Our Most Important Connection is with You.™

Section 12

Technical Information and Glossary of Terms

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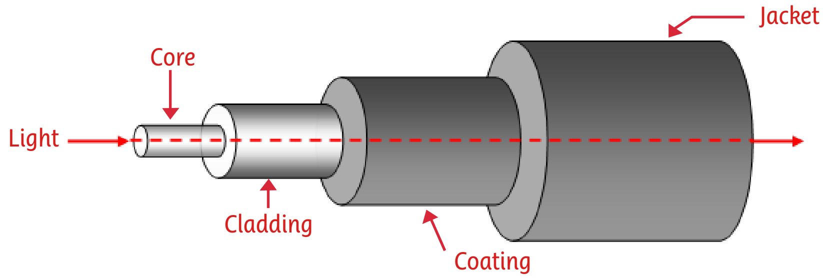
Fiber Optics Basics

WHAT IS AN OPTICAL FIBER?

Optical fiber is a "light pipe" carrying pulses of light generated by lasers, or other optical sources, to a receiving sensor. Usually manufactured from high purity silica glass-like rods drawn into fine hair-like strands and covered with a thin protective plastic coating, an optical fiber consists of four concentric layers:



- A core in which the light propagates
- A cladding that confines light in the core
- A coating or plastic buffer that acts as protection and allows the glass rod to be curved
- A jacket which provides outer mechanical and environmental protection

Then, fibers are subsequently packaged in various cable configurations (jacket) before installation in the external or internal networks.

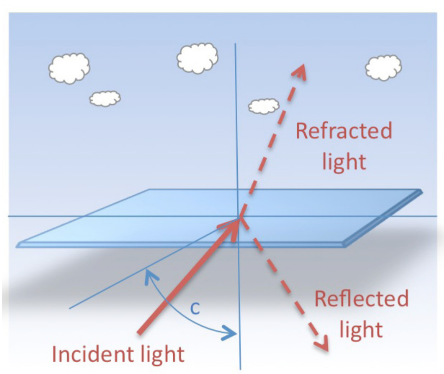
LIGHT PROPAGATION

Light pulses are launched into the core region. The surrounding cladding layer keeps the light traveling down the core and prevents light from leaking out.

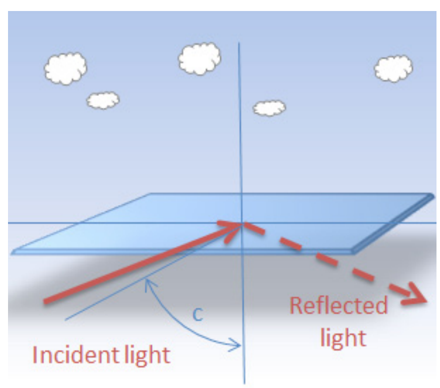
This phenomenon is called: Total Internal Reflection.

When light crosses a boundary between two mediums with different refractive indexes, the light beam is partially refracted and partially reflected. This depends on the incidence angle and the refractive indexes of each medium. If light comes from a more optical dense medium and with an angle bigger than the "critical angle", then all the light is reflected.

Example: The reflection of the light on a glass surface



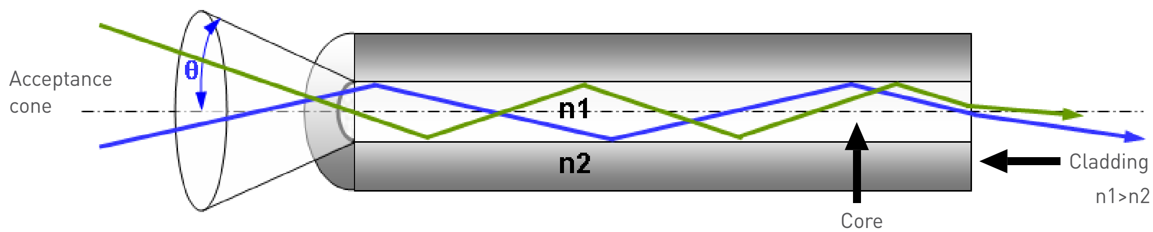
Light is partially reflected and partially refracted because its angle of incidence is inferior to the critical angle.



Light is totally reflected because its angle of incidence is superior to the critical angle.

Fiber Optics Basics

In an optical fiber, the light travels through the core (n1, high index of refraction) by constantly reflecting from the cladding (n2, lower index of refraction) because the angle of the light is always greater than the critical angle.



The light rays are totally reflected by the cylindrical surface between the core and the cladding because of their different refractive indexes. To confine the light (the optical signal) into the core, the refractive index of the cladding must be lower than that of the core: **n1>n2**.

There is a maximum angle from the fiber axis at which light may enter the fiber so that it will propagate in the core of the fiber. The sine of this maximum angle is the **numerical aperture (NA)** of the fiber. Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA.

REFRACTIVE INDEX

The refractive index (n) describes the way light travels into a substance. It is expressed as a ratio of the speed of light in a vacuum relative to that in the considered substance.

n = velocity of light in a vacuum/velocity of light in medium

For instance, the refractive index of water is 1.33, meaning that light travels 1.33 times as fast in a vacuum as it does in water.

Typical refractive index: refractive index of vacuum: n = 1 (reference/minimum value that cannot be improved)
refractive index of air: n = 1.0003 (value very close to the vacuum)
refractive index of glass: n ≈ 1.5

DISPERSION

This is the main cause of bandwidth limitations in a fiber. Dispersion causes a broadening of input pulses along the length of the fiber.

Three major types are:

- **modal dispersion** caused by differential optical path lengths in a MultiMode fiber
- **material dispersion** caused by a differential delay of various wavelengths of light in a waveguide material
- **waveguide dispersion** caused by light traveling in both the core and cladding materials in SingleMode fibers

As a result of the dispersion, the light pulses spread out over time and thereby restrict the bit rate and/or the length of the efficient optical link.

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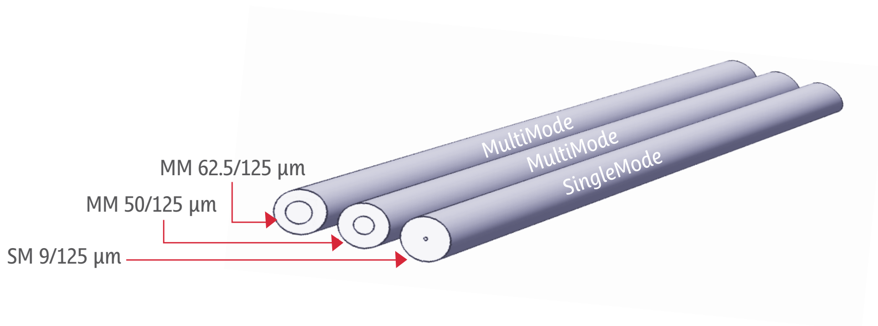
Fiber Optics Basics

MAIN FIBER TYPES

There are two types of optical fibers:

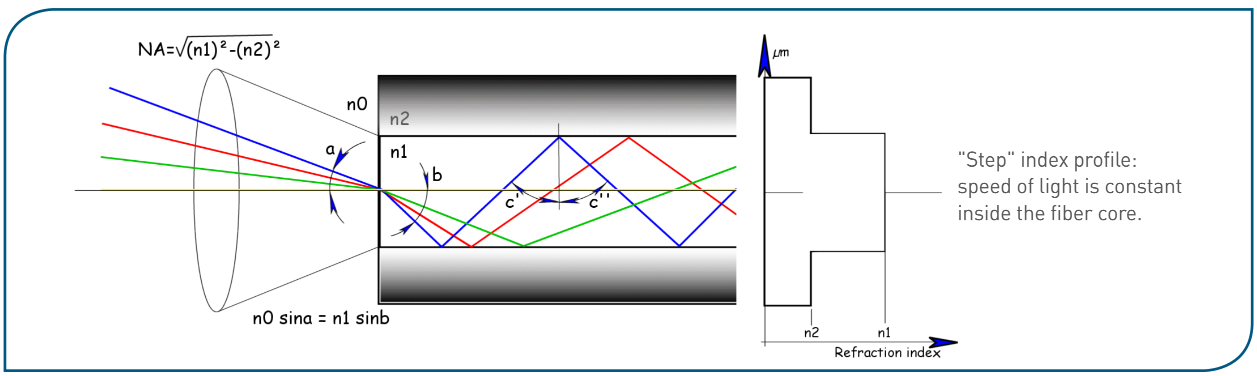
- MultiMode (MM) fibers where the fiber core can receive several propagation modes. Two technologies exist for MultiMode fibers: step index and graded index fibers.
- SingleMode (SM) fibers with only one propagation mode



Step-index MultiMode Fiber

In a step-index MultiMode fiber, many rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle, bigger than the critical angle, are completely reflected. The critical angle is determined by the difference in refractive index between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding and do not convey light along the fiber.

The critical angle determines the acceptance angle of the fiber, often reported as the Numerical Aperture. A high numerical aperture allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. However, this high numerical aperture increases the amount of dispersion as rays, at different angles, have different path lengths and therefore take different times to transit through the fiber.

