Fiber Optics: Fiber Preparation and Fiber Connectors

Fiber optics are used for a variety of applications in the photonics industry. Different applications require different physical configurations of fiber. The goal of this Tech Note is to describe the common physical components a fiber optic cable may contain. Fiber optics are typically connectorized for convenience of mating and coupling. These connectors come in many configurations and styles.

This Tech Note will be able to help you distinguish which type of fiber you have or require, which connector your fiber has or will need, and how to terminate a fiber connector.

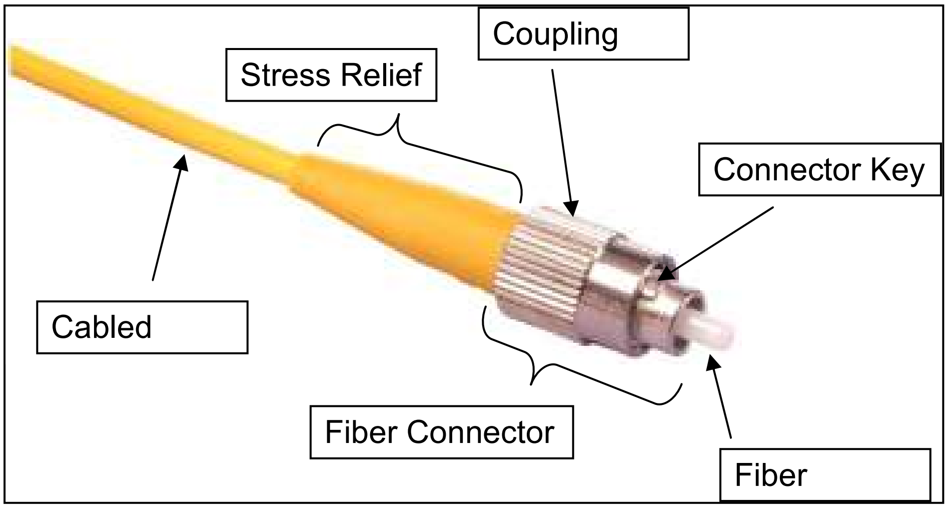


Figure 1 – Parts of a Fiber Optic Connector (FC/PC fiber displayed)

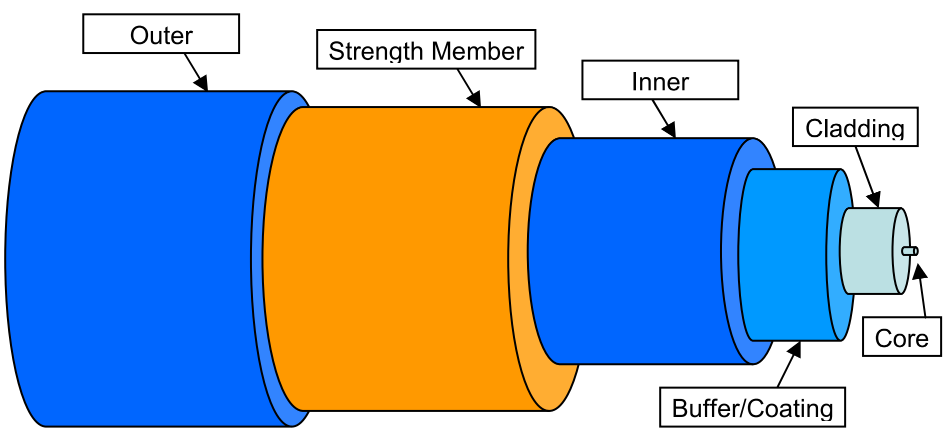


Figure 2 – Layers of a typical fiber optic (Single Mode, core ~9um, cladding ~125um)

Fiber Optic Connector Types

SMA — “**Sub Miniature A**”; Ferrule diameter = 3.14mm. Due to its stainless steel structure and low-precision threaded fiber locking mechanism, this connector is used mainly in applications requiring the coupling of high-power laser beams into large-core multimode fibers. Typical applications include laser beam delivery systems in medical, bio-medical, and industrial applications. The typical insertion loss of an SMA connector is greater than 1 dB.

