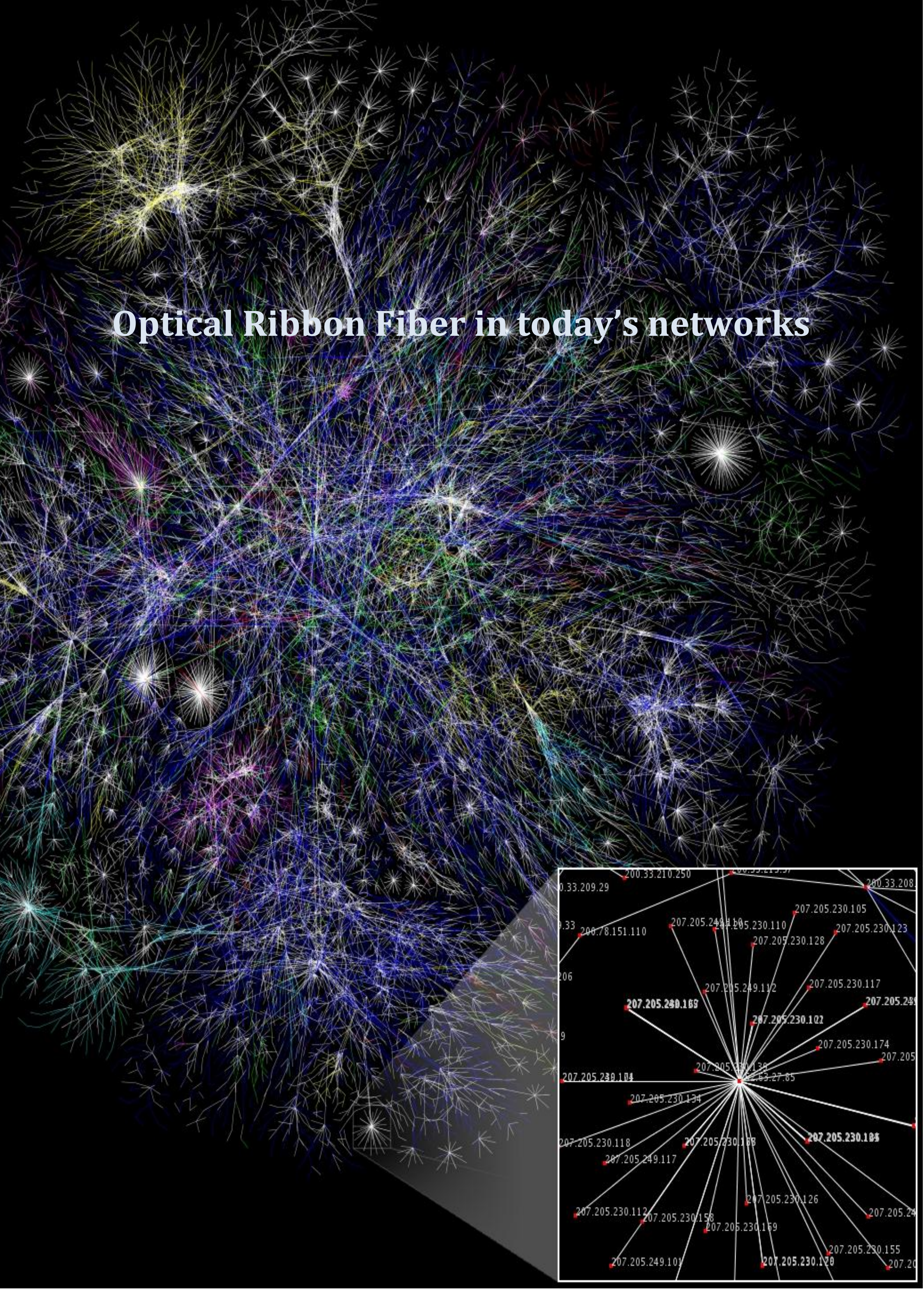
Optical Ribbon Fiber in today's networks



Prepared by Kevin Ledley for ACFIPS as part of its “Continual Professional Development” (CDP) program 2011.

http://www.acfips.org.au

Table of contents

1. An introduction to this resource

This guide provides an overview of **the handling and splicing of optical fiber ribbon cable.** The information was drawn from a number of sources and expertise but is by no means a definitive resource on the topic, but rather a framework of information that can be modified for a variety of situations. It is a work in progress.

The resource is for individuals and organisations involved in telecommunications to help build Professional Development skills and knowledge in the area of fiber optics. It has also been developed as a support material for workshops being conducted for the Training Package, ICT10.

There are many ways in which this guide can be used:

- You may be participating in the “Ribbon Fiber Interactive Workshop” being conducted in late 2012 as part of a Professional Development exercise and will use it as a reference
- You may be an enterprise or organisation that plans to implement fiber optics technology for clients and want to use and/or customise the guide to be used as a training tool for your own staff
- You may be a telecommunications worker such as a Cabler (Data and Communications), Telecommunications Cable Jointer, or Telecommunications Lines worker who is interested in learning more about the technology but can’t attend one of the workshops
- You may be an industry representative from a cable manufacturer, an NBN project builder, a trainer or someone who is affected by the particular ways that ribbon cable needs to be handled that may be different from standard cabling
- Or you may be a Registered Training Organisation (RTO) that offers training in telecommunications and want to provide this resource to your clients as support material.

Whatever the purpose, the resource can be downloaded and customised to suit your needs.

The National Broadband Network (NBN) rollout through the Federal government plans to utilise new types of cable, such as ribbon. Ribbon has been used in Australia but only on a limited basis. Trainers and assessors need to be up skilled to ensure that those persons working with ribbon cable are being trained appropriately. Others whom have worked in telecommunications over several years may want to have a better idea about how the ribbon cable differs from other types of cable and well as some of the knowledge and skills required for its uptake.

Based on consultations with the industry, it was identified that the ICT10 National Training Package contains qualifications and units of competency that cover cabling in broad terms but the specific skills and knowledge for handling and splicing of ribbon cable is not covered specifically. There are particular ways that the cable needs to be handled that are very different from the handling standard cable. Professional Development activities and resources in this area were identified.

The qualifications from ICT10 most relevant to the handling and splicing of ribbon cabling are the Certificate II and III in Telecommunications Cabling. For more information about the qualifications go to http://training.gov.au/Training/Details/ICT10.

2. Fundamentals of fiber optics

The Internet, smart phones, PAD’s and eReaders are a way of life in modern society. All of these technologies rely on optical networks.

The laser, born out of quantum mechanics, is one of the major building blocks of the optical network. Einstein used the theory of quantum mechanics to explain the photoelectric effect. In 1917 he discovered “stimulated emission” producing a single wavelength. Scientists applied this principle in the mid-1950s to stimulate emission of microwaves using a device called a maser. They then applied the same principle to visible light and used the term “laser” for this device.

In the 1960s, researchers had devised a method to operate lasers continuously at room temperatures using layers of semiconductors. Glass fibers could carry light over short distances, though it was not an efficient method with fiber having attenuation of 1,000dB per km. Charles Kao and George Hockham at Standard Communications Laboratories in England published a paper demonstrating theoretically that light loss in existing glass fibers could be decreased dramatically. Corning Glass Works scientists Donald Keck, Peter Schultz, and Robert Maurer soon after report the creation of optical fibers that meet the standards set by Kao and Hockham. The purest glass ever made, it is composed of fused silica from the vapour phase and exhibits light loss of less than 20 dB/Km.

1975 and 1976 saw commercial fiber optic systems installed in the UK and USA. Only one to two Km were achievable at this early stage though the industry leapt forward with distances and speeds rapidly increasing.

In 1978, the total of all fiber optic installations in the world came to only 1,000 km. By 1984 the total length of fiber cables in the United States alone approached 400,000 km.

In 1988 the first transatlantic fiber cable was installed, approximately 6,000 km. Within another 10 years, 1997 FLAG was installed (Fiber Optic Link Around the Globe) becoming the longest single network in the world, 28,000 km.

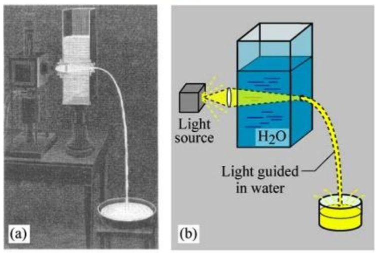
Fiber optics is forging ahead with major developments every few months giving us terabit communications and petabyte only around the corner.

3. Extracts of the history of optical telecommunication

Fiber optics plays such a major roll in our telecommunications network it is easy to take it for granted. The following list of events are extracted from published material and presented with only some events in the fast-paced and wide industry of fiber optics.

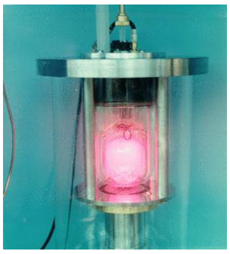
3000 BC Earliest known glass was used to make jewellery, mosaics, core-formed vessels, etc.

1841 Daniel Colladon demonstrates light guiding in jet of water.



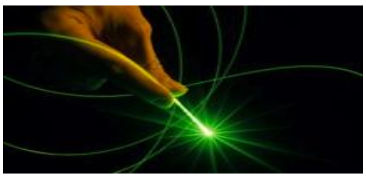
1905 Albert Einstein builds on Planck's theory to explain the photoelectric effect, showing that light is made up of packets, later called photons. In 1921, Einstein earned the Nobel prize for this breakthrough.

1951 Between 1951-1953, Charles Townes at Columbia University Radiation Laboratory discovers how to harness stimulated emission to generate a focused microwave beam. He names his invention the maser, for microwave amplification by stimulated emission of radiation. Townes shared the 1964 Nobel prize for this work with two Soviet physicists, N.G. Basov and A.M. Prokhorov, who had come up with a similar idea.



1960 Theodore Maiman of Hughes Aircraft Company builds a laser using synthetic ruby.

1961 Industry researchers Elias Snitzer and Will Hicks demonstrate a laser beam directed through a thin glass fiber. The fiber’s core is small enough that the light follows a single path, but most scientists still consider fibers unsuitable for communications because of the high loss of light across long distances.



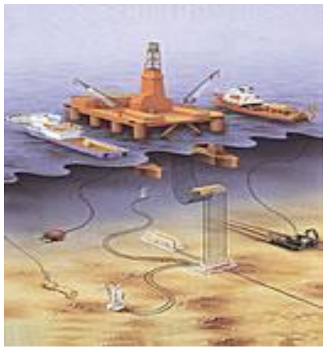
1970 Corning Glass Works scientists Donald Keck, Peter Schultz, and Robert Maurer report the creation of optical fibers that meet the standards set by Kao and Hockham. The purest glass ever made, it is composed of fused silica from the vapour phase and exhibits light loss of less than 20 decibels per kilometre, 1% of the light remains after traveling 1 kilometer. By 1972 the team creates glass with a loss of 4 decibels per kilometer. Also in 1970, Morton Panish and Izuo Hayashi of Bell Laboratories, along with a group at the Loffe Physical Institute in Leningrad, demonstrate a semiconductor laser that operates continuously at room temperature. Both breakthroughs will pave the way toward commercialisation of fiber optics.

1975 Standard Telephones and Cables in the United Kingdom installs the first fiber-optic link for interoffice communications after a lightning strike damages equipment and knocks out radio transmission used by the police department in Dorset.

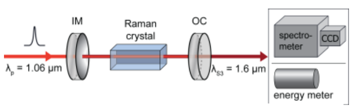
1984 AT&T fiber-optic cable enters service, connecting major cities in the Boston-Washington corridor.

1988 The first transatlantic fiber cable is laid, using glass so transparent that amplifiers are spaced about 40 miles apart.

1991 Tyco Telecommunications established another milestone by conducting the first successful transoceanic fiber-optic transmission using laser-pulsed light with a wavelength of 1.5 microns. This development opened the door to higher capacities by increasing the usable bandwidth.