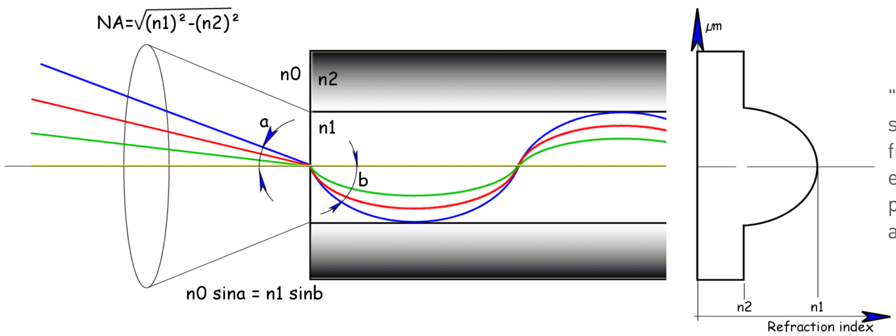


In short:
- Different light pathways (modes)
- Light rays arrive separately at the receiving point
- Space between pulses to prevent overlapping limits bandwidth
- Best suited for transmission over short distance
- High numerical aperture adapted to wide optical source (LED)

Fiber Optics Basics

Graded Index MultiMode Fiber

A graded index MultiMode fiber contains a core in which the refractive index decreases gradually from the center axis to the cladding. The high refractive index at the center makes the light rays close to the cladding progress faster than those near the axis. Because of the graded index, light in the core curves helically, reducing its travel distance. A shortened path and a higher speed allow the light rays to arrive at the receiver almost at the same time providing less dispersion.

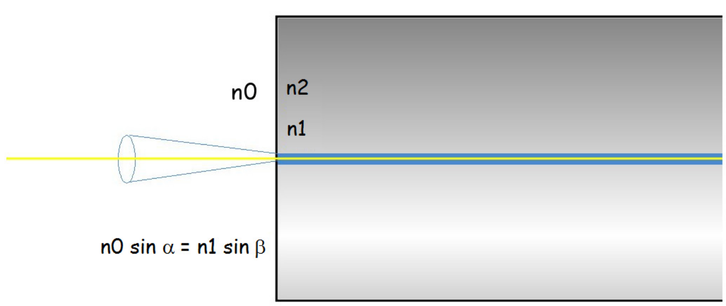


In short:

- Different light pathways (modes)
- No delay at the receiving point
- Best suited for transmission over medium to long distance
- High numerical aperture adapted to wide optical source (LED)

SingleMode Fiber

SingleMode fiber only supports one light ray (one mode of light propagation) because of the reduced dimension of the core. The core diameter is 9 µm for a SingleMode propagation of wavelength from 1300 nm to 1550 nm. This propagation mode provides higher transmission rate and no modal dispersion.



In short:

- One light pathway (mode) parallel to the axis
- Very limited pulse dispersion
- Adapted for long distance transmission
- Very widely used, not expensive for telecom
- Small numerical aperture adapted to high coherence optical source (Laser)

TECHNICAL INFORMATION

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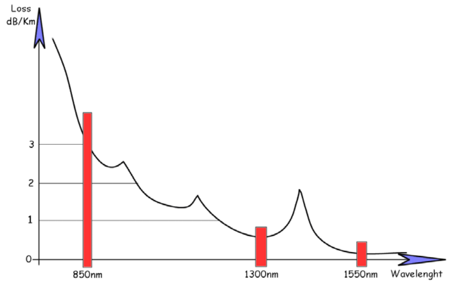
TYPICAL TRANSMISSION PROPERTIES OF GLASS FIBERS



For telecommunication and for glass optical fibers, we use light in the infrared region, typically around 850, 1300 and 1550 nm due to low attenuation of the glass fiber at those wavelengths.
Glass fibers are the most common fibers used for telecommunication applications.

The ISO/IEC11801 specification describes the data rate and reach of optical fiber grades referred to as:
OS1, OS2, OM1, OM2, OM3 and OM4 (the MultiMode fibers are prefixed with “OM” and the SingleMode fibers “OS”).

Performances of existing fibers compliant to relevant standards:

				Minimum Modal Bandwidth MHz x km		
		Maximum Attenuation dB/km		Overfilled Launch Bandwidth (LED source)		Effective Laser Launch Bandwidth
Optical Fiber Type	Core Diameter µm	850 nm	1300 nm	850 nm	1300 nm	850 nm
OM1	62.5	3.5	1.5	200	500	-
OM2	50	3.5	1.5	500	500	-
OM3	50	3.5	1.5	1500	500	2000
OM4	50	2.5	0.8	3500	500	4700

		Maximum Attenuation dB/km	
		Overfilled Launch Bandwidth (LED source)	Effective Laser Launch Bandwidth
Optical Fiber Type	Core Diameter µm	1310 nm	1550 nm
OS1	9	0.4	0.25
OS2	9	0.4	0.25

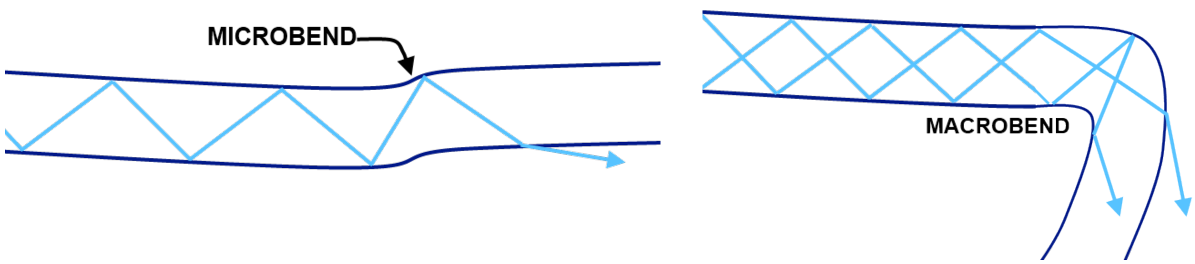
Distance capability of the fibers according to the relevant Gigabit Ethernet standards:

	1000BASE-SX 1 Gbit/s	10GBASE-S 10 GBit/s	40GBASE-SR4 40 Gbit/s	100GBASE-SR10 100 GBit/s
OM1	275 m	33 m	-	-
OM2	550 m	82 m	-	-
OM3	-	300 m	100 m	100 m
OM4	-	550 m	150 m	150 m
OS2	-	-	10 km	10 km

Fiber Optics Basics

Transmission losses caused by bend: Optical fiber is sensitive to stress, particularly bending which leads to some light losses. The smaller the bending radius is, the greater the losses are. Some fibers, like the G657 SingleMode fiber are optimized to be insensitive to bends. The minimum bending radius will vary according to cable designs. The manufacturer specifies the minimum radius to which the cable may safely be bent during installation and over the long term. If no minimum bend radius is specified, one can safely assume a minimum long-term low-stress radius not less than 10 times overall diameter for MultiMode cables, and 20 times overall diameter for SingleMode cables.

Beside mechanical destruction, another reason why one should avoid excessive bending of fiber-optic cables is to minimize microbending and macrobending losses. Microbending causes light attenuation induced by deformation of the fiber while macrobending causes the leakage of light through the fiber cladding and this is more likely to happen where the fiber is excessively bent.

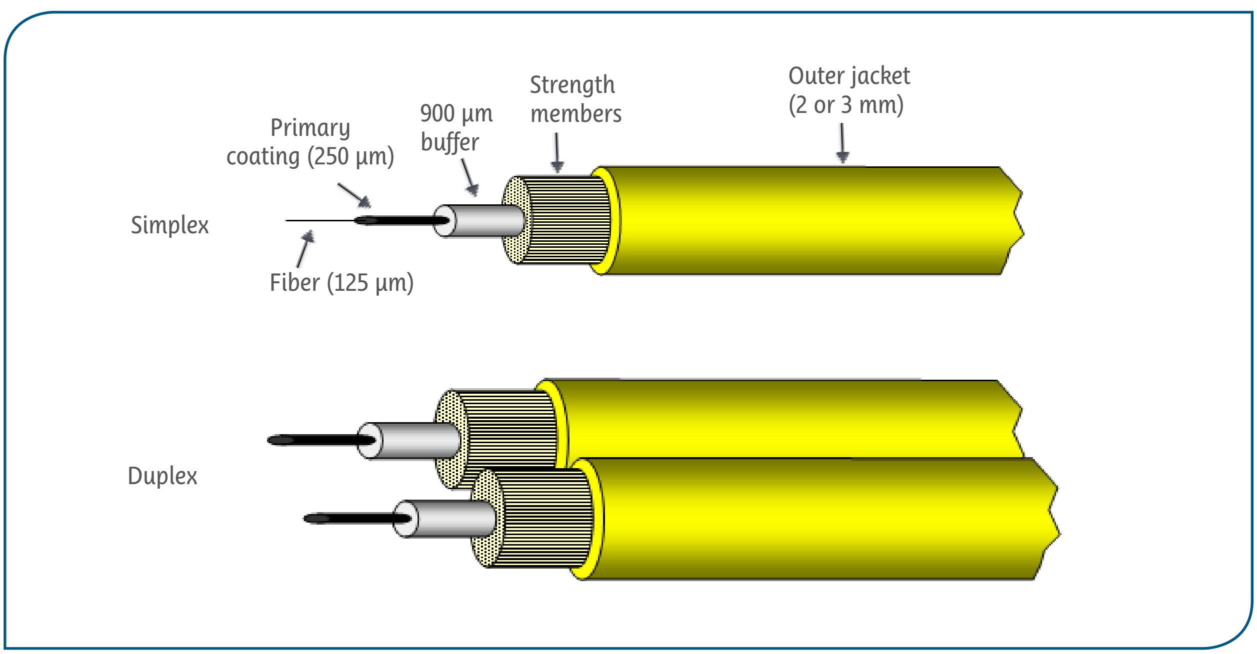


Cables

In order to cope with any stress (tensile, bending, torsion, etc.) or environmental conditions (weather, abrasion, chemical, thermal, etc.), fiber optics need to be protected by a suitable cable structure.

TYPICAL INDOOR CABLES

For inside buildings, houses and equipment. Typical temperature range: -20°C/+70°C.