ST — “**Straight Tip**”; Ferrule diameter = 2.5mm. The ST connector is used extensively both in the field and in indoor fiber optic LAN applications. Its high-precision, ceramic ferrule allows its use with both multimode and single-mode fibers. The bayonet style, keyed coupling mechanism featuring push and turn locking of the connector, prevents over tightening and damaging of the fiber end. The insertion loss of the ST connector is less than 0.5 dB, with typical values of 0.3 dB being routinely achieved. Drilled-out, metallic ST connectors, with insertion losses of >1 dB, are used with Newport’s large-core (>140 µm) fibers.

FC — “**Ferrule Connector**”; Ferrule diameter = 2.5mm. The FC has become the connector of choice for single-mode fibers and is mainly used in fiber-optic instruments, SM fiber optic components, and in high-speed fiber optic communication links. This high-precision, ceramic ferrule connector is equipped with an anti-rotation key, reducing fiber endface damage and rotational alignment sensitivity of the fiber. The key is also used for repeatable alignment of fibers in the optimal, minimal-loss position. Multimode versions of this connector are also available. The typical insertion loss of the FC connector is around 0.3 dB. Drilled-out, metallic FC connectors, having insertion losses of >1 dB, are being used with Newport’s large-core (>140 µm) fibers.

SC — “**Subscriber Connector**”; Ferrule diameter = 2.5mm. The SC connector is becoming increasingly popular in single-mode fiber optic telecom and analog CATV, field deployed links. The high-precision, ceramic ferrule construction is optimal for aligning single-mode optical fibers. The connectors’ outer square profile combined with its push-pull coupling mechanism, allow for greater connector packaging density in instruments and patch panels. The keyed outer body prevents rotational sensitivity and fiber endface damage. Multimode versions of this connector are also available. The typical insertion loss of the SC connector is around 0.3 dB.

LC — “**Lucent Connector**”; Ferrule diameter = 1.25mm.

Connector Endface Preparation

Once the optical fiber is terminated with a particular connector, the connector endface preparation will determine what the connector return loss, also known as back reflection, will be. The back reflection is the ratio between the light propagating through the connector in the forward direction and the light reflected back into the light source by the connector surface. Minimizing back reflection is of great importance in high-speed and analog fiber optic links, utilizing narrow line width sources such as DFB lasers, which are prone to mode hopping and fluctuations in their output.

Flat Polish — a flat polish of the connector surface will result in a back reflection of about -16 dB (4%).

PC Polish — the Physical Contact (PC) polish results in a slightly curved connector surface, forcing the fiber ends of mating connector pairs into physical contact with each other. This eliminates the fiber-to-air interface, there by resulting in back reflections of -30 to -40 dB. The PC polish is the most popular connector endface preparation, used in most applications.

SPC and UPC Polish — in the Super PC (SPC) and Ultra PC (UPC) polish, an extended polishing cycle enhances the surface quality of the connector, resulting in back reflections of -40 to -55 dB and < -55dB, respectively. These polish types are used in high-speed, digital fiber optic transmission systems.

APC Polish — the Angled PC (APC) polish, adds an 8 degree angle to the connector endface. Back reflections of <-60 dB can routinely be accomplished with this polish.

- Common types of FC connectors for example:
  - **FC/PC** – "Ferrule Connector/Physical Contact"
    - Most common of the FC connectors. The tip is slightly curved to ensure only the fiber cores make connection during mating not the ferrules themselves.
    - Keyed = 2.00mm
    - 25-40 dB return loss
    - PM, SM, or MM fiber
      - For PM fiber key is aligned to slow axis
  - **FC/APC** – "Ferrule Connector/Angled Physical Contact"
    - Common in most single mode applications where back reflection is critical to be minimized.
    - Identified by the 8 degree of angle present in the ferrule tip along with a typical green colored strain relief boot.
    - Narrow or Wide keyed = 2.02 or 2.14mm (narrow important for PM fiber)
    - 55-70 dB return loss
    - PM, SM, or MM fiber
      - For PM fiber key is aligned to slow axis
    - Only mate with other FC/APC fibers
  - **FC/UPC** – "Ferrule Connector/Ultra Physical Contact"
    - Higher quality polish with rounder edges than FC/PC to ensure better core mating
    - 45-50 dB return loss
    - PM, SM, or MM fiber
      - For PM fiber key is aligned to slow axis
    - Will mate with FC/PC connectors

Below is a table of useful Connector Key widths for PC and APC fiber endface preparations.

