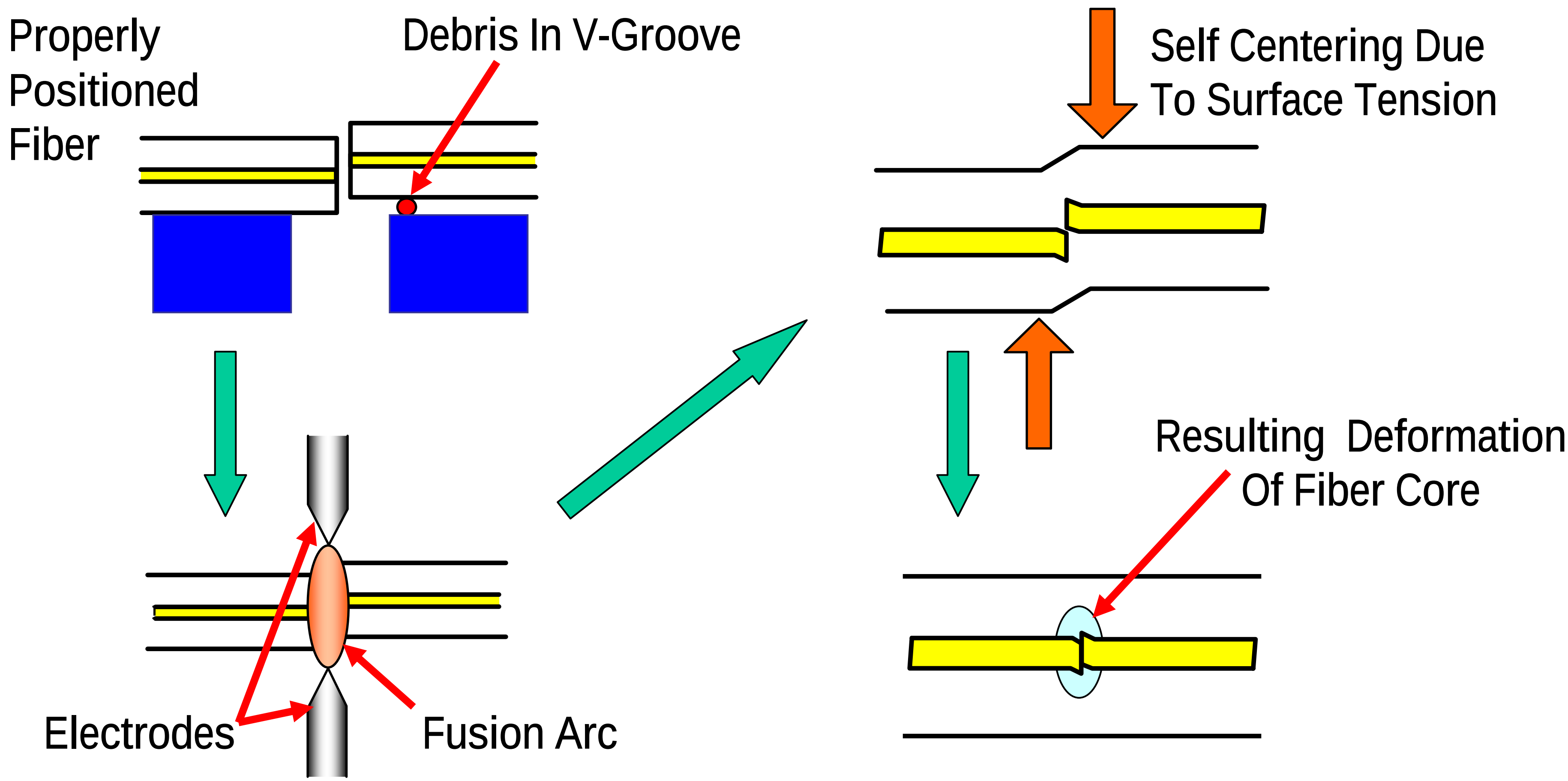
2. Fixed V-groove fiber alignment results in two splice loss factors not present with core-alignment splicers:
   a. Splice loss due to core-cladding concentricity error
   b. Deformation of the fiber core due to pre-splice cladding offset.