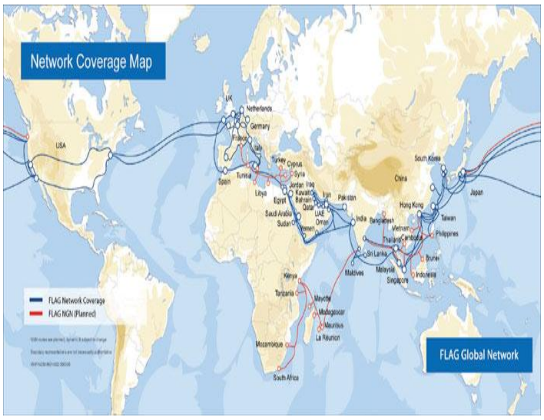


1993 First Raman laser, which overcomes the adverse effects of frequency shifts in individual light streams.



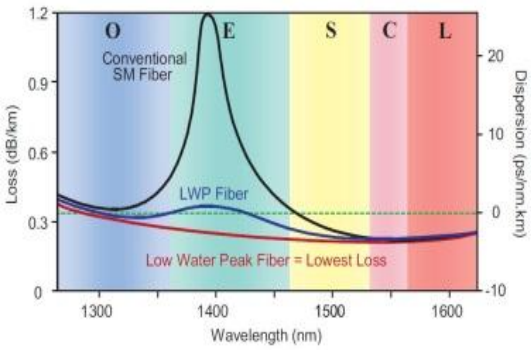
1995 LC connector design by Lucent Technologies released.

1997 The Fiber Optic Link Around the Globe (FLAG) becomes the longest single-cable network in the world and provides infrastructure for the next generation of Internet applications. The 17,500-mile cable begins in England and runs through the Strait of Gibraltar to Palermo, Sicily, before crossing the Mediterranean to Egypt. It then goes overland to the FLAG operations center in Dubai, United Arab Emirates, before crossing the Indian Ocean, Bay of Bengal, and Andaman Sea; through Thailand; and across the South China Sea to Hong Kong and Japan.



1999 First demonstration of ultra-dense WDM transmission of 1,022 channels on a single fiber.

2006 First bend insensitive Zero Water Peak fiber, 10 turns on a 15 mm radius mandrel achieving < 0.03 dB @ 1550 nm.



2010 Demonstration transmission of 40 × 112 Gb/s PM-QPSK[1] channels over a 365 km unrepeated span by Corning.

[1]polarization multiplexed quadrature phase-shift keying

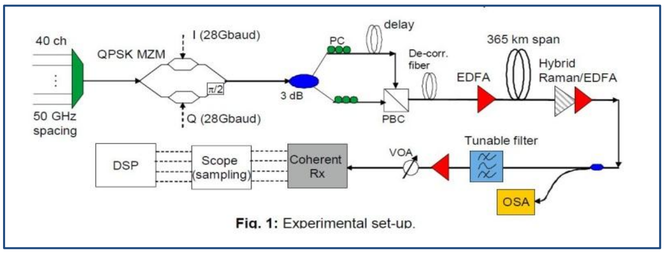


Fig. 1: Experimental set-up.

4. Key components used in optical fiber communications

Optical fiber communication systems commonly use various key components:

- optical transmitters, based mostly on semiconductor lasers fiber lasers, and optical modulators
- optical receivers, mostly based on photodiodes
- optical fibers designed with optimized properties, loss, dispersion, and nonlinearities
- dispersion-compensating modules
- semiconductor and fiber amplifiers
- optical filters, fiber Bragg gratings and couplers
- optical switches and multiplexers, reconfigurable optical add/drop multiplexers (ROADMs)
- devices for signal regeneration
- various kinds of electronics e.g. for signal processing and monitoring
- computers and software to control the system operation

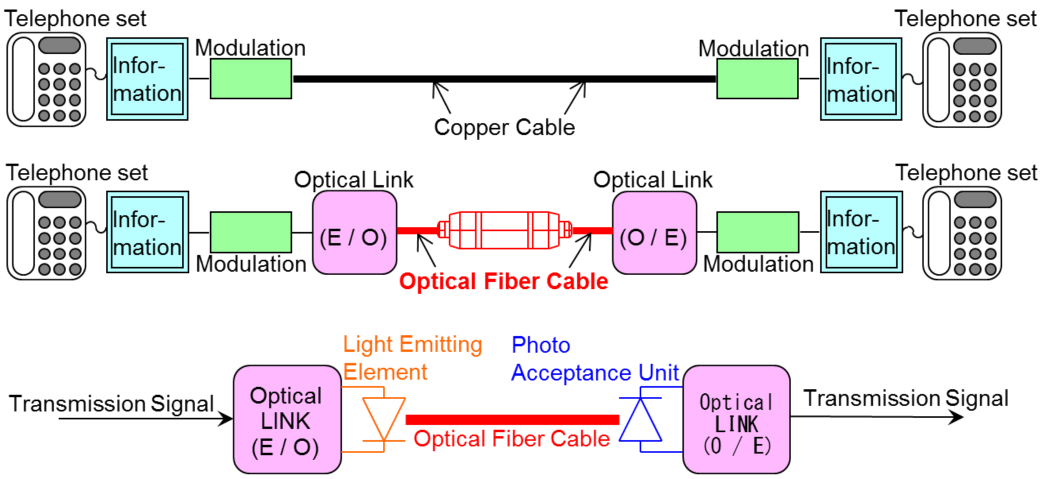
In many cases, optical and electronic components for fiber communications are combined on photonic integrated circuits.

5. Some typical communication systems

In the following examples, ribbon fiber is increasingly being deployed, high quality low cost fiber has enabled larger quantities of fiber to be deployed over wider networks and the use of mass fusion splicers deliver typical losses of 0.05 dB per splice.

Japan is one of the first countries to deploy ribbon fiber standardised on 8-fiber ribbon while later adopters have used 12-fiber ribbon.

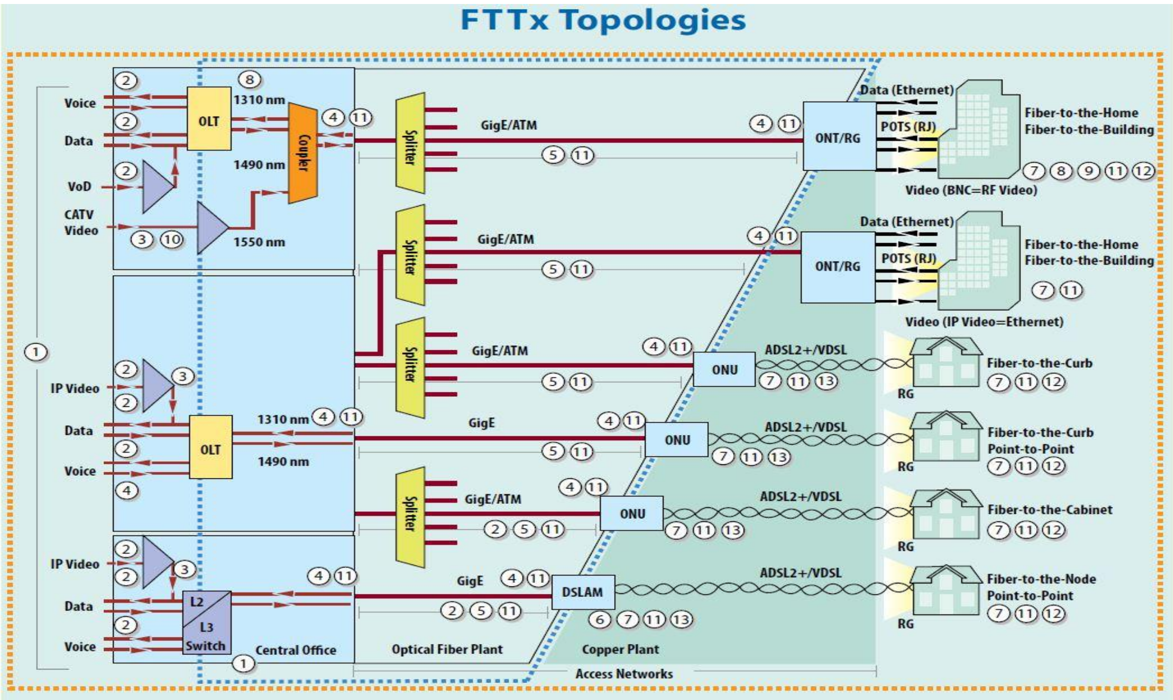
5.1 POTS system on copper and optical link



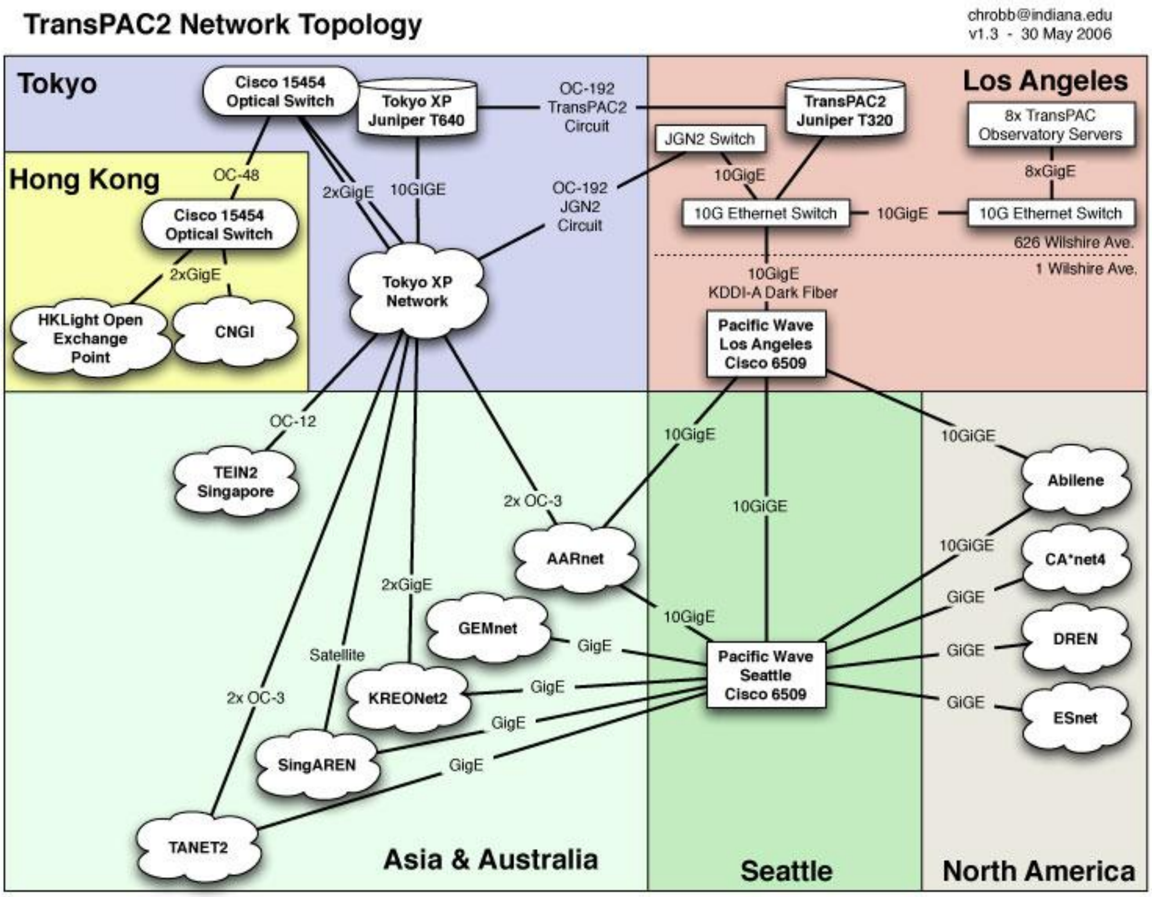
5.2 Various FTTX configurations

The telecommunications industry differentiates between several distinct configurations. The terms in most widespread use today are:

- FTTN - Fiber-to-the-node - fiber is terminated in a street cabinet up to several kilometres away from the customer premises, with the final connection being copper.
- FTTC - Fiber-to-the-curb - this is very similar to FTTN, but the street cabinet is closer to the user's premises; typically within 300m.
- FTTB - Fiber-to-the-building or Fiber-to-the-basement - fiber reaches the boundary of the building, such as the basement in a multi-dwelling unit, with the final connection to the individual living space being made via alternative means.
- FTTH - Fiber-to-the-home - fiber reaches the boundary of the living space, such as a box on the outside wall of a home.
- FTTP - Fiber-to the premises - this term is used in several contexts: as a blanket term for both FTTH and FTTB, or where the fiber network includes both homes and small businesses.
- FTTD - Fiber-to-the-desk - fiber connection is installed from the main computer room to a terminal or fiber media converter near the users desk.