TECHNICAL INFORMATION

Cables

For indoor cables, there are two basic designs of cable structures: loose and tight. Both contain some strength members, such as aramid yarn or glass fibers.

Loose Structure Cables:

- The optical fiber (250 µm) is inside a plastic protective tube that allows limited movements of the fiber
- Usually contains a water resistant gel surrounding the fiber
- Usually dedicated to pigtails

Tight Structure Cables:

- The fiber is strictly immobilized inside the jacket. This structure allows no movement of the buffered fiber with respect to the outer jacket and strength members
- Good behavior with temperature changes
- More robust than loose-tube cables, they are best suited for moderate length LAN or WAN connections, long indoor runs, direct burial and for underwater use.

Simplex Scindex Duplex Multiple

Other types of fibers and cable configurations exist, such as ribbon or POF (Plastic Optical Fiber).

Indoor Fiber Optic Cable Fire Prevention:

For European markets, communication cables must typically comply with IEC 60332-3 (EN 50266) or IEC 60332-1 (UL VW1) fire tests depending on the application. In most of the countries LSZH (Low Smoke Zero Halogen) materials are mandatory. LSZH cable jackets are composed of fire retardant materials that reduce the amount of smoke emitted when combusted. LSZH cables contain zero halogen during combustion. They have been cited as an ideal cable jacket in high risk areas of fire or crowded public locations.

For the US market, communication cables must comply with the National Electrical Code (NEC) requirements. There are three types of indoor spaces identified by NEC: plenums, risers and general purpose areas.

- What is a plenum area and plenum rated fiber optic cable?
Plenum is an air-handling, air flowing and air distribution system space such as that found above drop ceiling tiles or heating and ventilation ducts. Plenum rated cables must meet UL-910 specification and their outer jackets are made of materials that retard the spread of flame, produce little smoke and protect electronic equipment from damage in fires.

- What is a riser area and riser rated fiber optic cable?
Riser is a pathway such as floor opening, shaft or duct that runs vertically through floors. Riser rated cables can be run through building vertical shafts (risers) or from one floor to another floor. Riser rated cables must meet UL-1666 fire resistance specification and cannot be installed in plenum area. However plenum rated cables can be used as a substitute for it and installed in riser spaces.

- What is a general purpose area?
Any space on the same floor which is not plenum or rise is identified as general purpose area.

Based on NEC code, indoor fiber optic cables can be categorized under six types:

Figure	Description	Cable Application	UL Test	Possible Substitute
OFNP	Optical Fiber Nonconductive Plenum Cable	Plenum, overhead, fiber only	UL - 910	
OFCP	Optical Fiber Conductive Plenum Cable	Plenum, overhead, hybrid (fiber/wire)	UL - 910	
OFNR	Optical Fiber Nonconductive Rise Cable	Riser, backbone, fiber only	UL - 1666	OFNP
OFCR	Optical Fiber Conductive Rise Cable	Riser, backbone, hybrid	UL - 1666	OFCP
OFN	Optical Fiber Nonconductive	General purpose, horizontal, fiber only	UL - 1581	OFNP, OFNR
OFC	Optical Fiber Conductive	General purpose, horizontal, hybrid	UL - 1581	OFCP, OFCR

Cables

TYPICAL OUTDOOR OR AEROSPACE CABLES

Cable structure definition per ARINC 802:

- **Loose structure:** a fiber optic cable structure that allows limited movement of the buffered fiber (usually the 900 µm) with respect to the outer jacket and strength member.

- **Tight structure:** a fiber optic cable structure that allows no movement of the buffered fiber with respect to the outer jacket and strength member.

For communication uses:

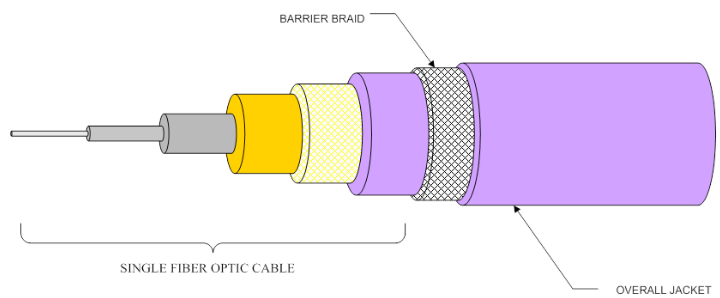
- **Distribution fiber cables:** This compact building cable consists of 900 individual micron buffered fibers. Connectors mounting the fibers' ends are generally re-tubed with a 2 mm buffer.

- **Breakout fiber cables:** Breakout cables are also called fanout cables. In tight buffered cables each fiber is only a 900 µm tight buffered fiber, but in breakout cables every fiber is a subcable by itself. Each fiber has a 2~3 mm jacket, then an outer jacket covers these subcables, aramid yarn and ripcord inside. This design allows users to divide the cable to serve users with individual fibers, without the need for a patch panel. Breakout cables enable the quick installation of connectors onto 2+ mm robust jacketed fiber.

- **For aerospace applications**, fiber optic cables are ruggedized to withstand harsher environment conditions, such as temperature range and abrasion resistance. Flammability and toxicity are also major requirements.

Ruggedization enables glass fiber cables to withstand harsher tests:

- Thermal
- Fluid resistance
- Abrasion resistance
- Impact resistance
- Clamping
- Cable crush



COLOR CODING

The buffer or jacket of fiber optic cables is often color-coded to indicate the type of fiber used:

Fiber & Cable Type	Color Code
MultiMode fiber (50/125) (TIA-492AAAB) (OM2)	Orange
MultiMode fiber (50/125) (TIA-492AAAC) (OM3, OM4)	Aqua
MultiMode fiber (62.5/125) (TIA-492AAAA) (OM1)	Orange
MultiMode fiber (100/140)	Orange
SingleMode fiber (TIA-492C000 / TIA-492E000) (OS1, OS2)	Yellow
Aerospace cables	Purple
Polarization Maintaining SingleMode	Blue

Outdoor patchcords are usually black.

Connections

According to Telcordia Generic Requirements for optical connectors and jumper assemblies, optical fiber connectors are used to join optical fibers where a connect/disconnect capability is required.

INTERFACE TECHNOLOGIES

There are several alignment technologies to connect the cores of fibers so that light can pass:

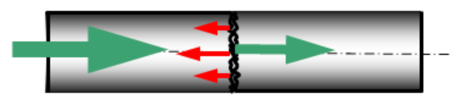
- Physical Contact: Fibers are core to core mechanically contacted
- Expanded beam: Beams are shaped by lenses; no contact

The various interfaces allow different performances and can be optimized to minimize the losses. In case of an interface issue several connection losses can occur.

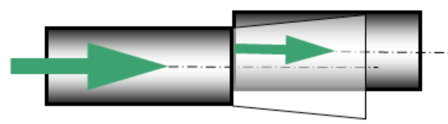
CONNECTION LOSSES

Optical losses depend on the quality of the optical interface and the accuracy of the alignment between the two ferrules.

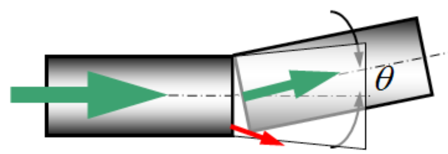
- Fresnel loss: The Fresnel loss can be the result of multiple causes: pollution, bad polishing quality, installation and any manipulation that can alter the end face connector or contact



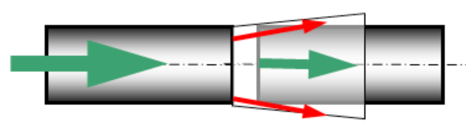
- Loss by lateral misalignment



- Loss by angular misalignment



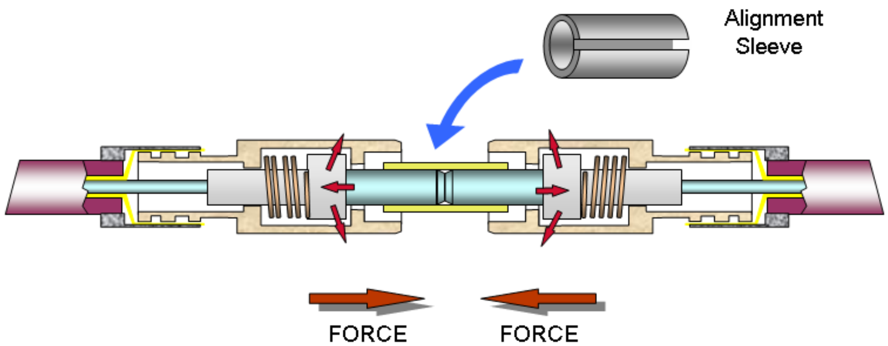
- Loss by axial separation (unseated contact)



Connections

PHYSICAL CONTACT (PC) TECHNOLOGY

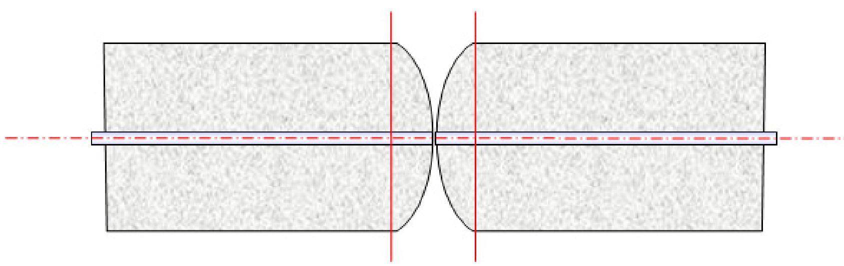
In PC technology, a connector assembly consists of an adapter and two connector plugs.
Fibers are core to core mechanically contacted.