Fixed V-Groove Loss Mechanisms
Core/Cladding Concentricity Error



- Fixed V-groove splicers cannot compensate for fiber geometry
- Not predicted by the loss estimation

Deformation of the Fiber Core Due to Pre-Splice Cladding Offset

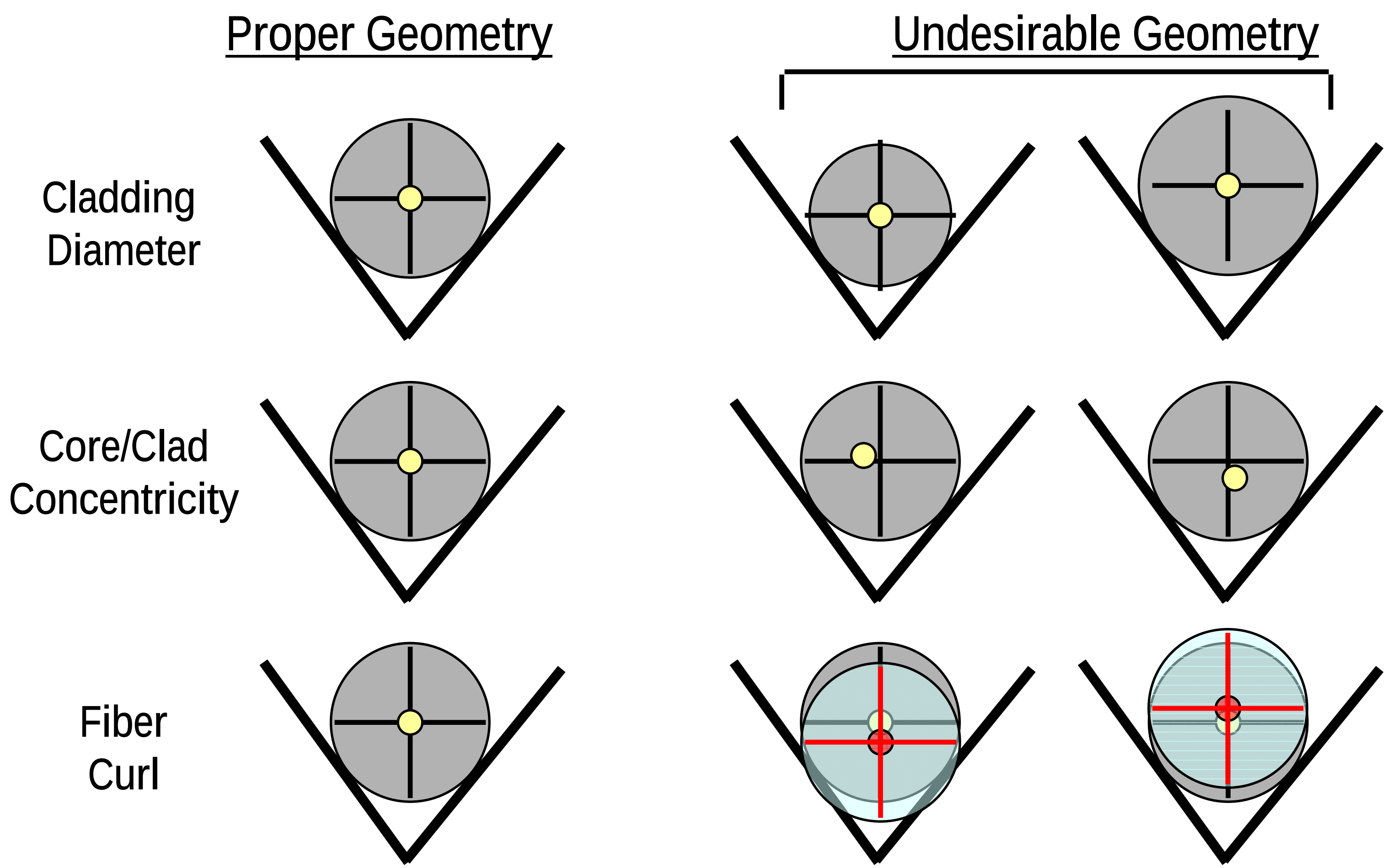


Fixed V-Groove Loss Mechanisms

Pre-Splice Cladding Offset

- Offset may be caused by ...
  - Debris in the V-grooves
  - Coating debris on the fiber
  - Fiber curl
  - Differences in fiber diameter
- During long arc cladding self centers
- Therefore, cores smear/deform
- Is included in loss estimation calculation