	PC	APC Wide Key	APC Narrow Key
Keyed Connector width (mm)	2.0 +/- 0.15	2.14 +0/-0.05	2.02 +0/-0.05
Adapter width (mm)	2.4 +/- 0.2	2.15 +0.05/-0	2.03 +0.05/-0

Fiber Stripping

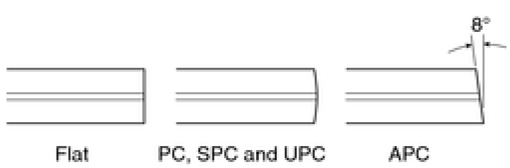
The outer sheath of fiber cables can be removed using electrical cable stripping tools, and scissors or a razor blade can trim the Kevlar strength member. However, the fiber coating must be very carefully removed to avoid damaging the fiber — surface flaws and scratches are the cause of most fiber failures. The coating can be removed using our **F-STR fiber strippers**.

Fiber Termination

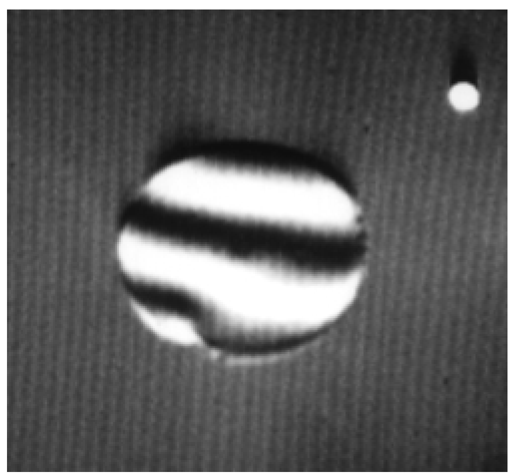
Endface surface quality is one of the most important factors affecting fiber connector and splice losses. Quality endfaces can be obtained by polishing or by cleaving. Polishing is employed in connector terminations when the fiber is secured in a ferrule by epoxy. The following describes the popular connectors and their endface preparation styles.

Fiber Cleaving

Fiber Cleaving is the fastest way to achieve a mirror-flat fiber end — it takes only seconds. The basic principle involves placing the fiber under tension, scribing with a diamond or carbide blade perpendicular to the axis, and then pulling the fiber apart to produce a clean break. Our **F-BK2** or **FK11 Cleavers** make the process especially quick and easy. It is wise to inspect fiber ends after polishing or cleaving.



Connector Endfaces



A typical F-BK2 cleave is clean, flat and perpendicular

Basic Steps for Preparing Fiber:

1. Prepare fiber
    a. Our Fiber Preparation Kit is very handy – **F-FPK**
    b. Determine the appropriate length of fiber that needs to be prepared and mark with a Sharpie (maybe ~80-100mm, always a good idea to prep more than less if you can afford it)
    c. Remove outer jacket
        i. This can carefully be done with an exacto-knife or razor blade
    d. Remove strength member if applicable
        i. Shears are handy for Kevlar strength member – **F-KS**
    e. Remove inner jacket if applicable
    f. Remove coating/buffer layer from fiber
        i. The easiest way to do this is with a fiber coating stripper designed for the diameter of fiber you have – **F-STR-175**
        ii. Another method is using an acetone soak to soften the coating so it can be pulled off. This takes some time (~10-15 min)
    g. Clean bare fiber with acetone wipe
    h. Cleave fiber – Not necessary for epoxy based connectorization where polishing is necessary, but needed to splice or simply use bare fiber as is
        i. Manual Cleaver – **F-BK3**
        ii. Electronic Cleaver – **FK11**
        iii. Angled Electronic Cleaver – **FK12**

2. Your fiber is now prepared for connectorization
    a. Bare fiber adapter kit is one method for connectorization – **F-AS-KIT**