The ferrules of the plugs are aligned into a guiding sleeve belonging to the adapter.

PC and UPC Polishing

Available for all types of fibers, SingleMode or MultiMode, the PC (Physical Contact) is a curved polishing, centered on the optical axis.

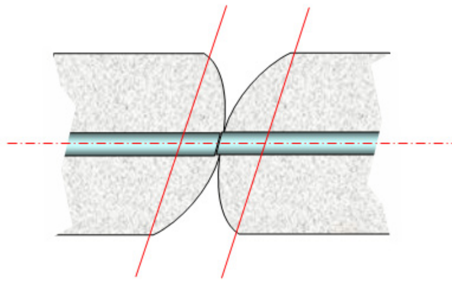


The UPC (Ultra Physical Contact) polishing may be required for SingleMode fibers. The geometry is the same as PC and leads to the same level of Insertion Losses but the quality of polishing is higher and provides Return Losses of 50 dB (compared to 30 dB in PC).

Connections

APC Polishing

APC (Angled Physical Contact) is a tilted curved polishing required for SingleMode fibers.



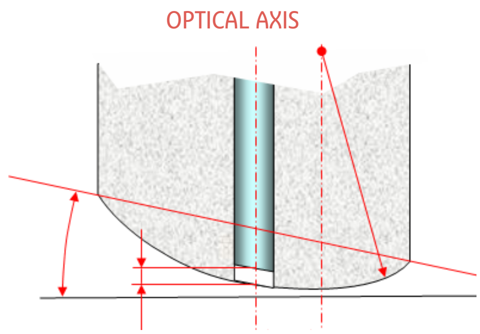
APC achieves excellent Return Losses (>65 dB), useful to avoid optical feedback in laser sources used in analog-over-fiber or fiber sensing applications. For standard SingleMode fiber, the 8° polish angle is chosen to ensure the modest magnitude of light that is otherwise reflected at the end face of a suitably polished terminus, is reflected at an angle greater than the maximum guide angle of the waveguide and is lost to the cladding and surrounding buffer layer.

1/End face Radius 5≤R≤12 mm

2/Polishing Angle 8° or 9°

3/Fiber Extension ± 0.1 µm

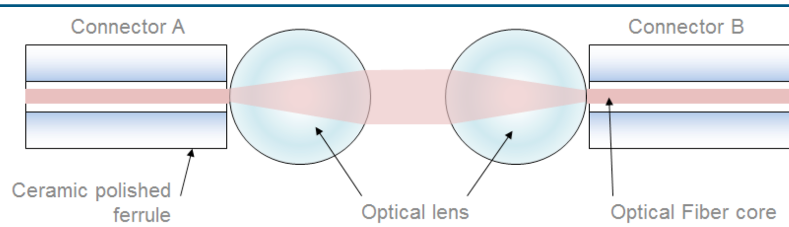
4/Apex Offset < 50 µm



APC: RL>65 dB

EXPANDED BEAM TECHNOLOGY (EB)

In EB technology, light is expanded at the output of the fiber due to a ball lens, collimated and transmitted across an air gap. By using a symmetric system for the opposite plug, the light can be refocused back down to the core of the receiving fiber.



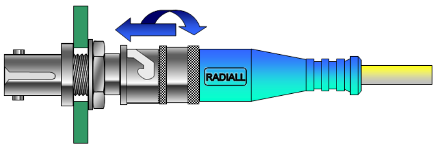
Most of the time, no adapter is required for this type of assembly: the plugs are able to connect to each other.

Due to the beam expansion, the optical connection is less sensitive to dust and lateral misalignment. As the optical ends are not in physical contact, there is no damage to the fiber even after repeated matings. These optical connectors allow a high number of matings. Optical losses are mainly due to air gap (Fresnel loss). They also depend on the accuracy of the positioning of the ferrule to the lens (focal distance).

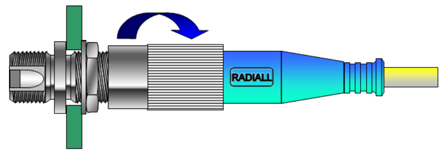
Connections

LOCKING MECHANISMS

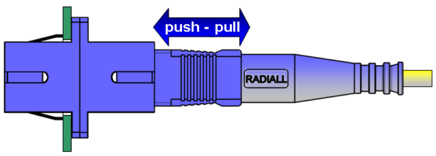
There are numerous types of plugs and sockets to connect optical fibers, using threaded, bayonet, push-pull and snap-lock connections.



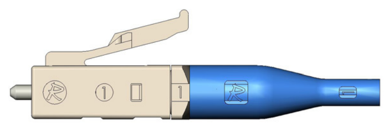
Bayonets: e.g. ST series



Screw-in: e.g. FC, RxF series

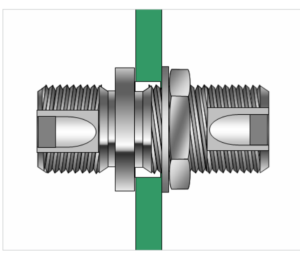


Push-pull snap-in: e.g. SC series

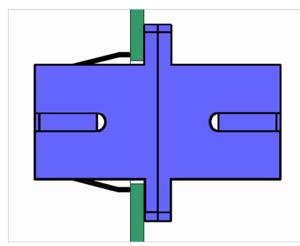


Push-pull latched: e.g. LC series

PANEL MOUNT MECHANISMS



Bulkhead: screw and nut feed through technology



Snap-in: elastic spring technology

Processes and Radiall Technologies

GENERAL GUIDELINES FOR FIBER OPTIC HANDLING

Proper care and cleaning of fiber and connectors will improve the long-term performance and quality of services delivered by the fibers in a network and minimizes the potential for injury.

Safety Reminders:

- Always work in the cleanest possible environment, no drinks, food nor smoking can be permitted close to fiber optics.
- Wear safety glasses with side shields to protect the eyes from fiber shards and splinters.
- Never look into a fiber, or connect to a fiber micro-scope, while system laser is on.
- Do not touch your eyes or face at any time while handling bare fiber.
- Wash your hands immediately after working with bare fiber or solvents.
- Never use your hands to clean a fiber work area.
- Fiber waste is a safety hazard, dispose of cleaved pieces properly.

Storage:

- Do not expose fiber optic cables to direct sunlight.
- Follow supplier instructions for recommended storage temperature.
- When a fiber-optic cable is disconnected, install a protective cap on both the cable connector and the equipment connector.
- Unused adapters and connectors should always be covered.

Handling:

- Always read and comply with the handling instructions of your supplier.
- Check your tools and materials for wear and expiry dates.
- Do not allow kinks or knots to develop in the fiber.
- Never use the fiber to pick up or support the weight of the device to which it is attached.
- Never apply excessive force to the fiber-optic cable by pulling, bending or twisting it.
- Never allow the fiber to come into contact with sharp edges.
- Never place tools or other hard and heavy items on top of the fiber.
- The minimum bend radius of the fiber must always be maintained (Refer to the cable specification to know the limits).

USUAL DAMAGE TYPES & GOOD PRACTICES

Fatigue damage:
Fatigue damages are a slow extension of a flaw due to a combination of stress, duration and moisture or humidity.
Good practices => Always follow the recommended applied stress design guidelines from your supplier.

Abrasive damage:
Abrasive damage may occur when a fiber comes into sliding contact with a sharp object. It can cause scratched or scraped fiber coating and expose the cladding surface or even damage the glass surface of the fiber.
Good practices => Do not allow an optical fiber to come into contact with a sharp or jagged edge. All work surfaces should be smooth and free of any defects or debris. Detect potential damage with tactile senses.

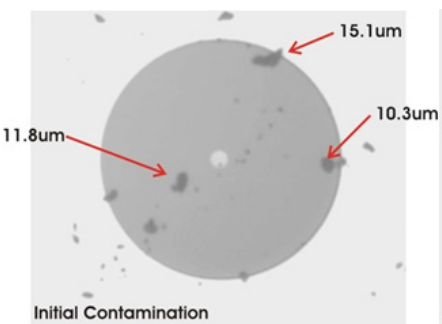
Compressive damage:
Compressive damage may occur when a fiber is pinched, clamped or constrained to a point where the coating or glass layers become damaged.
Good practices => Never allow the fiber to contact an uncontrolled surface (for example, the floor). Never put tools or heavy burdens on top of a fiber. Be careful not to constrain the fiber with wire ties, tie wraps, jewelry or nails.

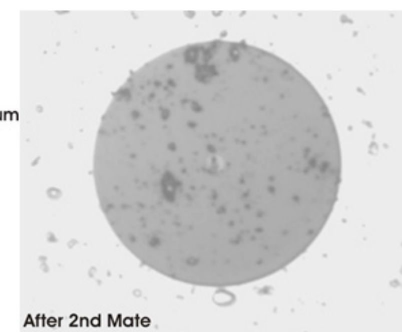
Particles penetration:
Particulates penetration occurs when a hard particle, such as glass or ceramic, penetrates the coating layer of the fiber.
Good practices => Always keep your work environment as clean as possible.

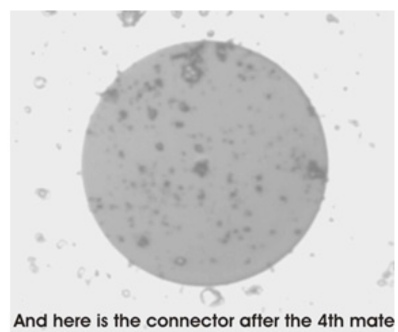
THE IMPORTANCE OF CLEANING

A "dirty" fiber optic end face is one of the main causes of poor fiber performance. The tolerance to dirt or contamination on the ends of the ferrules of a connector is near zero.