How Fiber Geometry Impacts Fixed V-Groove Splicing



Splice Protection Sleeves

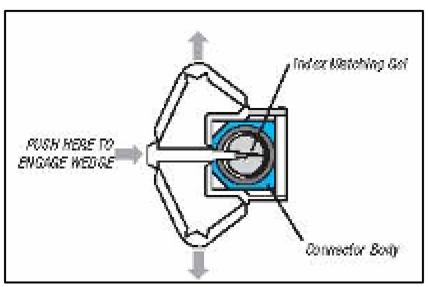
- Protecting the fiber
  - Most common method is using a heat shrinkable splice protection sleeve
  - These sleeves protect and reinforce splices
  - Various sleeve types are standardized for use:
    - Single fiber sleeve, 60mm length
    - Single fiber sleeve, 40mm length
    - Mass fusion sleeve, 12 fibers

Optical Connectivity & Apparatus (OCA)

- What does it mean?
  - It is what you do with the end of each fiber cable
  - The “what” (connectivity) and “where” (apparatus) with fiber cable
- Typical connectivity options:
  - Splice together one fiber to another fiber
  - Connectorize one or both ends of fiber
- Typical apparatus options:
  - Storage and routing of fiber in…
    - Panels
    - Closures
    - Enclosures

FAST™ Connectors

AFLs new FAST™ Connectors are pre-polished, field installable connectors that eliminate the need for hand polishing in the field. FAST™ Connectors provide an immediate termination to either single-mode or multimode fibers and are color-coded for ease of fiber identification. Connectors for Laser Optimized 50µm (10G) fibers are also available.



Features

- Easy assembly process
- Fiber can be reseated
- No expensive tools required
- No epoxy required
- Factory polishing eliminates loss concerns
- Meets TIA/EIA 568A performance requirements
- Meets TIA/EIA 604 (focis) connector interface specifications

Applications

- Premise environments
- Connections at the desk for LAN environments
- Patch panels
- Direct equipment termination
- Fiber to the Subscriber (FTTx) applications
- Repair/replacement requirements
- Equipment test leads

FuseConnect™ Fusion Spliced Field-terminated SC Connector

FuseConnect utilizes a fusion splicer to terminate a connector in the field, addressing return loss concerns present in analog optical networks. This advanced process yields true APC performance of >65dB return loss in an SC/APC configuration. Designed to work with an industry standard 10mm cleave length and splicers utilizing a fiber holder system, FuseConnect is compatible not only with Fujikura's fusion splicers, but also with most other industry available, fiber holder-based fusion splicing platforms.

Features

- Field installable
- Only four components
- No adhesives, crimping or polishing
- True APC performance
- Performs to GR-326-CORE
- Meet TIA/EIA-604-3 (FOCIS-3)
- Compatible with most fusion splicers

Applications

- RF-overlay FTTP network connectorization
- Cable TV backbone network connectorization
- Outside plant connectorization
- Central office connector replacement
- Data center installation
- MDU optical fiber termination