5.3 Intercontinental transmission systems

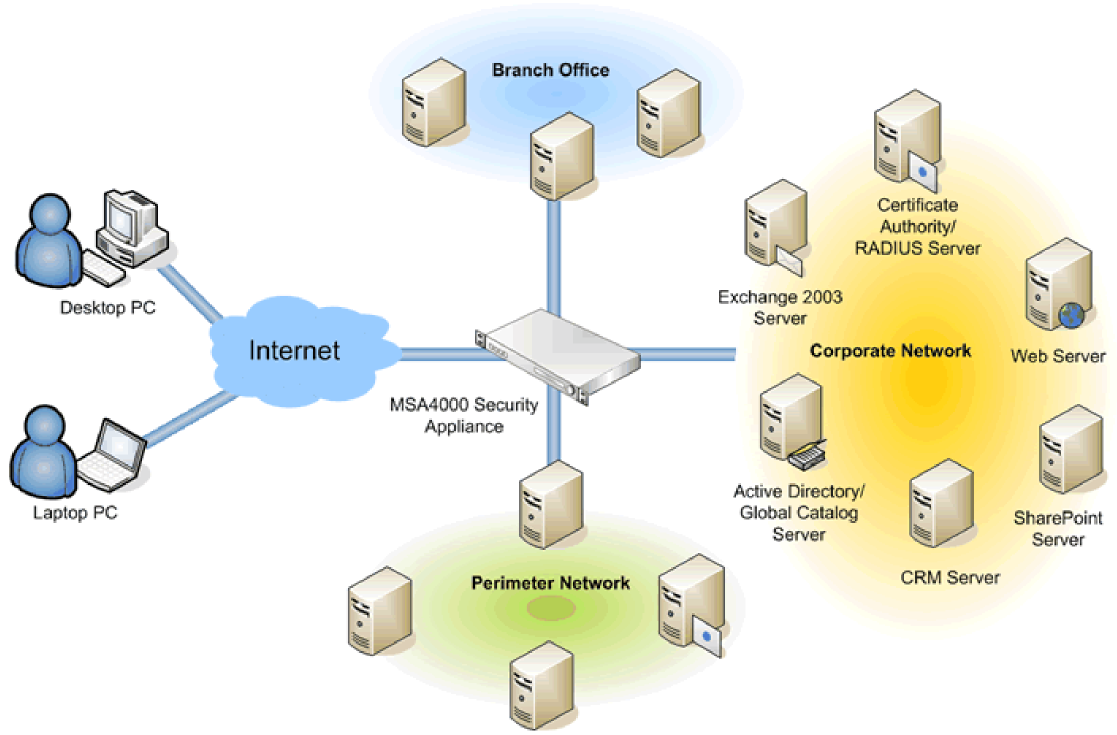


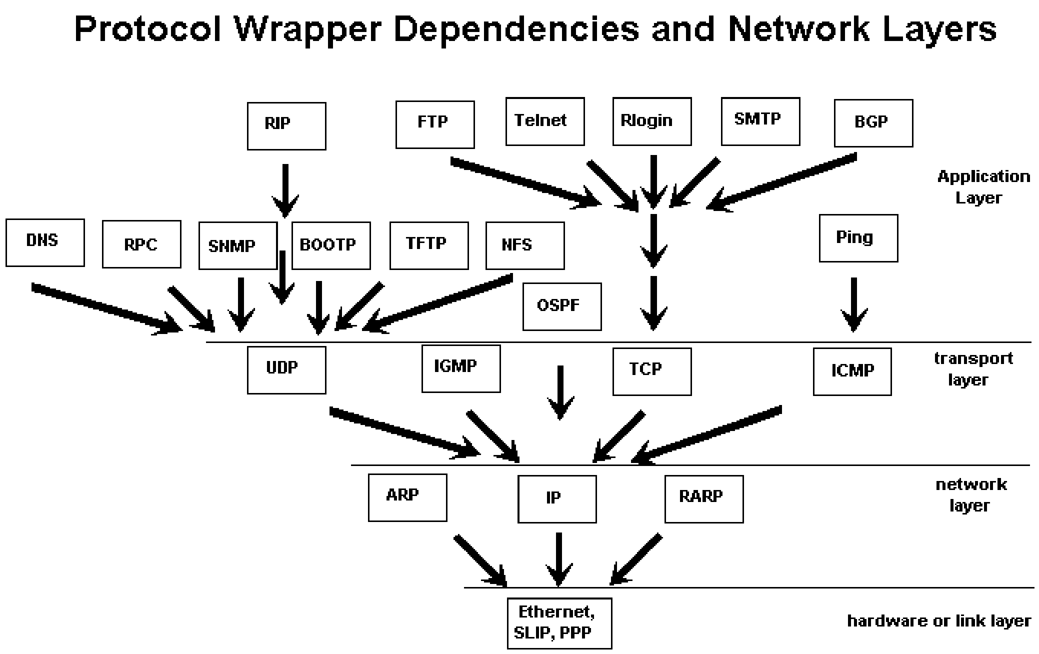
SONET/SDH Designations and Bandwidths

SONET Optical Carrier Level	SONET Frame Format	SDH level and Frame Format	Payload bandwidth[nb 3] (kbit/s)	Line Rate (kbit/s)
OC-1	STS-1	STM-0	50,112	51,840
OC-3	STS-3	STM-1	150,336	155,520
OC-12	STS-12	STM-4	601,344	622,080
OC-24	STS-24	–	1,202,688	1,244,160
OC-48	STS-48	STM-16	2,405,376	2,488,320
OC-192	STS-192	STM-64	9,621,504	9,953,280
OC-768	STS-768	STM-256	38,486,016	39,813,120

5.4 LAN and WAN networks

The figures below provide: an image of a common LAN and WAN configuration where ribbon is being used in each of the segments of the network and protocols identifying IPs in such configurations.





6. Optical fiber - from sand to a light pipe

Quartz (silicon dioxide - SiO2) is commonly found in nature and is one of the most important rock-forming minerals. It can be found in magmatic, metamorphous and sedimentary stone and deposits. Most naturally occurring silicon dioxide is in the form of trigonal quartz.

When silicon dioxide SiO_2 is cooled rapidly enough, it does not crystallize but solidifies as a glass. The glass transition temperature of pure SiO_2 is about 1600 K (1330 °C or 2420 °F).

6.1 Uses of silicon

Aluminium

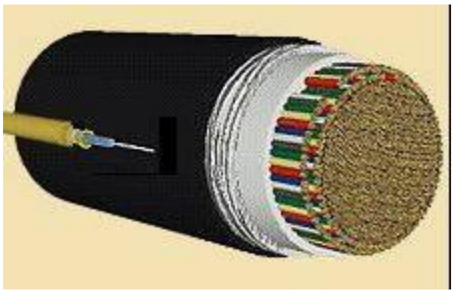
The ability of silicon to improve the strength of aluminium alloys has far reaching consequences for the transport industry. Aluminium alloys are light, yet strong and replace heavier cast iron components. Car wheels, cylinder heads, and engine blocks are routinely seen made from aluminium alloys. Weight reduction in automobiles decreases fuel consumption, which in turn reduces green house gas emissions and plays a role in conserving our fossil fuels.

Silicons

Silicon based polymers, known as silicones, provide an alternative to environmentally harmful hydrocarbon based products. We unknowingly use these polymers in everyday items from lubricants, greases & resins to skin and hair care products, antiperspirants, polishes, anti foam agents and fabric softeners.

Silicon chips

Electronic products that we rely on every day Cannot operate without semi-conductor chips made from silicon.



Optical glass

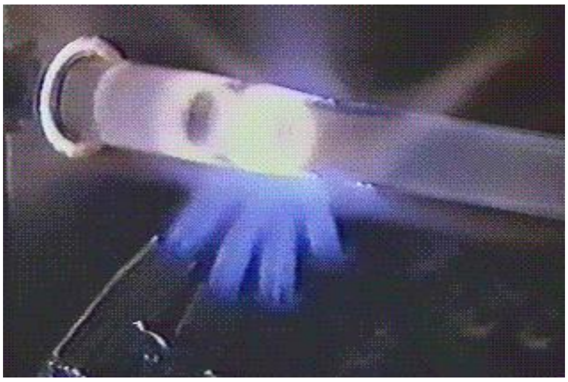
Today's modern high-speed communications are made possible by silicon. Optical glass produced from silicon is used to manufacture both optical fiber and liquid crystal displays.

Solar Energy

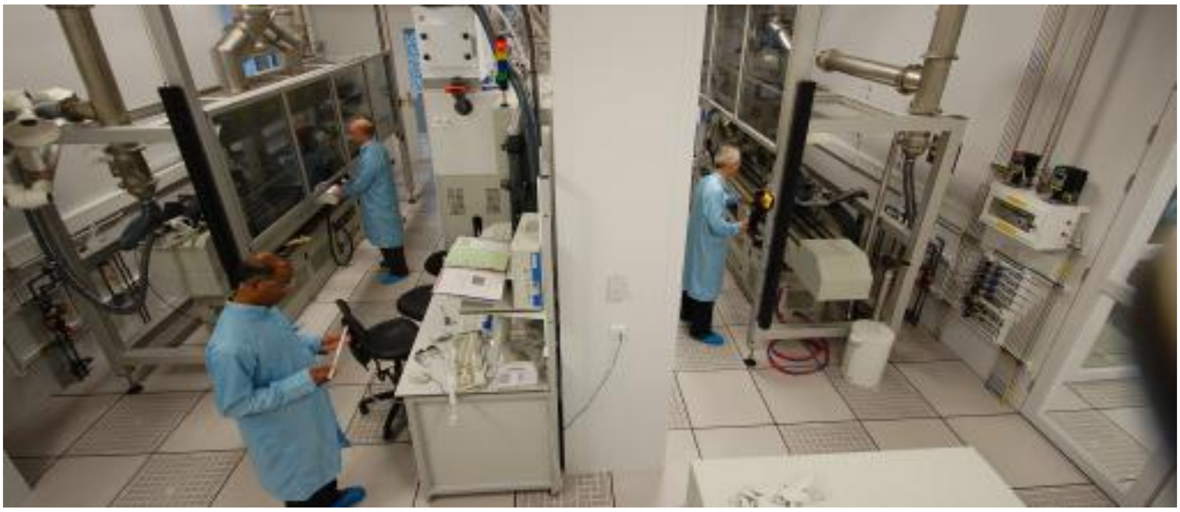
Silicon plays an important role in the photovoltaic industries where solar panels, made from silicon, use the sun's rays to generate space and water heating, produce domestic and industrial electricity and power remote telecommunications, weather and irrigation facilities

The pure silica tube is mounted on a lathe equipped with a special heat torch. As the gasses flow inside the tube, they react to the heat by forming solid submicron particles, called "soot," in the vicinity of the heat zone. Once the soot is formed, it is deposited on the inner wall of the tube. As the burner traverses over the deposited soot, the heat transforms these solid white particles into pure, transparent glass, in a process called vitrification. The deposited material will form the core region of the optical fiber.