Typical contamination from 0 to 4 matings:







To perform cleaning and inspection processes, Radiall provides high-end kits with a detailed procedure and everything you need for an optimal maintenance of your optical systems.
Refer to section 11, tool kits & accessories, for more information.

REMINDERS AND PRECAUTIONS

- The person performing the cleaning must be trained
- The area where the cleaning is to be done must be as clean as possible
- Never re-use any wipes, swabs or cleaning materials
- Cleaning material should be lint-free and smooth
- Always keep a protective cap on unplugged connectors and contacts
- Never touch an optical end face or blow on it with your mouth
- When cleaning the fiber end with lint free optic paper, apply only light pressure
- Always ensure that the solvent you use is adapted to optical fiber and is not contaminated

Processes and Radiall Technologies

CLEANING PROCESS

INSPECT

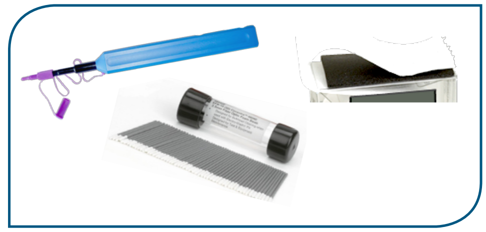
Inspect First:

With a microscope and dedicated adapter **check for contamination on the optical end faces**

CLEAN

Dry Technique:

If necessary **gently apply and swipe** the optical end face with a dry lint-free wipe, a swab or a mechanical stick cleaner, according to your configuration (in or out multipin connectors, type of polishing, etc.).



INSPECT

With a microscope and dedicated adapter **check for contamination** on the optical end faces of the contact or connector. If the connector and contact is still dirty, proceed with the **wet cleaning technique.**

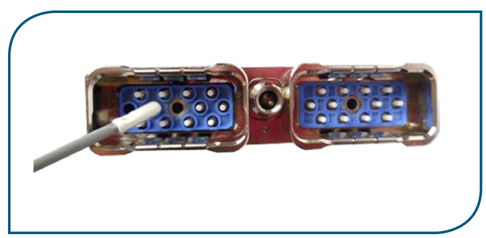
WET CLEAN

Wet Technique:

Take a swab or a wipe, dampen it lightly with a dedicated solvent and apply it gently on the terminus end face that needs cleaning.

DRY CLEAN

Apply a dry swab on the end face to remove any remaining solvent.



INSPECT

With a microscope and dedicated adapter **check for contamination on the optical end faces** of the contact or connector. If the connector or contact is still dirty, start over with the wet cleaning technique.

PLUG OR RE-CAP

Processes and Radiall Technologies

TECHNICAL INFORMATION

TERMINATION PROCESS

Different techniques to terminate connectors on optical fibers exist. In all cases, the connector mounting should be performed following the supplier's instructions. The following steps are the main ones that may differ upon connector type. Contact your Radiall representative to get the instructions corresponding to the product to assemble.

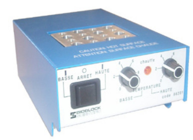
WORKSTATION PREPARATION

1-Preparation of the Work Station

Verify your tools according to the type of fiber, structure of cable and contact or connector you wish to terminate. Always refer to your supplier instructions and comply to the procedure provided.

Plug in and heat up the curing oven.

Never touch any part of the curing unit during and after polymerization.



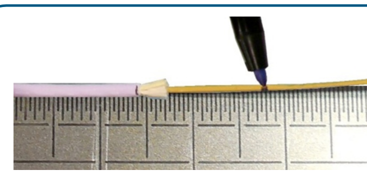
Prepare a resin batch
Make sure to minimize the introduction of air bubbles

CABLE PREPARATION

2-Cable Preparation

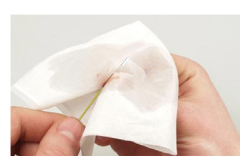
Pay attention to the stripping dimensions and that the appropriate tools are used. Depending on the cable type, you'll need to strip through different layers until you reach the bare fiber.

Measure and mark cable to desired length.



Gently strip the different layers of the cable with the dedicated tools and the helping dimensions on the cable until you reach the bare fiber.

Remove any residual coating material from the bare fiber with a wipe dampened with solvent. A properly cleaned fiber should squeak.



TECHNICAL INFORMATION

Processes and Radiall Technologies

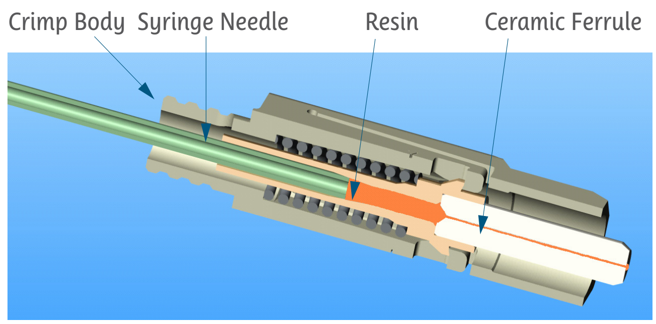
ASSEMBLY

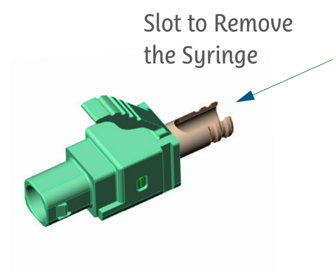
3-Assembly:

Inject the resin in the contact or connector you want to terminate until it appears at the ceramic tip.

Secure Bonding® (Radiall Patent)

Patented system protects the floating mechanism during the resin-injection process. A slot on the crimping body allows removing the syringe freely without the needle touching any sensitive inner surfaces. This system avoids calibrating the volume with a dispenser. The resin will be injected inside the cavity, with no risk of excess or insufficient volume, thus guaranteeing proper fiber retention. (Too much resin can break the fiber during the connection while not enough resin does not properly maintain the fiber).





With a twisting motion and very gently, **insert fiber into the terminus** until it bottoms.

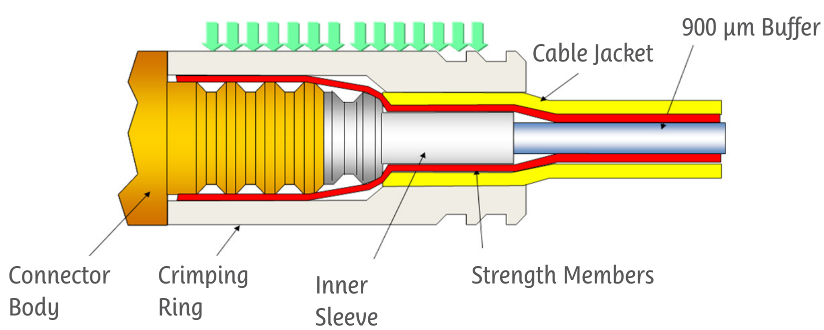
CRIMPING

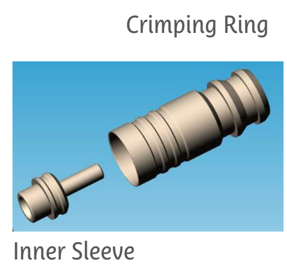
4-Crimping

The crimping allows securing the fiber position inside the connector.

Crimping Reliability® (Radiall Patent)

Only one crimp operation is required for both strength members and jacket retention. A mini metallic tube (inner sleeve) is inserted between the fiber and the cable jacket to protect the fiber and avoid any stress. The shape of the crimping ring is adapted to ensure excellent cable retention.





Using a crimp tool, firmly crimp the crimp ring of the terminus.

Processes and Radiall Technologies

CURING

5-Curing/Polymerization

Typically, polymerization is made by a hot process, however, it can also be done at ambient temperatures for field installations.

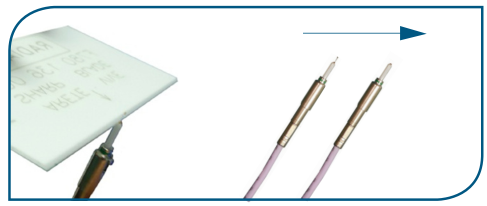
Place the termini in the curing unit cavities and **heat cure the resin** to the recommended temperature and for the recommended duration.

Incomplete polymerization weakens the fiber and may cause it to break during cleaving and polishing.

CLEAVING

6-Cleaving

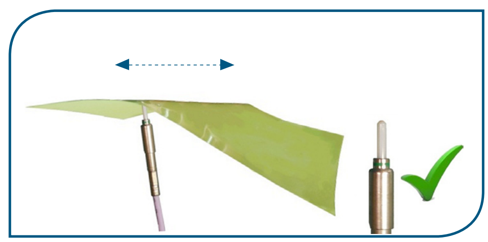
Cleave the excess fiber from terminus end. Apply a gentle but straight pressure at the end of the fiber to break it clean at the cut.



DEBURRING

7-Deburring

Polish off the end of the fiber by lightly running the abrasive paper over the top of the terminus tip to remove any remaining resin or fiber at the end of the ferrule.



To terminate fiber optic cables with an optimized process, Radiall provides high-end kits with a detailed procedure and everything you need for a reliable and easy termination process. Refer to section 11, tool kits & accessories, for more information.

Processes and Radiall Technologies

POLISHING PROCESS

The polishing process is crucial to get the smoothest end face to guarantee the lowest losses and most reliable connection. There are two techniques that can be used: manual polishing or mechanical polishing.