FuseConnect™ – *Termination Sequence*

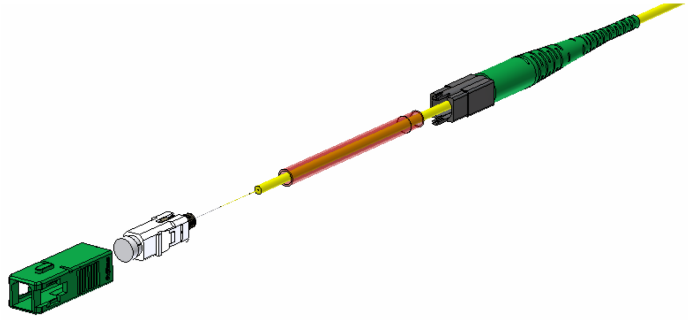
1- Fiber preparation

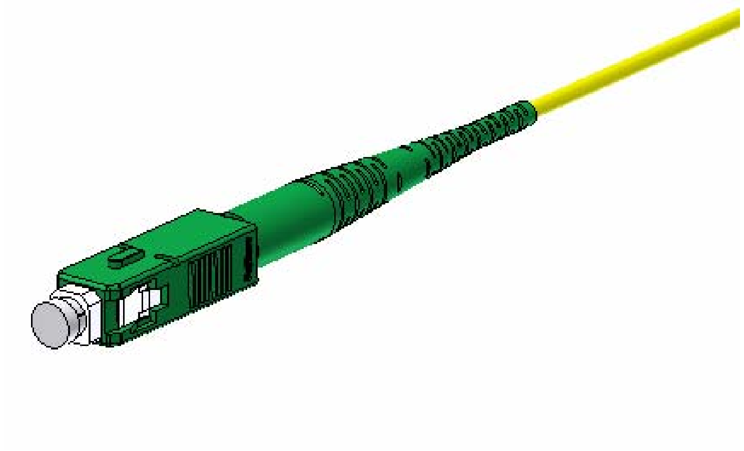
2- Splice cable to connector stub

3- Transfer spliced fiber to heater

4- Shrink splice protector

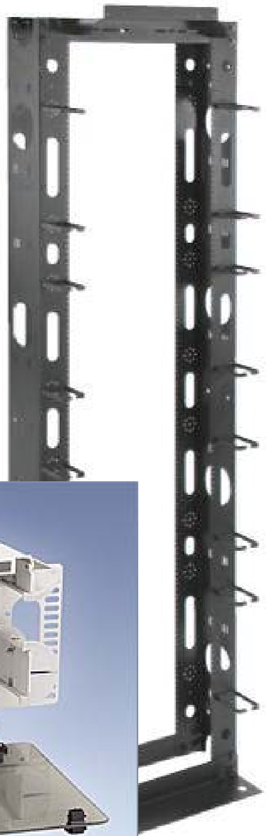
5- Assemble boot and housing





Apparatus Basics

- Interconnect Panels
  - Rack mount
    - Organized fiber routing & management
    - Plurality of optical connectors
    - Adaptable to various applications
  - Features
    - 19” and 23” mounting
    - Universal footprint
      - LGX®
        - » WECO standard
    - Various Rack Unit sizes (RU)
      - 1RU to 5RU



Typical OSP Products

- Connectivity
  - Drop Cables
    - Factory terminated
    - Field terminated
      - Fuse-Connect
    - Spliced
- Apparatus
  - Closures
  - Enclosures
  - Fiber Distribution Hubs

OSP Apparatus Basics

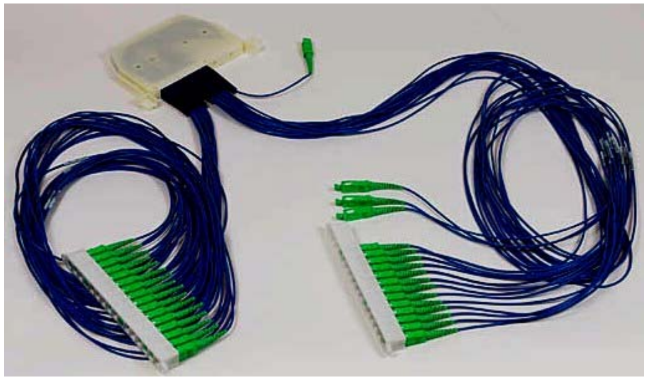
- Closures
  - Weather-tight or sealed
  - Aerial or buried installation
    - Strand, hand-hole or man-hole
  - Key performance specs:
    - Weatherability (UV, rain, temperature, etc)
    - Impact
    - 20ft. water-head (sealed)
  - Key features:
    - Ease of cable sealing
    - Splicing and routing of fiber buffer tubes
    - Easy-to-use splice trays