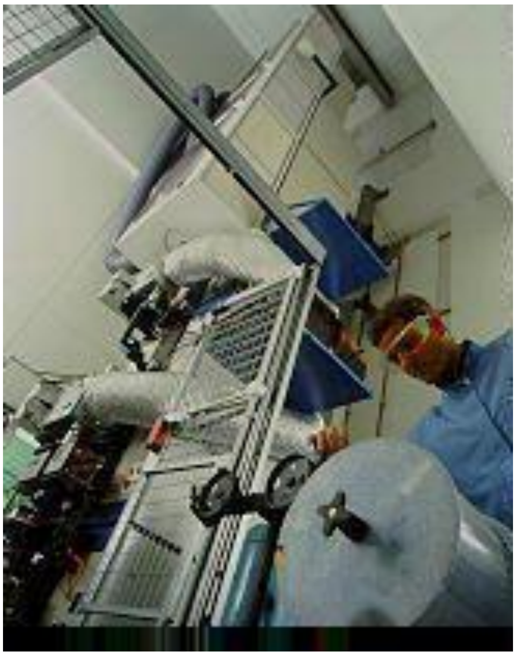
6.1.1 Preform manufacture



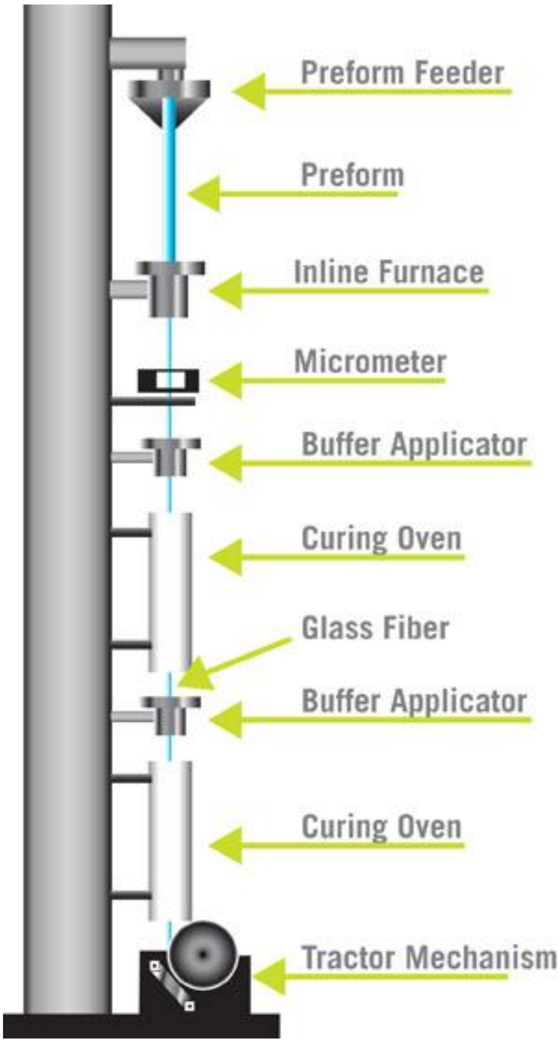
6.1.2 Preform production



6.1.3. Low loss preforms at the Sumitomo factory



The diagram below is of draw tower. If you have a spare million you can set one up.



A re-spooled drum of fiber at this point is coated with a clear 250um coating ready to have a 900um coating applied.

The resulting optical fiber made of ultra-pure silica is an extremely strong, loss glass that has the ability to handle exposure to temperature and pressure extremes. In fact, tensile strength of optical fiber exceeds 600,000 pounds per square inch – making it stronger than copper or steel strands of the same diameter and easily surpassing the strength requirements of today's communications applications.

7. Optical fiber types used in LAN and Telecommunications

There are two primary sources of specification of single mode optical fiber:[1]

- The ITU-T G.65x series
- IEC 60793-2-50 (and the equivalent to BS EN 60793-2-50)

At the time of writing 19 different single mode optical fiber specifications were defined by the International Telecommunications Union (ITU-T) -- the world's most universally recognised info communications standards. These are:

- ITU-T G.652a, b, c and d;
- ITU-T G.653a and b;
- ITU-T G.654a, b and c;
- ITU-T G.655a, b, c, d and e;
- ITU-T G.656;
- ITU-T G.657 Categories A1, A2, B1 and B2.

Each type has its own area of application and the evolution of these optical fiber specifications reflects the evolution of transmission system technology from the earliest installation of single mode optical fiber through to the present day. For example, the G.652a and G.652b specifications entitled "Characteristics of a single mode optical fiber and cable" define an optical fiber with performance specified at 1310 nm, 1550 nm and 1625 nm but intended for use at, and with azero chromatic dispersion slope in, the 1310nm region. These optical fibers would be expected to be found in extended length LAN, WAN and access network systems. The more recent variants (G.652.c and G652.d) are not specified at 1625 nm but feature a reduced water peak that allows them to be used in the wavelength region between 1310 nm and 1550 nm supporting Coarse Wavelength Division Multiplexed (CWDM) transmission.

For more details please refer to FIA document in the resource folder.

In addition to the different applications for which the optical fibers are used and the wavelengths at which they are specified, there are substantial differences in the specific construction of the optical fibers. The most obvious of the construction differences is their mode field diameter.

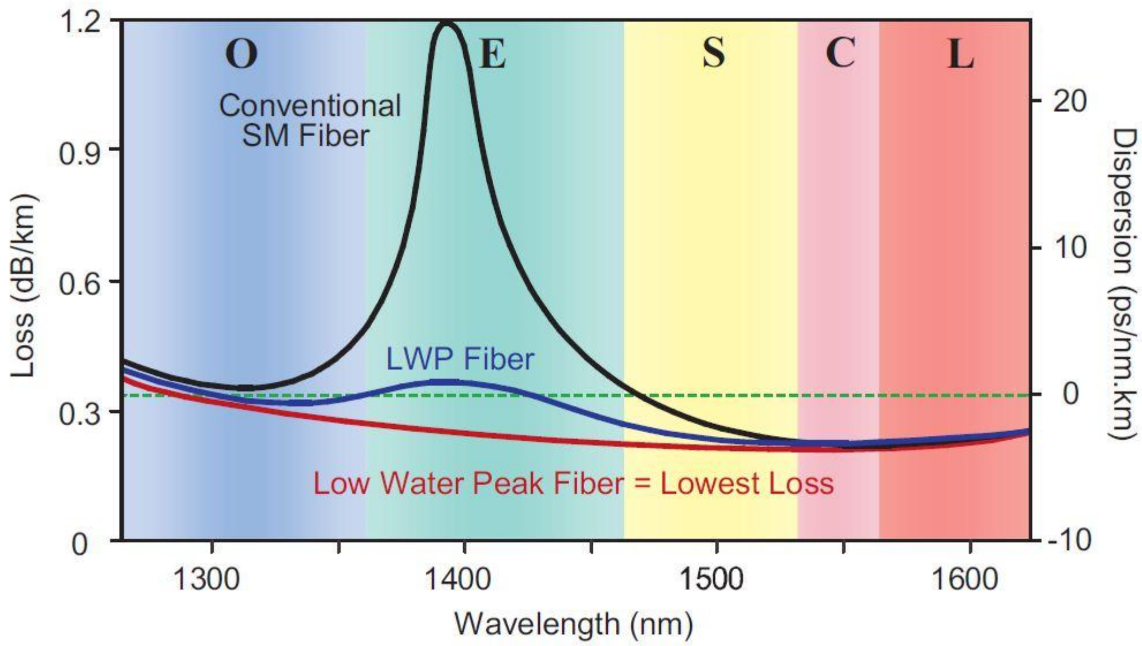
[1] This section is from *Overview of Singlemode Optical Fiber Specifications*, Mike Gilmore, Technical Director, The Fiberoptic Industry Association, UK.

As shown in the Table below, the mode field diameters of optical fibers meeting these specifications can differ substantially. The tolerances shown in the table are wider than those typically stated by manufacturers.

		Nominal	Nominal	MFD	Wavelength
IEC 60793-2-50: 2008	ITU-T	MFDmin	MFDmax	Tolerance	
		(um)	(um)	(um)	(nm)
Type B1.1	G652a, b	8.6	9.5	0.6	1310
NA	G654a	9.5	10.5	0.7	1550
Type B1.2_b	G654b	9.5	13	0.7	1550
Type B1.2_c	G654c	9.5	10.5	0.7	1550
Type B1.3	G652c, d	8.6	9.5	0.6	1310
Type B2	G.653a, b	7.8	8.5	0.8	1550
NA	G.655a	8	11	0.7	1550
NA	G.655b	8	11	0.7	1550
Type B4_c	G.655c	8	11	0.7	1550
Type B4_c	G.655d	8	11	0.7	1550
Type B4_c	G.655e	8	11	0.7	1550
Type B4_c	G.656	7	11	0.7	1550
Type B4_c	G.657 Cat A1/2	8.6	9.5	0.4	1310
Type B4_c	G.657 Cat B2/3	6.3	9.5	0.4	1310

*Mode field diameter mismatches can dramatically affect losses at joints. For more information see FIA Technical Support Document TSD-2000-4-1-1.
**ITU-T G.65* standards are available for free download from http://www.itu.int/publications/.

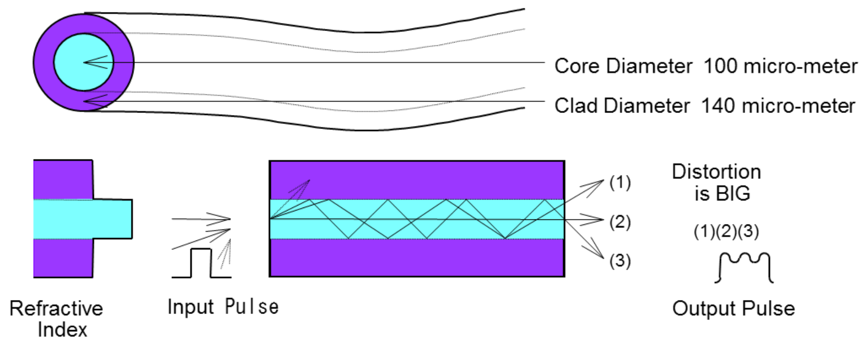
The table below represents a comparison of SM G652 and low water peak variants.



8. Stepped Index, Graded Index and Singlemode

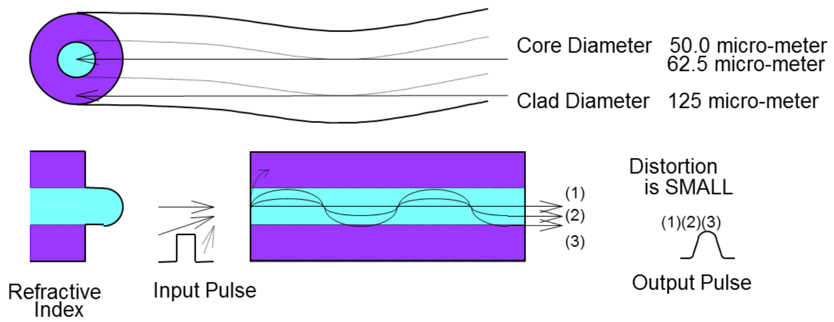
8.1 Multi Mode Fiber (SI) Step Index

Step Index fiber has a uniform refractive index in its core and a sharp decrease in refractive index at the core-cladding interface. Each arrival time at output is different since each traveled speed is constant. The optical signal is distorted in its core. SI can be used only on limited band and is not popular now.



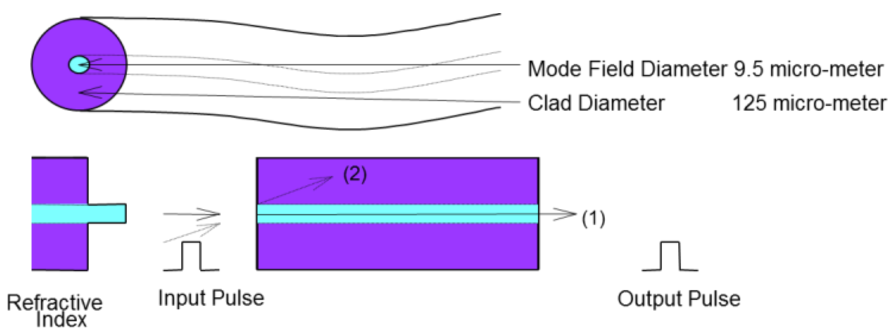
8.2 Multi Mode Fiber (GI) Graded Index (ITU-T G.651)

Graded Index fiber improves the Stepped Index fiber by providing a larger bandwidth. The refractive index at the core's center decreases gradually toward the core-cladding boundary. Each arrival time at output is not very different due to the refractive index. 50-micron and 62.5 micron cores are available in the industry as LAN application.



8.3 Single Mode Fiber (ITU-T G.652)

SI and GI have many modes inside core, a fiber having a small core diameter and in which only one mode will propagate at the wavelengths of interest. Optical signal is not distorted due to a single mode. This fiber is applicable to the communication system with high speed and capacity.