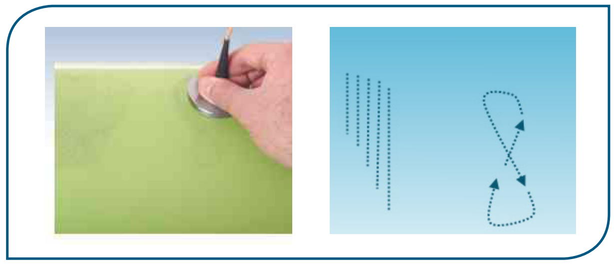
- Always make sure all your tools are properly prepared and cared for.
- Change polishing film regularly.
- Don't over-polish, you'll create a concave fiber surface, increasing the loss.

Manual Polishing:

Used in the field, manual polishing is a practical technique which allows a medium end face quality with a small amount of time and material. However practical and field friendly, the manual polishing technique will not guarantee various parameters:

- Radius of Curvature
- Apex (critical in case of APC)
- Constant Visual Aspect (scratches)
- UPC (50 dB)

Refer to your termini supplier for the best adapted process (time, motion, tool) for manual polishing.

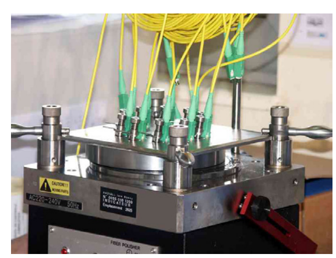


Mechanical Polishing:

Mechanical polishing guarantees the highest quality with a high level of consistency from batch to batch. PC, UPC and APC polishing grades are possible on automatic polishing machines; either on collective polishing machines dedicated to mass production or on unitary polishing machines for small volumes of production or field application.

Benefits:

- Permits APC, UPC and PC polishing
- Low and high volume polishing possible
- Quality consistency from one termini to the other
- Time saving
- Safe repolishing process if necessary



Processes and Radiall Technologies

WORK STATION SET UP

1-Preparation of the Work Station

Always work in the cleanest environment possible. Polishing films must be verified every day before use due to tool wear.

Plug and turn your polisher on.

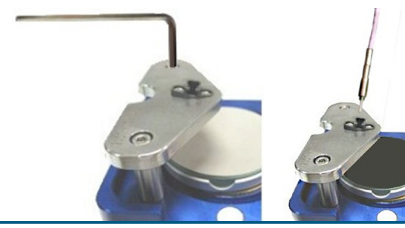
Set up your mechanical polisher for load up and load down.

Install the right polishing jig.

Install the terminus in the jig.

Depending on the polishing program, install the adapted polishing pad and film. Always put some demineralized water between the film and the pad to create a vacuum effect and immobilize the film on the pad.

Dispense 1 to 2 ml of demineralized water on the film on the area where the ferrule will touch the film and lower the jig to put the terminus in polishing position.



POLISHING

2-Polish

Start your polishing program. Clean plate and contact with demineralized water after each step.

CLEANING

3-Clean

When the program is complete, remove the termini.

Remove pad and film from the machine and thoroughly clean the polisher.

Inspect the optical end face.

To polish fiber optic termini with an optimized process, Radiall provides high-end kits with a detailed procedure and adapted tools. Refer to section 11, tool kits & accessories, for more information.

Radiall offers pre-angled connectors (LC & SC series) with a 8° pre-polishing of the ferrule for faster fiber termination process.

Radiall can also provide the complete set of tools for manual polishing.

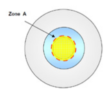
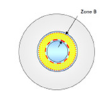
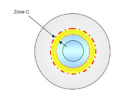
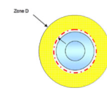
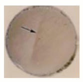
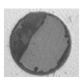
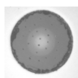
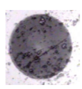
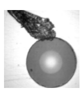
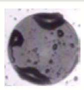
Processes and Radiall Technologies

VISUAL INSPECTION

Various types of contaminations and defects of the optical end face may weaken or disrupt the signal. Their origins range from environmental to uncompleted termination and polishing processes. To optimize optical losses during the optical system integration, Radiall recommends inspecting each connection side before mating.

Best practice: Inspect before you connect

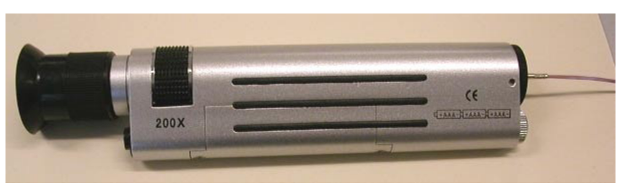
Types of contaminations and visual inspection criteria based on ARINC 805-3

Visual inspection criteria	Not permitted examples	Zone A Core area 	Zone B Cladding area 	Zone C Adhesive bond area 	Zone D Ferrule area 
Cracks		None	None	No limit of size or number	None
Chips/pits/ contamination	 	Not to exceed 5% of total area	Not to exceed 10% of total area	No limit of size or number	No limit of size or number
Scratches		No more than 3 ≥3 µm in width, any length	No more than 6 µm in width, no limit on number	No limit of size or number	No limit of size or number
Debris	 	None ≥3 µm	None ≥3 µm	Max 5 pieces of debris ≤10 µm in diameter	Max 5 pieces of debris ≤10 µm in diameter
Film/oil		None	None	None	None

The quality of the inspection varies according to the tool you use, we recommend the use of a digital microscope with a 200x to 400x magnification.

Benefits of using Radiall recommended inspection tools:

- Automated Pass/Fail analysis
- Automatic fiber-image centering
- Select your microscope according to your precision needs.
- Select your tip according to the configuration (polishing, ferrule size, in or out multipin connectors)
- Select your barrel according to your tip



Manual fiberscopes are also available but offer a less clear view of the end faces:

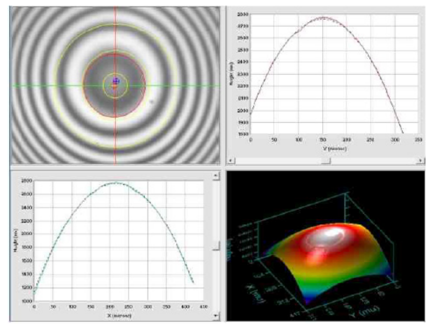
- Can't come close to the ferrule end face
- Difficulties to view APC polished end faces
- Not practical when inspecting in multipin connectors
- Subjectivity of the technician inspecting

Processes and Radiall Technologies

END FACE GEOMETRY & INTERFEROMETRY

Importance of the End Face Geometry:
The geometry of the end face determines which areas come into contact when two connectors or termini are mated. It allows controlling the performance of the connector and assessing its compliance to the standards. Measuring end face parameters such as the radius of curvature, the apex offset and the fiber height after termination and polishing process provides quality control and quality assurance.

Measurement Technique:
The interferometer is one of the most common instruments that can provide information on the end face geometry. It is widely used in science and industry for the measurement of small displacements, refractive index changes and surface irregularities.
Interferometry uses light waves to measure the surface in three dimensions. This makes it the preferred method for analyzing fiber optic end faces because it provides accurate and immediate information on the entire surface topography.



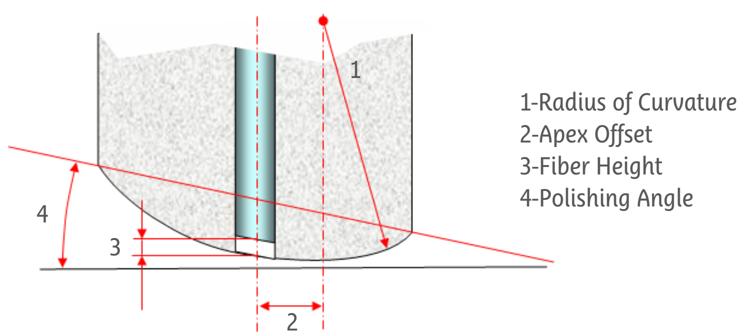
Key Measurement Parameters:

Radius of Curvature:
The end face of ferrules is domed to ensure that the contact area between mating connectors is at the center of the ferrule. The radius of this dome is called the "Radius of curvature". If the radius is too low, there will be a smaller contact area thus putting more force on the fiber during mating. If the radius is too high, physical contact between the two fibers may not be achieved because there will be a larger contact area resulting in less ferrule deformation. Measurement is performed by calculating the best fitting sphere over this area.

Apex Offset:
Apex offset is a measure of the distance between the highest point of the convex of the polished end face and the center of the fiber. The objective is for the center of the fiber to be the highest point on the end face, thus guaranteeing contact between mating fibers.

Fiber Height:
Fiber height is the difference in height between the center of the fiber and the theoretical height of the ferrule where the center would be when considered a continuous sphere. Both EIA/TIA and Bellcore standards allow a fiber height to be calculated based on the measured radius of curvature.

Example of an APC polished ferrule:



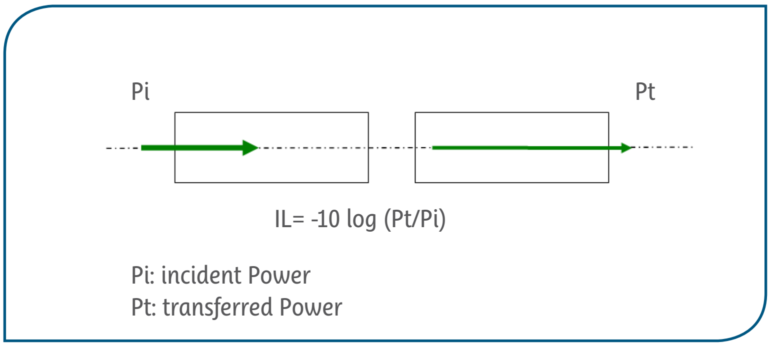
TECHNICAL INFORMATION

INSERTION LOSS (IL) AND RETURN LOSS (RL) MEASUREMENTS

In order to qualify how efficiently light is transmitted in a connection, we measure two key characteristics: Insertion Loss and Return Loss.