3. Follow instructions for connector termination and polishing
    a. Sample instructions for FC/PC connector termination
        i. Slide stress relief and retaining ring down fiber to be used later
        ii. Apply epoxy bead to the inside of the fiber ferrule
        iii. Slide prepped fiber through the connector body and ferrule
            1. Important to make sure the epoxy encases the ferrule
            2. A small amount of epoxy and fiber should extrude from the ferrule tip
            3. Allow the epoxy to cure
        iv. Pull the retaining ring and stress relief back down into place and interweave with strength member and jacket of the rest of the fiber
        v. Tighten the retaining ring to the connector body
        vi. Scribe the extra fiber off of the tip – **F-RFS**
        vii. Begin to polish the fiber tip
            1. Start with coarse polish paper and progressively use finer and finer polishing paper
            2. A fiber puck or automated fiber polisher should be used

4. Inspect
    a. Fiber Scopes make great inspection tools
    b. Microscopes can also handle this task

5. Optically Test for transmission and back reflection

Fiber Splicing

Mechanical Splice – **F-SK-SA,** a mechanical splice is a reusable splice that aligns and mates the end face of two cleaned and cleaved fiber tip together. The mechanical splice will have an index matching fluid **F-IMF-105** (Refractive index = 1.52 @ 589nm) that eliminates the fiber-to-air interface, there by resulting in less back reflections. Typically mechanical splices are used for temporary splicing of fibers, couplers, WDMs, and other fiber optic elements. Typically the mechanical splice will contain a splice to key to lock the fibers into place for a secure splice.

Fusion Splice –This is the process of physically melting the tips of two cleaned and cleaved fibers together. Fusion splices are more permanent solution for continuous fiber application. Fusion splices have the best return loss performance of all the mating and splicing techniques. This is due to the action of creating one continuous fiber optic train. If fibers with identical core and cladding dimensions are used, the interface is nearly non-existing. As the fusion splice itself can be strong, the region around the splicing area can be weakened due to the heating process during splicing. It is recommended that strain relief and/or strength members be used. The draw back to this type of connection is the initial cost of the fusion splicing machine itself. They tend to be rather expensive, but pay for themselves over repeated use. Most fusion splicers are automated and some even have polarization control characteristics.

Coupling Light into Fibers

Good coupling efficiency requires precise positioning of the fiber to center the core in the focused laser beam. For multimode fibers, with their large cores, fiber positioners (e.g., Newport's **FP Series**) can achieve good coupling efficiency. Single-mode fibers require more elaborate couplers with submicron positioning resolution, like the **ULTRAlign** and **562F** stainless steel positioners and the **F-915** and **F-1015 Couplers**. These are also useful with multimode fibers when maximum coupling efficiency is required. The characteristics of the focused beam must match the fiber parameters for good coupling efficiency. For multimode fibers this is straightforward. General guidelines are:
The focused spot should be comparable to the core size.

The incident cone angle should not exceed the arcsine of the NA of the fiber (e.g. 23° for 0.2 NA and 35° for 0.3 NA).

To maximize coupling into a single-mode fiber, you must match the incident field distribution to that of the fiber mode. For example, the mode profile of the HE_{11} mode of a step index fiber can be approximated by a Gaussian distribution with a 1/e width w given by:

$$w = d\left(0.65 + \frac{1.619}{V^{1.5}} + \frac{2.879}{V^{6}}\right)$$

where: d is the core diameter, and V is the "V-number."

For our F-SV fiber, for which V = 2, the Gaussian width is approximately 28% larger than the core diameter, so the light should be focused to a spot size 1.28 times the core diameter at the fiber surface. For a Gaussian laser beam, the required beam diameter D incident upon focusing lens of focal length f to produce a focused spot of diameter w is $D = 4\lambda f/(\pi w)$. Given the laser beam waist and divergence, it's easy to determine the distance needed between the focusing lens and the laser to expand the beam to the required diameter.

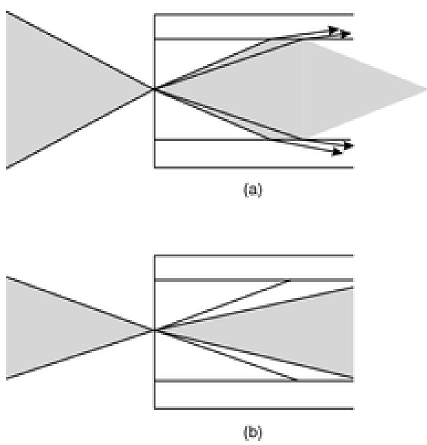
The mode field diameter is now given to provide easier matching of lens to optical fiber for a Gaussian beam.