8.4. Other variants of Single Mode Fiber

8.4.1 DSF: Dispersion Shifted Fiber (ITU-T G.653)

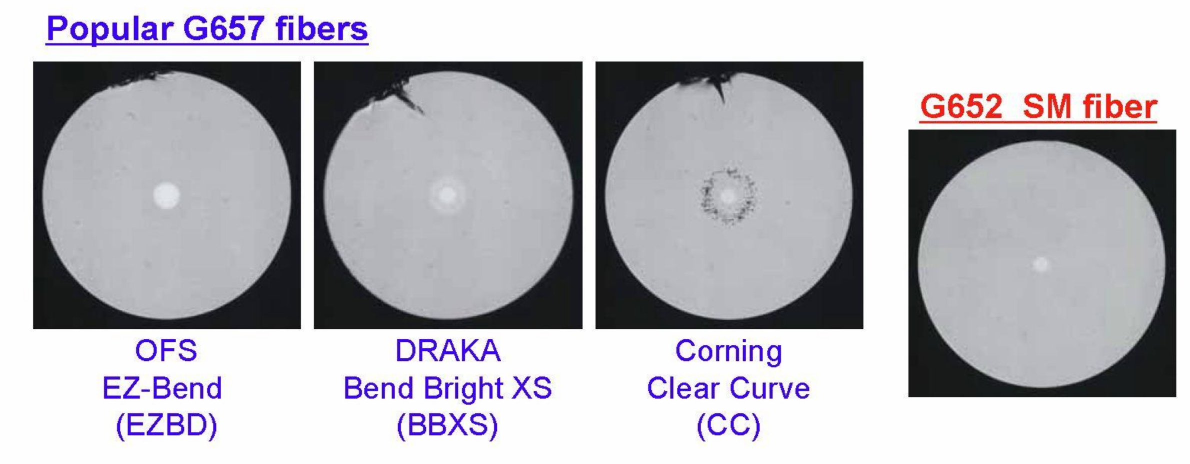
Dispersion shifted fiber was developed with a zero-dispersion wavelength at 1550 nm. This fiber works fine if only one laser is used, but it has dispersion non-linearities making it unsuitable for use with the multiple lasers needed for Dense Wavelength Division Multiplexing (DWDM). Non-linearity causes the generation of spurious interference crosstalk when several lasers are used with closely spaced center wavelengths. Dispersion shifted fibers are no longer commonly used and have been replaced by the newer Non-Zero Dispersion Shifted Fiber types.

8.4.2 nNZ-DSF: Non-Zero Dispersion Shifted Fiber (ITU-T G.655)

Non-linearities of the dispersion-shifted fiber are greatly reduced by suppressing the zero-dispersion wavelength within the operational 1550 nm window. These fibers have uniform dispersion characteristics over a wide range of wavelengths in the 1550 nm window. NZ-DSF fibers can accommodate many different closely spaced lasers with reduced crosstalk interference between channels. Crosstalk in NZ-DSF fibers can be further improved in large-effective-aperture fibers by reducing the power density within the fiber. These enhanced NZ-DSF designs have large core size or mode field diameters and exhibit measurable performance improvements with DWDM systems for long distance links.

8.4.3 Bend insensitive fiber (ITU-T G.657.A1)

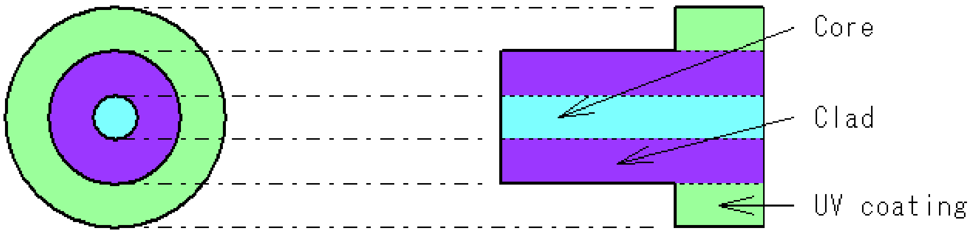
Bend insensitive fibers are fully compatible with G.652D, G.657. It was developed for the access networks including last one-mile application such as FTTH where the fiber is placed in uncontrolled domestic environments like customer premises. The mode conditioning cladding around the core gives G.657.A fiber the remarkable ability to handle much tighter bends than G.652.D (10 mm verses 50mm @ 1550nm). The industry is continuing to develop standards to address the extended application of optical fiber. G.657.A1, A2, B1, B2, B3 are the current versions.



9. Basic fiber configurations used in cable

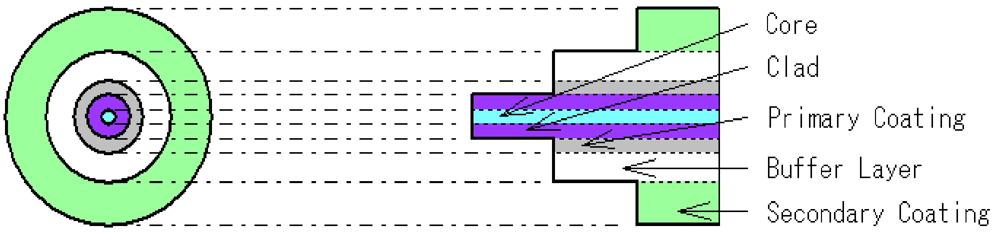
9.1 250 um fiber (with primary coating)

The 250 um UV cured acrylate coated fiber is used in loose tube, slotted cable, uni-tube cables, furcated, ribbon and cordage. It offers very small DIA fiber ideal for reducing the cable diameter.



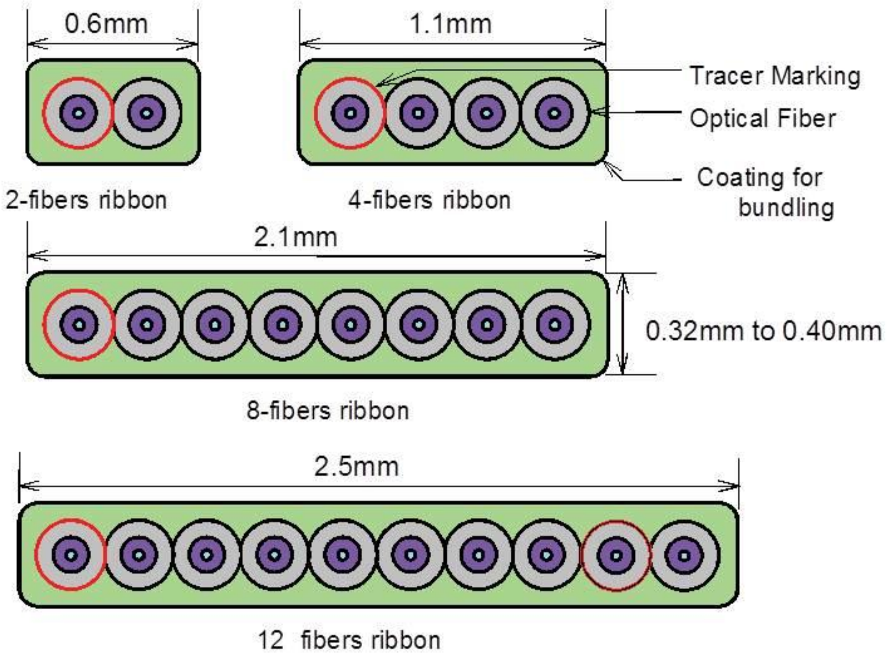
9.2 900 um buffer (with secondary coating)

The 125 um cladding is covered with Silicon-resin as primarily coating, building it up to 250 um and then with Nylon, PVC, LSZH or other suitable material as secondary coating for protection. These are bonded, loose or semi loose providing a 900 um finish.



9.3 Ribbon fiber

250micron UV single fibers are in parallel, color coded and are coated with a thin tape or film. Called ribbon fiber, normally fiber counts are 2-, 4- and 8-ribbon in Japan, while 12-ribbon is popular in the U.S., China, Australia and newly designed networks. 24-ribbon is becoming popular in the U.S., though when it is terminated or spliced it is treated as 2 x 12 by splitting the 24.

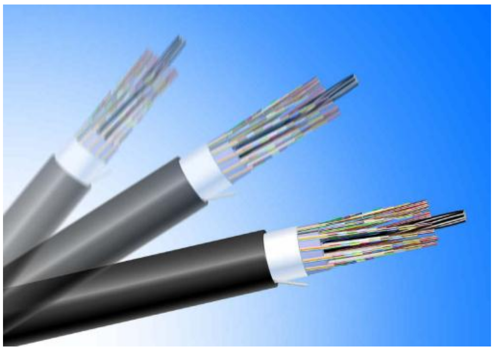


10. Structure of Optical Cable

The industry uses a wide variety of cable types for the many applications that present themselves including military, mining, commerce, automotive and telecommunications, to name a few.

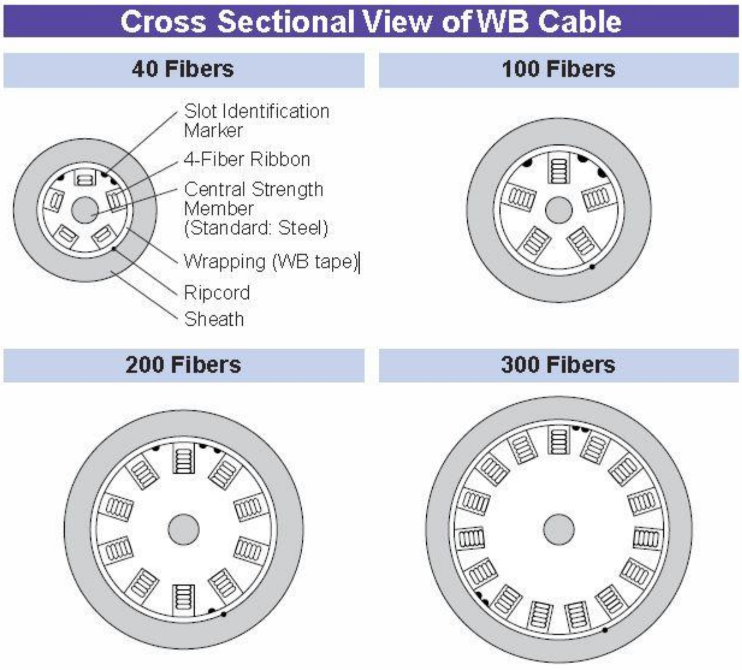
In the telecommunications sector we are most likely to see the following cable types using ribbon fiber optics, with pictures of each type found in this section.

- Slotted core
- Loose tube
- Uni Tube
- Riser
- Cord

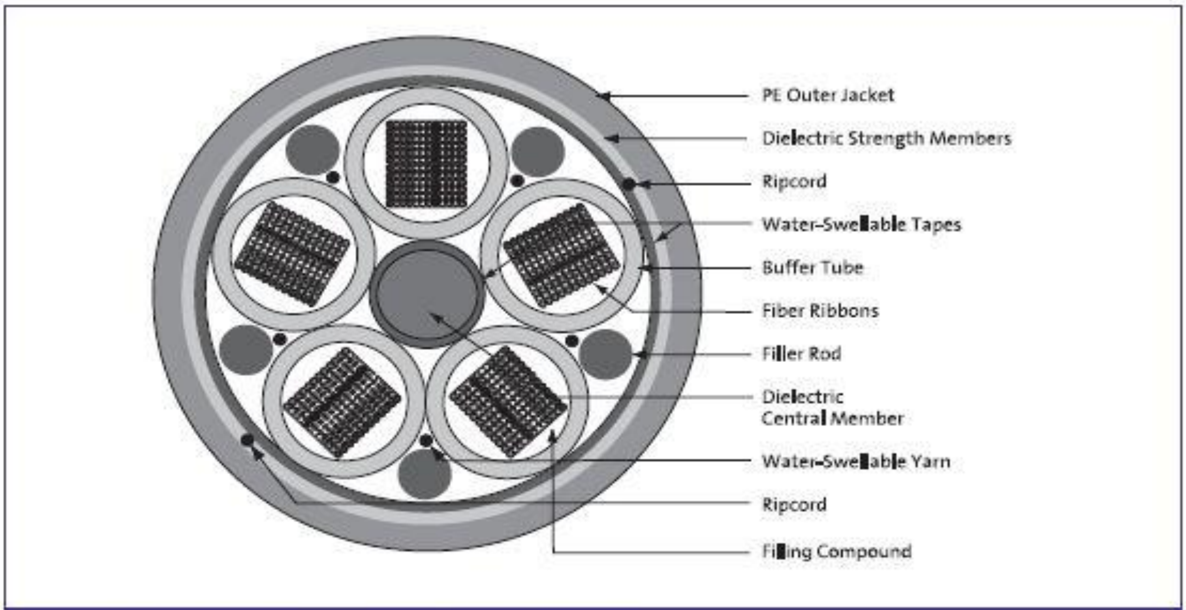


They all have a number of variants depending on the application with armoring, LSZH, and endless options that will make a cable suitable for the application.