OSP Apparatus Basics

- Enclosures
  - Pedestal or wall mount
  - Key performance specs:
    - Weatherability (UV, rain, temperature, etc)
    - Impact
    - NEMA rating
  - Key features:
    - Ease of cable entry
    - Splicing and routing of fiber buffer tubes
    - Easy-to-use splice trays

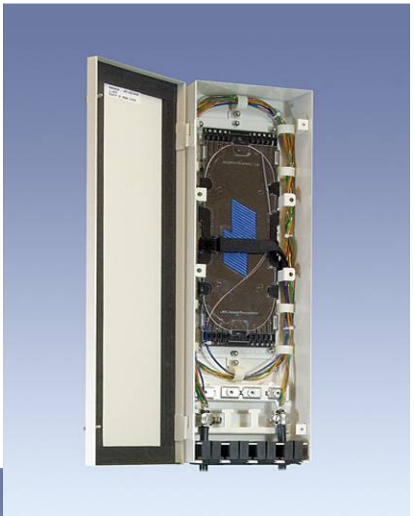
OSP Apparatus Basics

- Fiber Distribution Hubs
  - Location point for splitting of optical signals
    - 1 fiber split into 32 equal signals (PON architecture)
    - Provide means of fiber to the home
  - Key features:
    - Small sizes
    - Easy-to-use fiber routing
    - Common splitter components
    - Durable construction



CP Apparatus Basics

- Enclosures
  - Wall mount
  - Application
    - Store, splice and drop off individual fibers
  - Key features:
    - Easy of cable entry
    - Splicing and routing of fiber buffer tubes
    - Easy-to-use splice trays
    - Interior – flame retardant (metal)



CP Apparatus Basics

- Fiber NID
  - Wall mount
  - Application
    - Customer handoff of individual fibers
  - Key features:
    - Provider and customer access
    - Easy of cable entry
    - Splicing and routing of fiber buffer tubes
    - Easy-to-use splice trays
    - Interior – flame retardant (metal)

Connectivity Basics

- Connector Types
  - SC is market leader
    - LC (small form factor)
  - UPC vs. APC Polish
  - Mechanical splice
  - FAST Field Installable
  - FUSE Connect

Cable Installation Considerations

- General Precautions
- Key Parameters
- Installation planning & Techniques

General Precautions

- Prior to installation, be sure to…
  - Inspect each cable reel for any damage in shipping that may have caused sharp edges or protusions that could damage the cable during install.
  - Optically test the cable with an OTDR to be sure cable has not sustained in damage in transport.
  - Be sure all personnel have adequate personal protective equipment.

Important Cable Parameters

- Take care to ensure the cable is not kinked, crushed, or twisted during installation as this can cause damage to the optical fiber.
- Check to be sure that all pulleys, sheaves, or bullwheels are in good condition and do not exceed the minimum bend radius of the cable being installed.
- Make sure that the minimum pull tension for the cable being installed is defined and that tension limiting devices are available.

Installation Planning

- Survey proposed cable route prior to installation.
- Be sure the route is free of obstructions.
- Never drag or pull the cable over obstructions as this may damage the cable jacket.
- Select locations of pulling and splicing sites. These selections will be based on a number of factors
  - Cable drum lengths and maximum pull tension
  - Number of allowable splices
  - Capability and accessability of equipment

Installation Planning

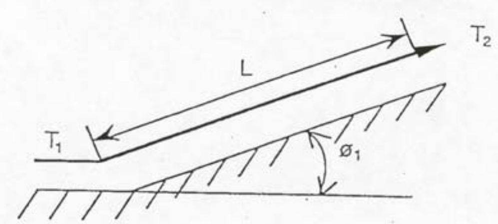
- If the cable is be pulled through a duct it may be necessary to calculate the required pulling forces prior to installing. Be sure these forces do not exceed the maximum rated cable load.