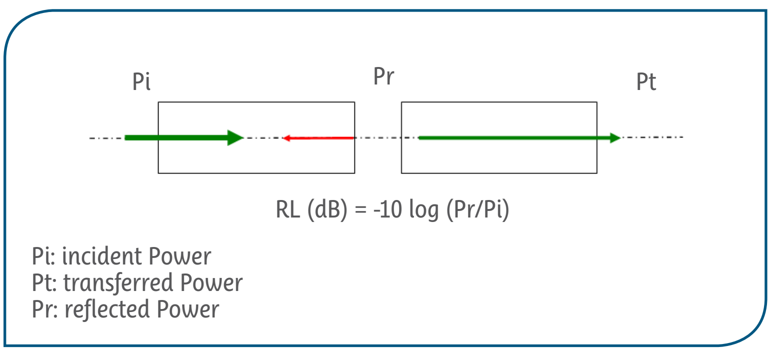
Insertion Loss Definition:

Insertion Loss (IL or attenuation) refers to the loss of signal power (light) resulting from the insertion of a device (for example a connector) in a transmission line or optical fiber. Insertion loss can result from absorption, misalignment or air gap between the fiber optic components. The smaller the IL, the better.



Return Loss Definition:

Return Loss (RL) is the ratio of the reflected optical power to the incident power. When light is transmitted into a connector, a portion of light is reflected back from the fiber end face. It is desirable for this figure to be as high as possible (meaning to have as little reflected light as possible) to avoid problems with transmission lasers.



Measurements Standards:

IL and RL measurement methods are described in IEC 61300 standards (Fiber optic interconnecting devices and passive components) – Basic test and measurement procedures and ARINC 805 standard (Fiber Optic test procedures).

Specifically:

- IEC 61300-3-4: Examinations and measurements - Attenuation
- IEC 61300-3-34: Examinations and measurements - Attenuation of random mated connectors
- IEC 61300-3-6: Examinations and measurements - Return loss

Processes and Radiall Technologies

IL MEASUREMENT

IEC 61300-3-4 method B and C (only usable if each extremity is the same connector):
These methods describe the procedure for the insertion loss due to one cabled end (or attenuation) based on a master reference. This measurement is based on the use of an optical power meter. The power meter consists of an optical detector and associated electronics for processing the signal.

Two measurements of power are required for each measurement of attenuation:

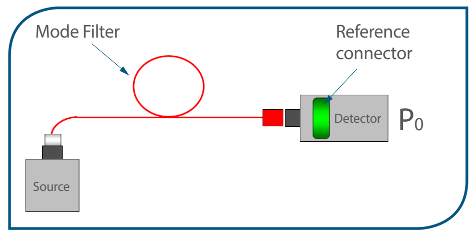
$$A = -10 \log (P1/P0) \text{ dB}$$

Where P1 is the measurement of power with the Device Under Test (DUT) in the circuit
Where P0 is the measurement of power without the DUT in the circuit

CALIBRATION

1-Calibration of the Measurement Tools

Connect the reference connector on the Detector
Measure P0 power.

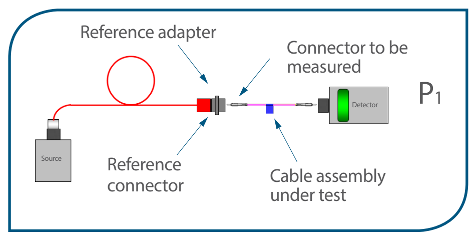


MEASURE

2-Measure

Insert the cable assembly between the reference connector and the detector.
Measure P1 to get the connector extremity A insertion loss.
Turn the cable assembly and measure P1 to get the connector extremity B insertion loss.

Note: This measurement only includes the plug on the source end of the DUT in the measurement. To measure both ends of the DUT the measurement shall be repeated with the patchcord reversed.



IEC 61300-3-34:
This method describes the procedure to measure the statistical distribution and mean attenuation for random mated optical connectors. This measurement is based on the use of random patchcords and adapters. All the connectors are sequentially used as "reference" plugs and all the remaining are tested against them.

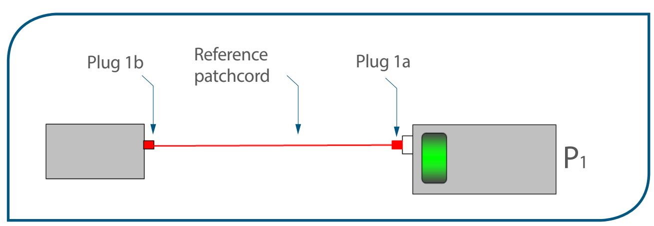
Measurement of the Loss is calculated with the following equation:

$$A = -10 \log (P1/P2) \text{ dB} - (AxL) \text{ dB}$$

Where A is the fiber attenuation per kilometer and L is the length of fiber in km.

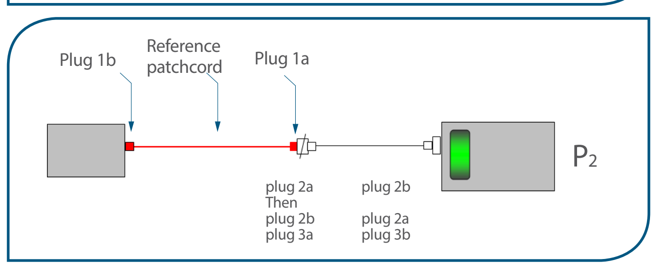
MEASURE

1-Measure of P1 power



2-Measure

Measure the loss of each mated connector pair (1a/2a, 1a/2b, 1a/3a, ... 1b/2a, ..., 2a/3a, ...)



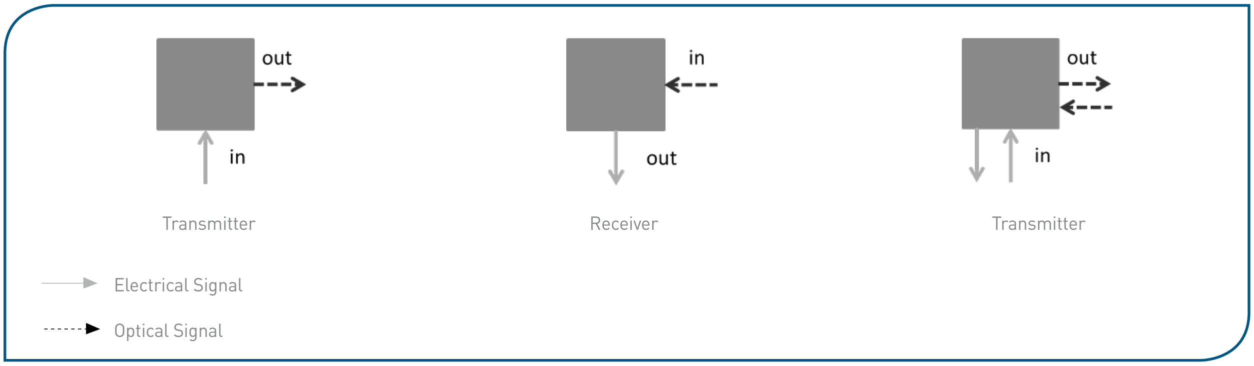
Note: the product (AxL) may be ignored when patchcord length is ‹10 m

TECHNICAL INFORMATION

Optical Active Devices

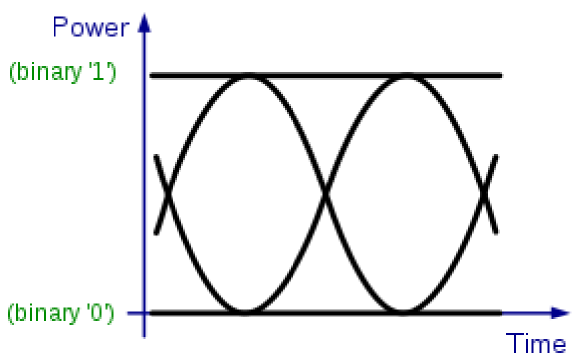
TRANSMITTER, RECEIVER AND TRANSCEIVER

Fiber optics communication requires active devices to convert electrical signals to optical ones in order to ensure the propagation of the information through optical fiber. Symmetrically opto-electronical conversion is needed to recover data at the end of fiber. An active device can be a transmitter, a receiver or a transceiver versus the way it handles optical and electrical signals, as sketched below:



OPTICAL EXTINCTION RATIO (ER) AND OPTICAL MODULATION AMPLITUDE (OMA)

In digital communication, for bi-level coding schemes, the optical extinction ratio is the ratio of energy (power) used to transmit a logic level "1" to the energy used to transmit a logic level "0".