10.1 Slotted Core

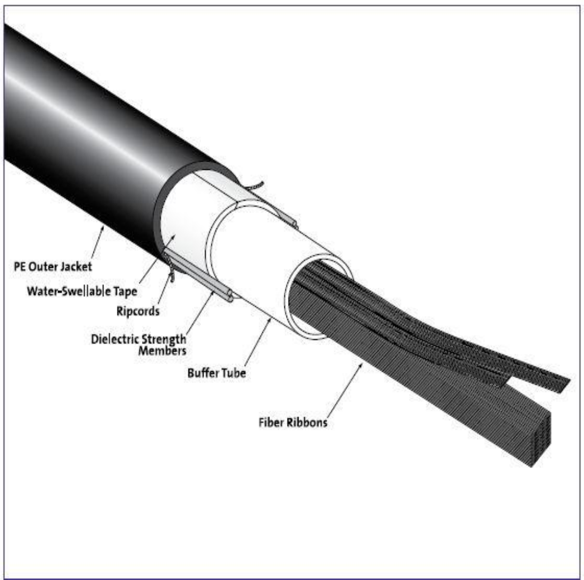


10.2 Loose tube

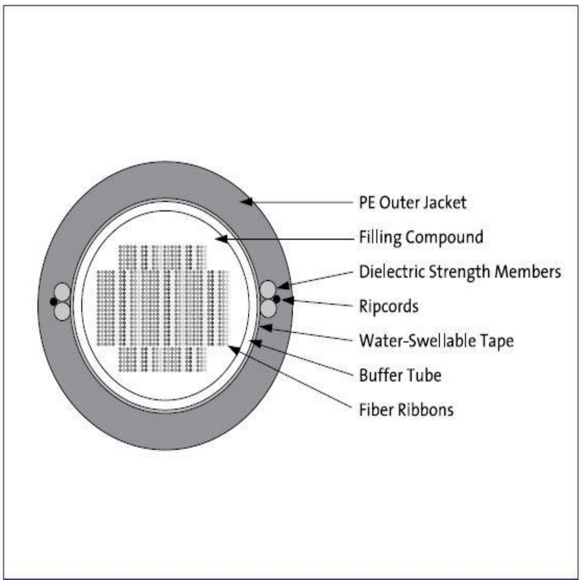


ALTOS® Ribbon All-Dielectric Cable, 720-Fiber | Drawing ZA-2102

10.3 Uni Tube

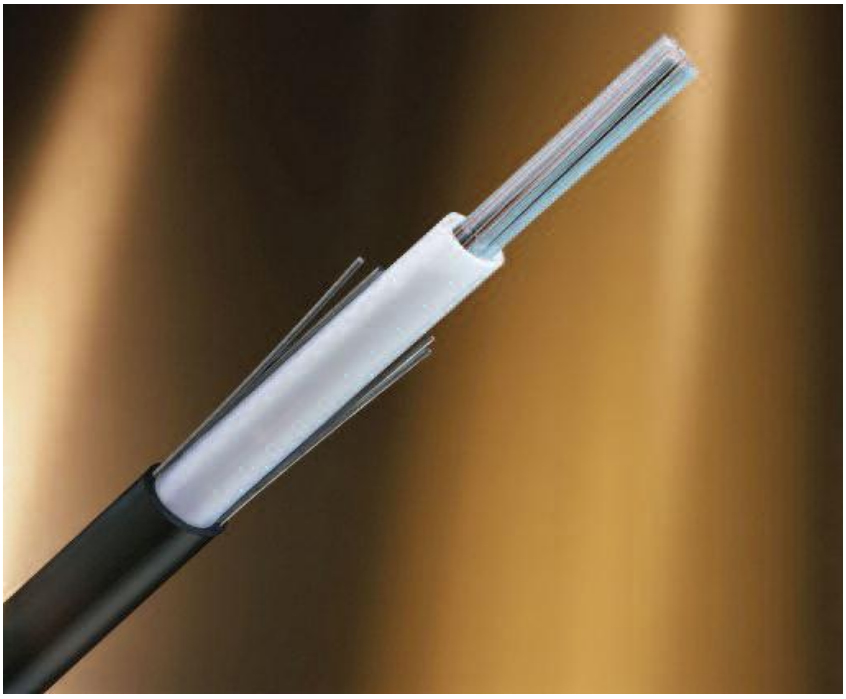


SST-UltraRibbon Cable | Drawing ZA-1751

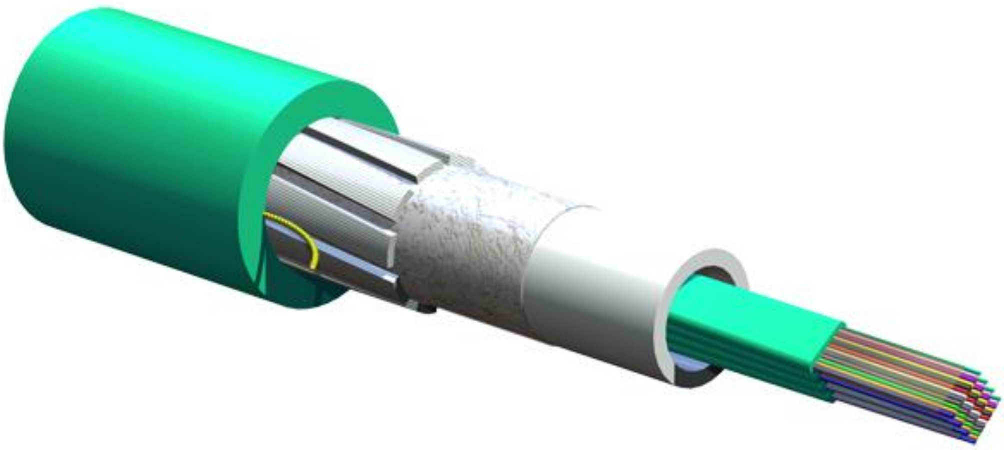


SST-UltraRibbon All-Dielectric Cable, 864-Fibers | Drawing ZA-2313

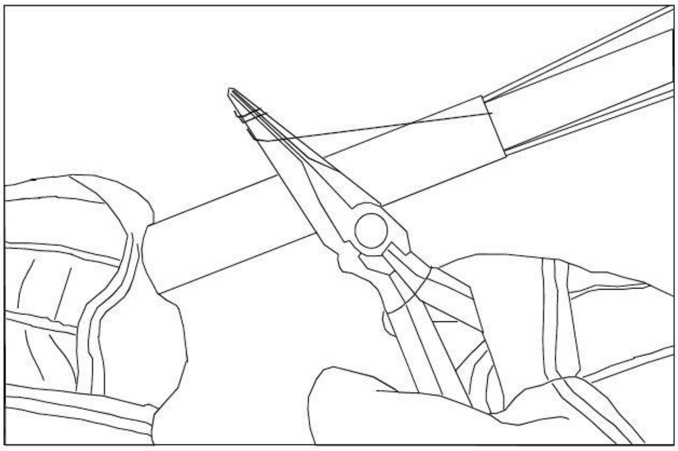
10.4 Outdoor Uni tube



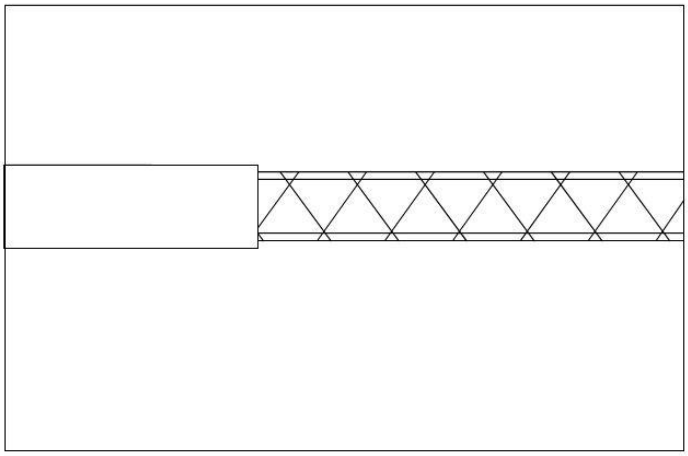
10.5 Indoor Uni tube (Riser)



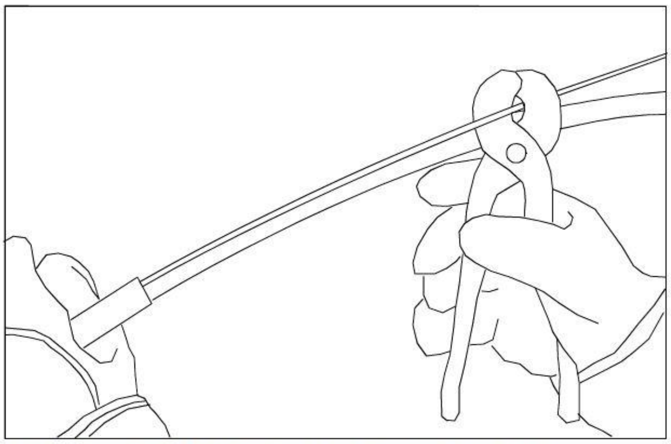
11. Some basic cable preparation



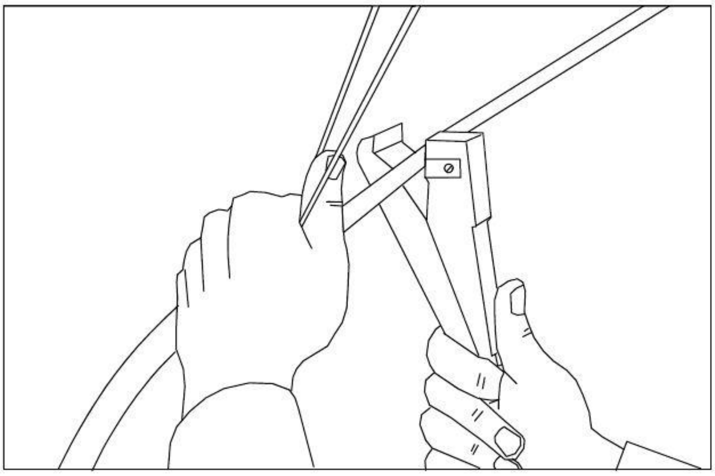
(Figure 3.1.e) Grasp and pull the ripcord with the needle nose pliers



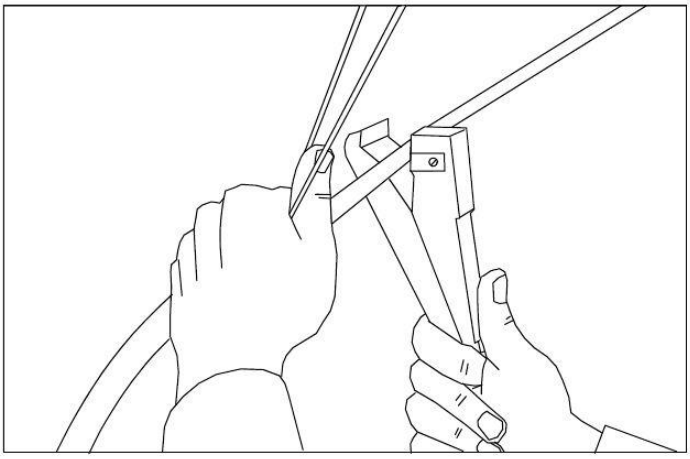
(Figure 3.1.g) The exposed cable core with two dielectric strength members bound to a central loose tube



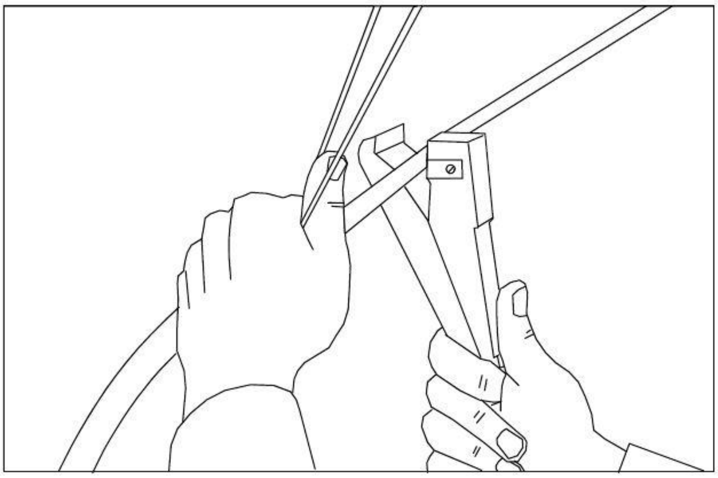
(Figure 3.1.h) Cut the excess strength members