Straight Line Pull with No Change in Slope

- When laying a cable into a straight-line duct containing no change in elevation, the pulling force, T2, can be calculated as follows:
- $T2 = To + \mu * W * L$
- where:
- T2: Pulling force (lb)
- μ: Coefficient of friction (lb)
- W : Weight of cable
- L : Length (kft)
- To: Unassisted payoff "tail load" (the force required to pull the cable off the payoff reel). If assisted, To = 0 (lb).

Straight Line Pull with Change in Slope

- When laying the cable in a straight line, use the following equation to find the tension; T2, of the pulling end of the cable slope for a given slope:
- $T2 = W * L (\sin\varnothing + \mu \cos\varnothing 1) + T1$ . . . . . . (See Figure 1)
- where:
- T1 : Laying tension (lb)
- W : Weight of cable, per mile (lb/ft)
- L : Length (kft)
- μ : Coefficient of friction of cable and conduit (0.5 is usually assumed unless a lubricant is used, thereby reducing μ to a value of approximately 0.25)
- $\varnothing 1$: Gradient
- An upward slope is positive
- A downward slope is negative
- Special cases:
- a) Horizontal ($\varnothing 1 = 0$) then, $T2 = \mu WL + T1$
- b) Vertical ($\varnothing 1 = 90°$) then, $T2 = WL + T1$

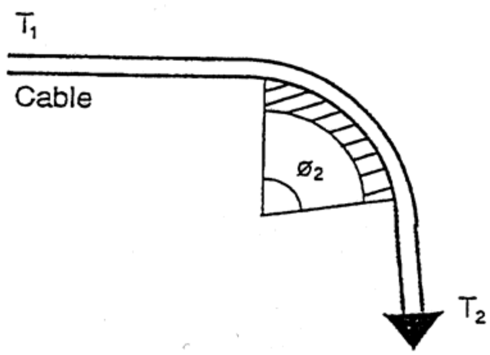


Straight-line pull with change in slope

Figure 1

Horizontal Curve

- When optical cable is laid around a curve with the tensions T1 and T2 before and after the curve respectively, they are related according to the following equation:
- T2 = K * T1 . . . . . . (See Figure 2)
- where:
- K : exp (0.0175μ∅2) (see Table 1)
- T1 : Back tension before entering the curve (lb)
- T2 : Tension after passing the curve (lb)
- ∅2 : Angle (°)



Horizontal Curve

Figure 2

Installation Techniques

- Cable pulling coniderations
  - If using an unassisted payoff use a reel brake to prevent the reel from runaway at stopping points
  - For longer lengths, an assisted payoff should be used to minimize the “tail” load on the cable.
  - This can be accomplished manually by a craftsperson or by a motor controlled payoff system.

Installation Techniques

- Cable Pulling techniques
  - Fiber optic cable is generally small and lightweight and able to pulled by hand.
  - For longer lengths, a back pull method may be used.
    - The cable strength member should be tied off and securely anchored to a pulling rope of sufficient strength. A swivel is also recommended to avoid cable twist.
    - A stationary payoff reel is positioned at one end of the cable run with a powered take up at the other end.
    - If pulling the cable through a duct, a fiberglass rod may be pushed through the duct, secured to the cable, and pulled back.
    - A dynamometer should be used to monitor tension at all times.

Installation Techniques

- Securing the cable
  - Depending on the application, the cable may need to be secured to a structure.
  - Methods to anchor the cable include:
    - Cable clamps and adapters
    - Metal or plastic banding
    - Custom anchoring devices
  - Be careful to consider:
    - Temperature ratings of anchoring devices
    - Crush force on cable
    - Bending stress at anchor transition point.

Installation Records

- The optical circuit should be mapped and diagrammed to include all splice and connection points.
- An optical test report should generated for each fiber in the circuit to include attenuation coefficients in the primary wavelengths of the fiber type installed – 1310/1550 for SM and 850/1300 for MM.

Summary

- AFL Provides
  - AFL/Fujikura Technology
  - Cable and Accessory Manufacturing Expertise
  - Optical Sensing Experience
  - System Knowledge
  - End-to-End product solutions
- Next Steps?