$$Er = \frac{P1}{P0}$$

$$Er(dB) = 10 \log \frac{P1}{P0}$$

In an ideal transmitter P0 would be zero, but in most situations, its lower value is limited by the laser threshold. For data link optimization, ER is set by manufacturers at the best compromise between the transmitter optical power requirement and the bit error rate of the link. The Optical Modulation Amplitude, OMA, is defined as the difference between the high and low levels:

$$OMA = P1 - PO$$

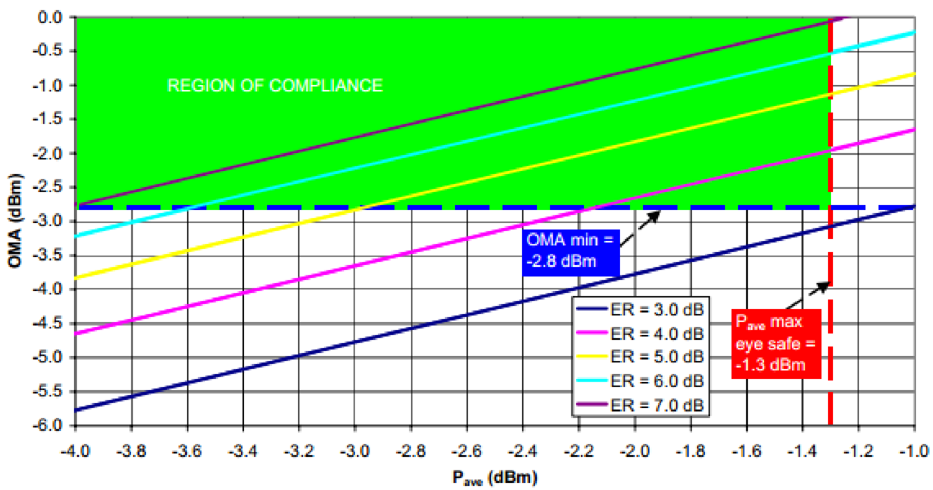
Pavg is defined as the average between the two power levels: $$Pavg = \frac{P1 + PO}{2}$$

Optical Active Devices

OMA is a function of average launch power (Pavg) and extinction Ratio (Er):

$$\text{OMA} = 2.\,\text{Pavg} = \frac{\text{Er} - 1}{\text{Er} + 1}$$

The following chart shows the relationship between Er, Pavg and OMA parameters



Then, for every transmission link configuration a region of compliance can be defined, setting the range of values that Er, OMA and Pavg need to comply with to fulfill the targeted standard.

The above chart shows for instance the region of compliance [Pavg-OMA] to fullfill the 802.3ae 10GBASE-S TX standard. The dashed blue line shows the minimum OMA set by the standard (-2.8 dBm) and the dashed red line shows the Class1 eye safety limit over wavelength range of 840-860 nm (IEC 60825-1 2001) for the related optical source.

The intersection of the graphed lines with the minimum OMA (dashed blue) line defines the minimum compliant average power. For example, this occurs at an average power equal to -3 dBm for Er=5 dB. This is a useful low-end setting for Er; lower values would not provide enough operating range for average optical power. Higher extinction ratios (>6 dB) are more desirable.
For a digital optical data link, the receiver sensitivity is the minimum average received optical power required to achieve a fixed BER (Bit Error Rate). The BER is the ratio of error bits to the bits sent over a certain time interval.

The optical sensitivity and the transmitter average power are used to calculate the power budget of the optical transmission link. The power budget is the difference between the minimum Pavg and the maximum receiver sensitivity.

For example, with a Pavg of -4 dBm and a receiver sensitivity of -17 dBm, the transceiver budget is 13 dB. That value sets the amount of losses affordable for the link, achieving the targeted BER.

Glossary of Terms

APC connector: Angled Physical Contact connector with the end-face polished at 8° (or 9° in some cases). This polishing profile provides very low back reflection (RL>65 dB).

Attenuation: Reduction of signal magnitude, or loss, normally measured in decibels. Fiber attenuation is measured at a specified wavelength in decibels per kilometer. The decrease in signal strength along a fiber optic waveguide caused by absorption and scattering. Attenuation is usually expressed in dB/km.

Bandwidth: The highest frequency that can be transmitted by an analog system. Also, the information-carrying capacity of a system (especially for digital systems). The range of frequencies within which a fiber optic waveguide or terminal device can transmit data or information.

Bend radius: The smallest radius an optical fiber or fiber cable can bend before excessive attenuation or breakage occurs.

Bit: The smallest unit of information upon which digital communications are based; also an electrical or optical pulse that carries this information.

Bonding: Gluing technology to immobilize the fiber inside the optical ferrule.

Breakout Cable: A type of fiber optic cable containing several fibers, each with its own jacket and all of them surrounded by one common jacket.

Broadcast Transmission: Sending the same signal to many different places, like a television broadcasting station. Broadcast transmission can be over optical fibers if the same signal is delivered to many subscribers.

Buffer: The fiber buffer layer is a polymeric coating applied over the cladding glass principally for the purpose of protecting the optical fiber from mechanical damage. Fabrication techniques include both tight jacket or loose tube buffering, as well as multiple buffer layers.

Bulkhead panel mounting: Panel attachment of a connector using a screw and nut feed through technology.

Cladding: The layer of glass or other transparent material surrounding the light-guiding core of an optical fiber. The clad has a lower refractive index than the core thereby confining light in the core by the process of total internal reflection.

Coating: An outer plastic layer applied over the cladding of a fiber for mechanical protection. The material surrounding the cladding of a fiber. Generally a soft plastic material that protects the fiber from damage.

Core: The central area of an optical fiber which serves as a waveguide. It has a refractive index higher than the surrounding cladding.

Crimp Sleeve: A crimped metal cylinder that holds the connector to the cable through the cable's strength member.

Data Rate: The number of bits of information in a transmission system, expressed in bits per second (b/s or bps), and which may or may not be equal to the signal or baud rate.

Duplex: In cables, one that contains two fibers. For connectors, one that connects two pairs of fibers.

Electromagnetic Interference (EMI): Noise generated when stray electromagnetic fields induce currents in electrical conductors.

End face: Term often used to describe the end of a ferrule. The end face is finished or polished to have a smooth end, which can minimize connector loss or backreflection. Typical polish types are PC, UPC, and APC.

Glossary of Terms

Fan-Out: A multi-fiber cable constructed in a tight buffered tube design. At a termination point, cable fibers must be separated from the cable to their separate connection positions.

Ferrule: A cylindrical part, usually ceramic, which holds and aligns the fiber in a connector.

Fiber buffer: Consists of one or more materials that is used for protecting the individual fibers from damage and provides mechanical isolation and/or mechanical protection.

Flange mount: Panel connector screwed into the wall and requiring several holes (5 holes for square flange, 3 holes for rectangular flange).

Graded-index fiber: An optical fiber where the core has a non-uniform refractive index. The core is composed of the glass where the refractive index decreases from the center axis with a predetermined profile. The purpose is to reduce modal dispersion and thereby increase fiber bandwidth.

IEC: International Electro technical Commission.

Index of Refraction: The ratio of the velocity of light in free space to the velocity of light in a given medium.

Insertion Loss: The loss of power that results from inserting a component, such as a connector or splice, into a previously continuous path.

Interferometer: An instrument that employs the interference of lightwaves to measure the accuracy of optical surfaces; it can measure a length in terms of the length of a wave of light by using interference phenomena based on the wave characteristics of light. Interferometers are used extensively for testing optical elements during manufacture. Typical designs include the Michelson, Twyman-Green and Fizeau interferometers

ISO: Abbreviation for International Standards Organization. Established in 1947, ISO is a worldwide federation of national standards committees from 140 countries. The organization promotes the development of standardization throughout the world with a focus on facilitating the international exchange of goods and services, and developing the cooperation of intellectual, scientific, technological and economical activities.

Jacket: The outer, protective covering of the cable. Also called the cable sheath.

Jumper Cable: A short single fiber cable with connectors on both ends used for interconnecting other cables or testing.

Key: A feature of a terminus that prevents the terminus from rotating when it is installed in a connector. This ensures proper alignment of tuned termini and termini that use an APC polish. The key also prevents torsion stress from being applied to the portion of the fiber that is within the terminus.

Large-Core Fiber: Usually, a fiber with a core of 200 µm or more.

Local-Area-Network (LAN): A network that transmits data among many nodes in a small area (e.g. a building or campus). A communication link between two or more points within a small geographic area, such as between buildings. Smaller than a metropolitan area network (MAN) or a wide area network (WAN).

Loose structure cable: A fiber optic cable structure that allows limited movement of the fiber with respect to the outer jacket and strength member.

Mechanical ferrule/crimp ferrule: Immobilization technology used to secure the connector at the extremity of the fiber.

Glossary of Terms

MIL-SPEC: Abbreviation for military specification. Performance specifications issued by the Department of Defense that must be met in order to pass a MIL-STD.

MIL-STD: Abbreviation for military standard. Standards issued by the Department of Defense.

Mode: In guided-wave propagation, such as through a waveguide or optical fiber, a distribution of electromagnetic energy that satisfies Maxwell's equations and boundary conditions. Loosely, a possible path followed by light rays.

Optical ferrule: Guide pin for fiber connectors in which the fiber is secured (generally ceramics).

Return Loss (RL): The ratio (expressed in dB) of optical power reflected by a component or an assembly to the optical power incident on a component port when that component or assembly is introduced into a link or system.

PC: Abbreviation for Physical Contact. Refers to an optical connector that allows the fiber ends to physically touch. Used to minimize backreflection and insertion loss.

Pull-proof: A fiber optic cable and connector construction such that a pull applied to a single fiber behind the connector will not move or separate the ferrule end faces.

Profile Dispersion: Dispersion attributed to the variation of refractive index contrast with wavelength.

Refraction: The change in direction experienced by a ray (wave) when it passes between different materials having different refractive indices.

Step-index: An optical fiber core that has a uniform refractive index. This construction has a large modal dispersion as compared to graded-index fiber. This leads to pulse widening and limits the bandwidth as the pulses blur into one another.

Strength Member: The part of a fiber optic cable composed of aramid yarn, steel strands or fiberglass filaments that increase the tensile strength of the cable.

Termination: Preparation of the end of a fiber to allow connection to another fiber or an active device, sometimes also called "connectorization".

Tight structure cable: A fiber optic cable structure that allows no movement of the fiber with respect to the outer jacket.