(Figure 4.0.a) Score the buffer tube



(Figure 4.0.a) Score the buffer tube



(Figure 4.0.a) Score the buffer tube

12. Connections in Optical Fiber Network

Diagram for FTTH Network in Japan

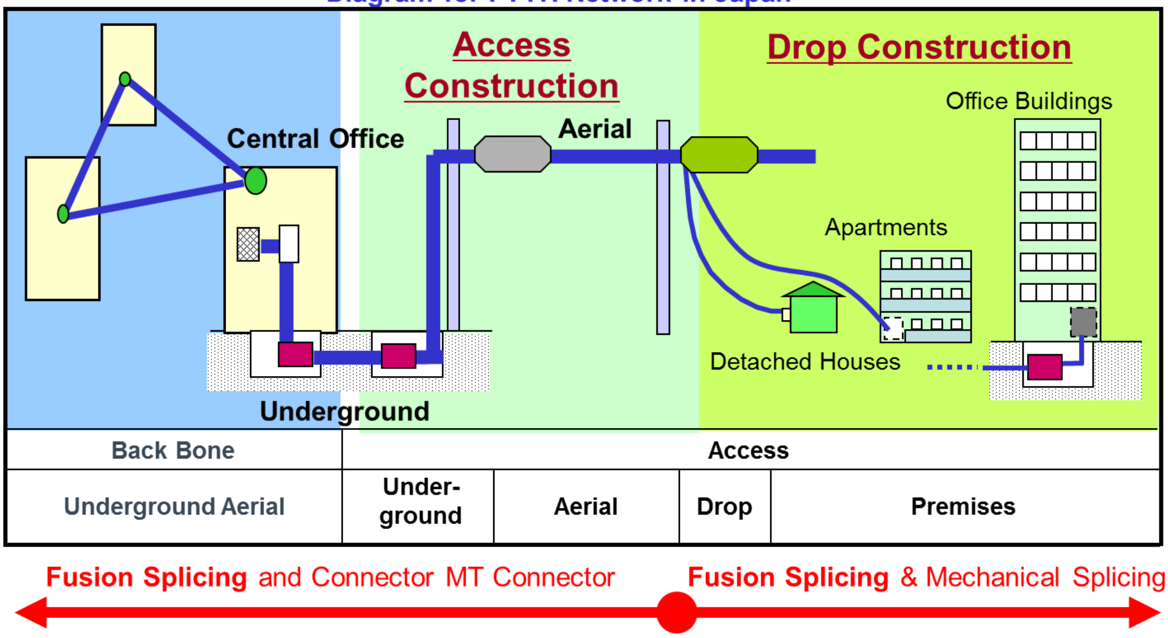
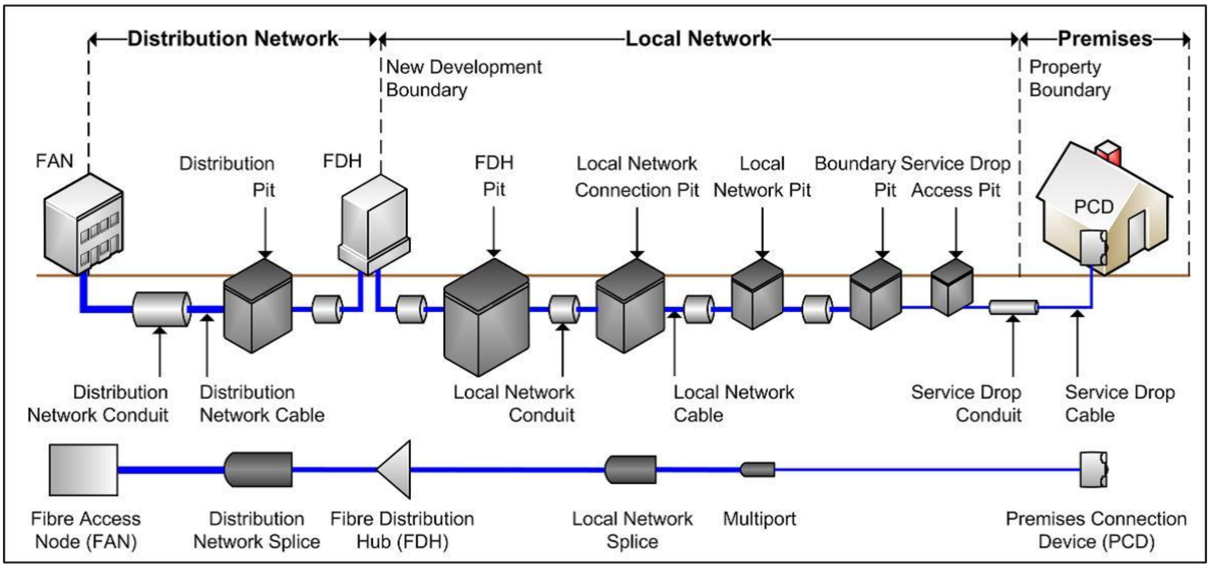


Diagram for NBN FTTH network in Australia



13. Ribbon Universal splice enclosure

Ribbon Universal splice enclosure has a “spine type” splice protector holder system. It is common for the spare ribbon to be stored outside of the splice zone in most enclosures with smooth surfaces and sweeping bends that care for the fiber. The ribbon fiber is difficult to manage within the cassette unless they are very large. Various types are outlined in this section.

13.1 Corning universal enclosure

13.2 Tyco universal enclosure

13.3 3M universal enclosures

13.4 Warren and Brown 17RU cabinet (as used in a Fiber Access Network (FAN))

Warren and Brown 17 RU patch system (image below) is designed to take in the ribbon cable from the street and splice onto blocks of 12 fan out pigtails.

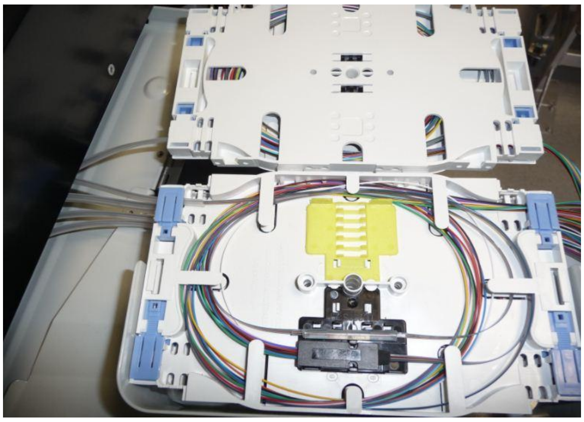
This type of pigtail system is splicing 12 SC-APC's at a time. This can equate to 8 to 10 times the number of pigtails per shift that can be spliced when compared to other types of systems. So for example, if a technician is doing 80 pigtails per day with single fiber core alignment splicing he would now be doing 800 pigtails per day simply by using the ribbon system.

13.5 12 iber SC-UPC Ribbon fan out pigtail using a Sicore fan out module

The 250um fiber when de-ribbonized is fed into the 900um tubes of the Siecor fan out before termination. The ribbon has a film encapsulating the 250um making it suitable to be stored in splice trays, rack and universal enclosures without further protection.

13.6 Warren and Brown standard cassette with a propriety fan out module and comb to hold the fan out, and splice protector

The images below show the ribbon sleeved in an oval clear tube with one tube per tray then fanned out to 12 SC-APC pigtails.

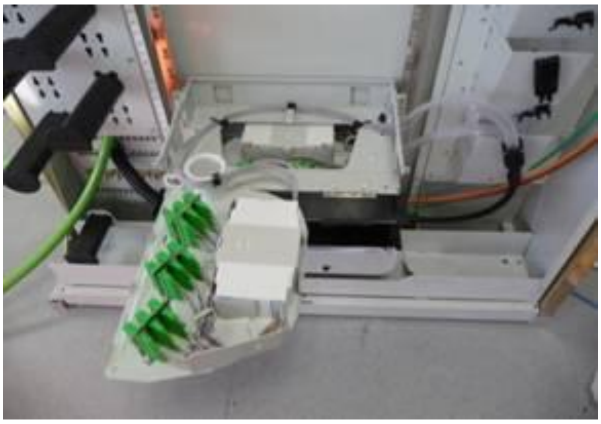


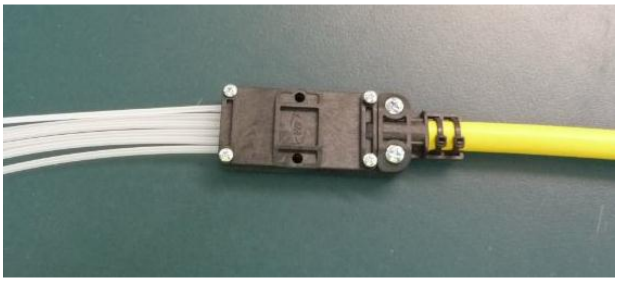
13.7 Warren and Brown swing out splice enclosure with 72 only SC-APC pigtails (6 ribbon fusion splices, one per tray).

The clear tube from the trays goes back to a propriety cable fan module.

13.8 Warren and Brown 17RU with rack mount splice enclosure swung out

The cable fan out is used to transport the fiber from the right hand side across the back of the enclosure and onto the swing out tray (images next page).

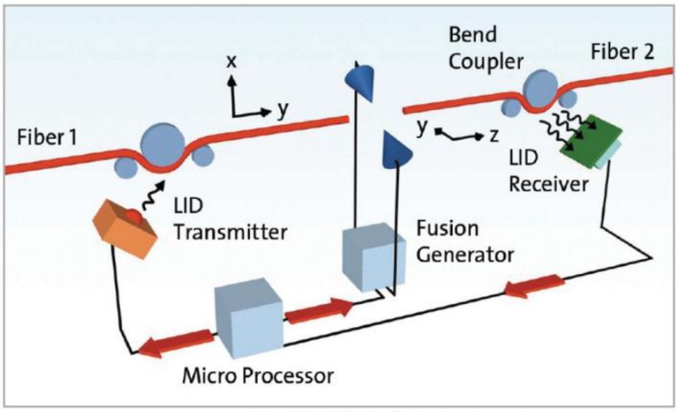




14. The Fusion Splice

While fiber technologies were advancing in laser, fiber development methods were also being explored and pioneered in terminating and splicing the fiber. The FR-1 was the first Cladding alignment fusion splicer, developed by Fujikura in 1977(image below).

In 1984 Siemens (Corning, Siecor) released the LID Option for the M67 (image below). The LID system (Light Inject Detect) passes a light source through the fiber and, based on the amount of light received, the alignment can be accessed. All the functions of the equipment are manually controlled.



LID-SYSTEM Unit Technology | Drawing ZA-2736

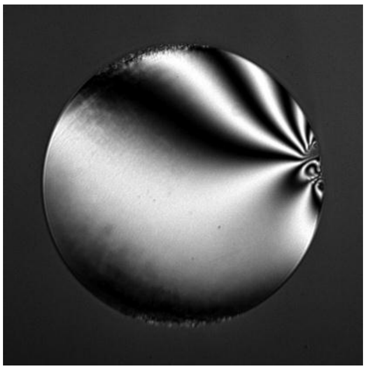
The next big development was the FSM-20 using the PAS (Profile Alignment System). This system (image below), developed in 1985 by Fujikura with some inspiration from NTT, uses precision controlled optics that gives engineers the ability to view the core of the single mode fiber, and align the fiber before splicing. enabling a low loss fusion splice.

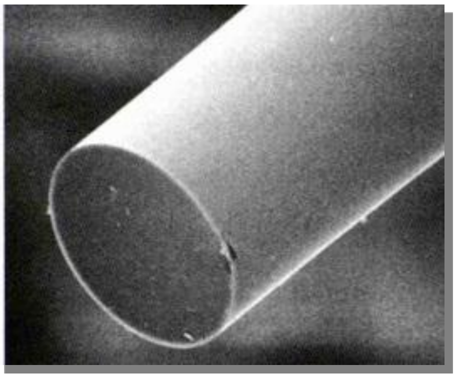
Splicers have come a long way in the last 30 to 40 years. There are now fully automated systems that are delivering extremely low loss splices. At the same time, the quality of the fiber itself has improved to the point where cladding alignment today is achieving better results than core alignment splicers did 20 years ago.