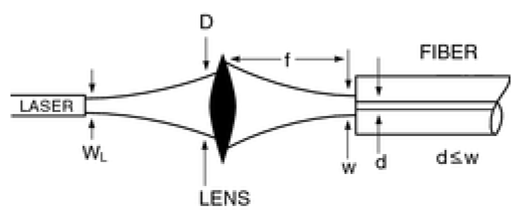
A high numerical aperture lens must collimate the diverging output beam of a laser diode. Newport's **F-L Series Diode Laser Focusing Lenses,** are AR-coated for high transmittance at popular laser diode wavelengths and — with numerical apertures up to 0.5 — are useful for collimating or focusing.

Mode Scrambling and Filtering

Many multimode fiber experiments are sensitive to the distribution of power among the fiber's modes. This is determined by the launching optics, fiber perturbations, and the fiber's length. Mode scrambling is a technique that distributes the optical power in a fiber among all the guided modes. Mode filtering simulates the effects of kilometer lengths of fiber by attenuating higher-order fiber modes.

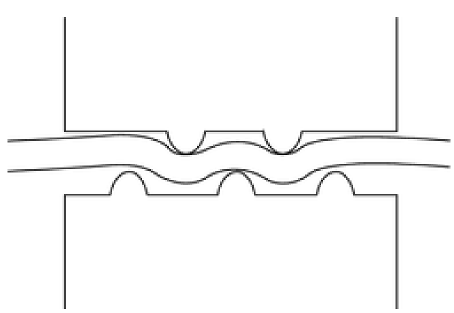
One scrambling technique is to splice a length of graded-index fiber between two pieces of step-index fiber — this ensures that the downstream fiber's core is overfilled regardless of launch conditions. Mode filtering can be achieved by wrapping a fiber several times around a finger-sized mandrel; bending sheds the high-order modes.
One way to achieve both scrambling and filtering is to introduce microbending to cause rapid coupling between all fiber modes and attenuation of high-order modes. One approach is to place a stripped section of fiber in a box filled with lead shot. A more precise way is to use Newport's **FM-1 Mode Scrambler**. This specially designed tool uses a calibrated mechanism to introduce microbending for mode scrambling and filtering.





A schematic of Coupling of light into an optical fiber

Launching conditions in a multimode optical fiber (a) Overfilled (b) Underfilled



Mode scrambler for optical fibers. The bends tend to couple out higher-order and radiation modes and to distribute the light into a distribution of modes that will remain stable over long distances.

Cladding Mode Removal

Some light is invariably launched into a fiber's cladding. Though cladding modes dissipate rapidly with fiber length, they can interfere with measurements. For example, the output of a single-mode fiber will not have a Gaussian distribution if light is propagating in the cladding. You can remove cladding modes by stripping a length of fiber coating and immersing the bare fiber in an index matching fluid such as glycerin.

Common Optical Parameters

The following is a list of common optical parameters associated with fiber optic components. Please call or visit Newport's website for application notes on how to measure these parameters.

Port Configuration: Number of input ports x number of output ports. e.g. 2 x 2

Coupling Ratio: The ratio of the power at an output port to the launched power expressed in dB. e.g. -10log (P2/P1).

Isolation: The ratio of the power at an output port in the transmitted wavelength band to that in the extinguished wavelength band, expressed in dB.

Directivity: The ratio of the power returned to any other input port to the launched power, expressed in dB. e.g.-10log (P4/P1).

Bandwidth: The range of operating wavelengths over which performance parameters are specified.

Excess Loss: The ratio of the total power at all output ports to the launched power, expressed in dB. e.g. -10log [(P2+P3)/P1].

Uniformity: The difference between maximum and minimum insertion losses.

Extinction Ratio: The ratio of the residual power in an extinguished polarization state to the transmitted power, expressed in dB.

Return Loss: The ratio of the power returned to the input port to the launched power, expressed in dB. e.g.-10log (P5/P1).

Polarization-Dependent Loss (PDL): The maximum (peak-to-peak) variation in insertion loss as the input polarization varies, expressed in dB.