14.1 The process

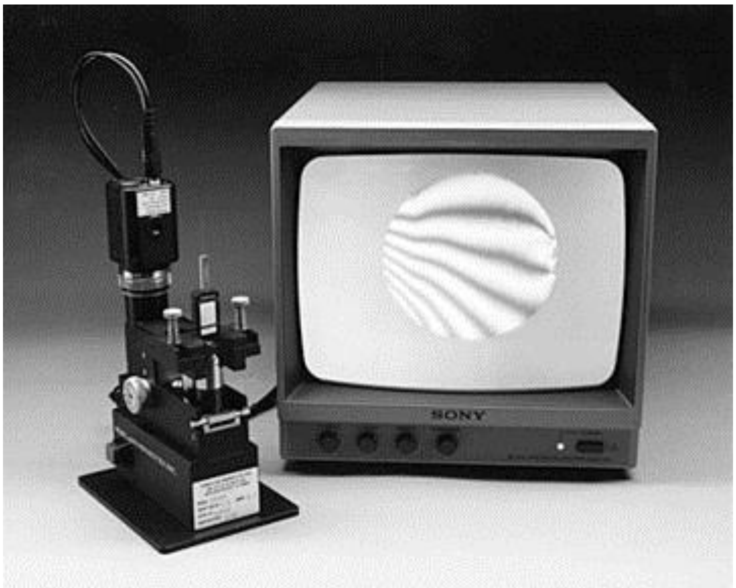
The method of joining two optical fibers consists of applying localised heat, sufficient enough to fuse or melt two fibers ends together, forming a continuous fiber. A pair of electrodes generate localised heat while Silica glass starts to melt when the temperature reaches around 1,800 C. The fiber is, at the same time, fed together forming a seamless joint.

In order to prepare fiber for splicing it is necessary to cleave the fiber and produce a low angle face (as seen in the image below). The figure on the left is a cleave as seen by an interferometer and the figure on the right is a cleave as seen under magnification (approximately 80X).



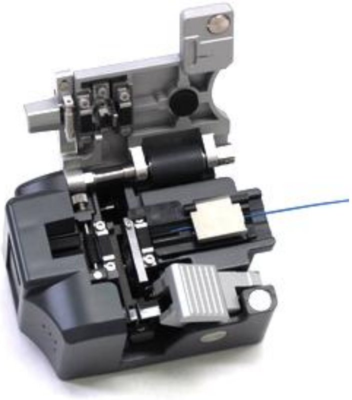


The picture below is an Interferometer with a cleaved fiber face on screen. The 6 odd fringes indicate approximately 1.0 degree angle.



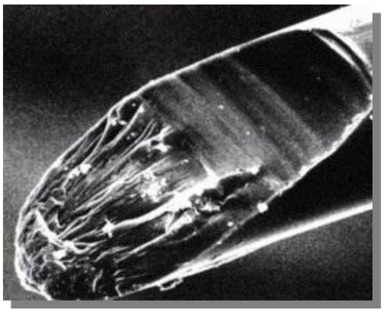
The clean cut is typically done by a dedicated optical fiber cleaver (such as the one pictured below). The cleaving process involves holding the fiber firmly and scoring the surface. It is then propagated to break by either tension or by bending the fiber**.**

S325 Cleaver with sharps management

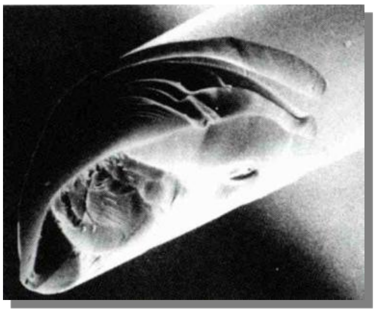


The following images show the surface from which we can study and estimate the type of stress.

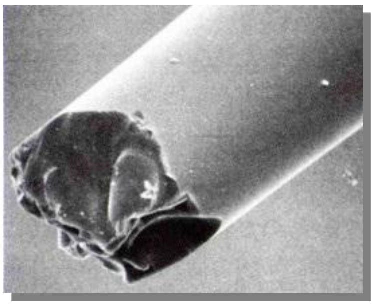
Bending



Twisting

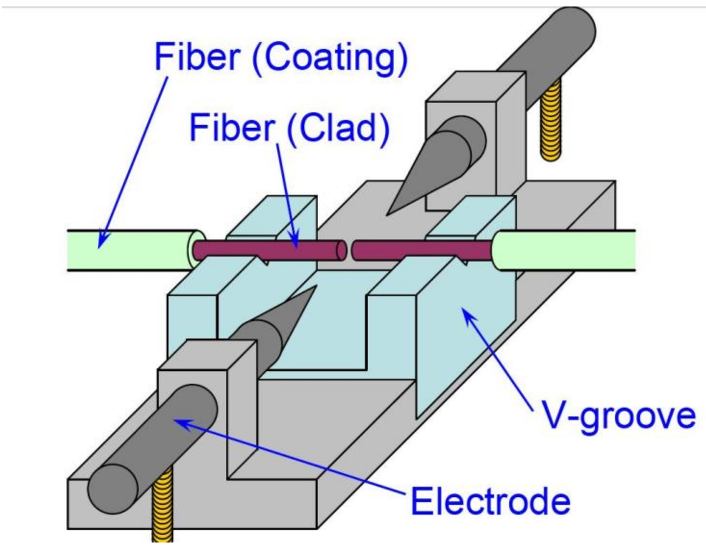


Pulling fiber to break



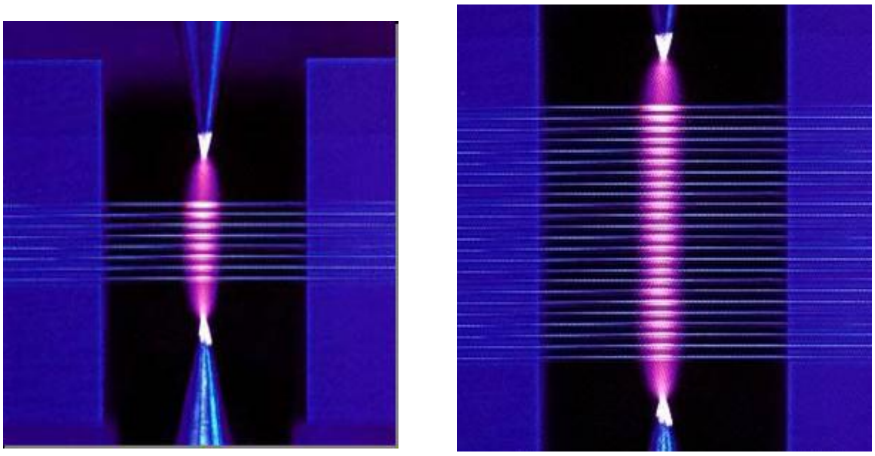
The fiber has the splice protector slid into position. The fiber is cleaned and cleaved and placed in the splicer.

The image below shows the fixed vee groove alignment system. A fixed vee-groove alignment system has two vee shaped groves that are machined from one block of ceramic and are perfectly aligned. The fiber, which is also precisely manufactured with the same diameter cladding along its length and with a tightly controlled concentric core, will deliver reliable low loss splicing.

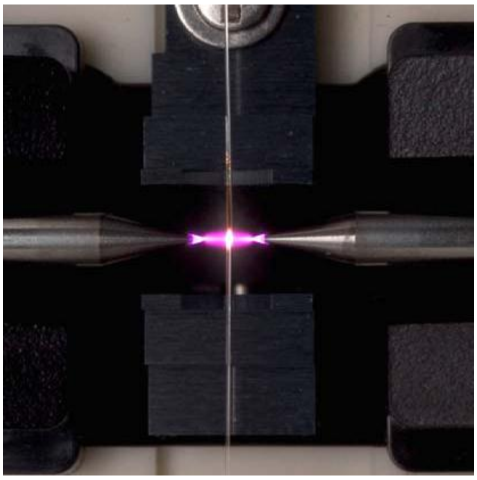


In order to position and inspect the fiber, a lens and display system is used. The images provide some insight into the process. Notice the fiber is closer to the lens at one end. This gives the image on screen a slight distortion or taper.

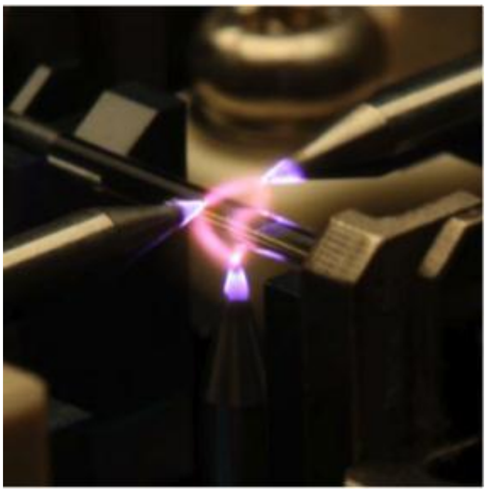
An arc involved in fusing the optical fiber



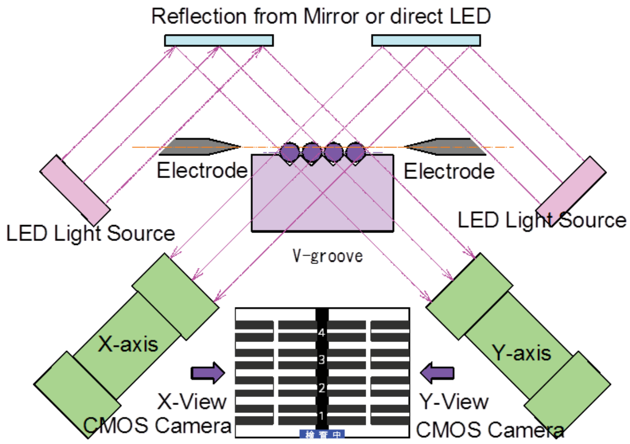
An arc across a single fiber (S177)



An arc generated by three electrodes that can form a large even heat zone suitable for large diameter fiber and specialised applications (S184)



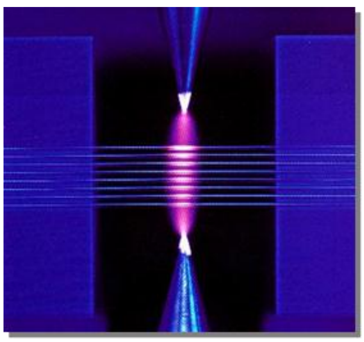
The picture below is a diagrammatic representation of the lens, fiber and electrodes.

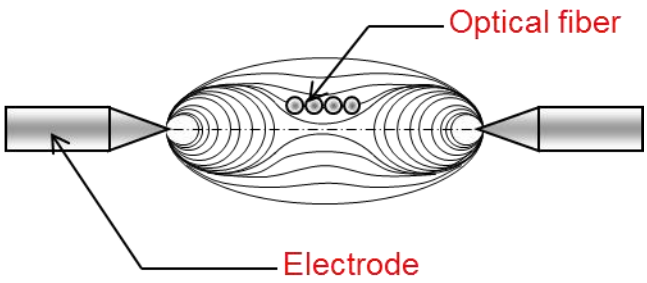


The fibers are in a zone (top left image below) of the arc that gives the fibers even temperature. This is off center for ribbon while core alignment splicer uses a centered position for the fiber in order to take advantage of the higher heat and intensity.

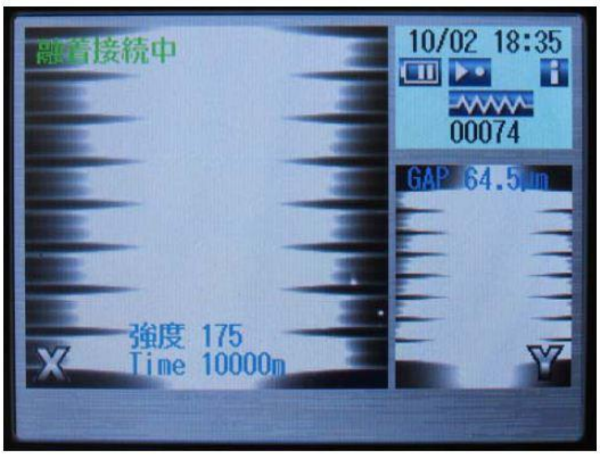
8 fiber ribbon in the arc

Ribbon positioned in the even zone of the arc





Fiber as seen on the screen during the arc discharge



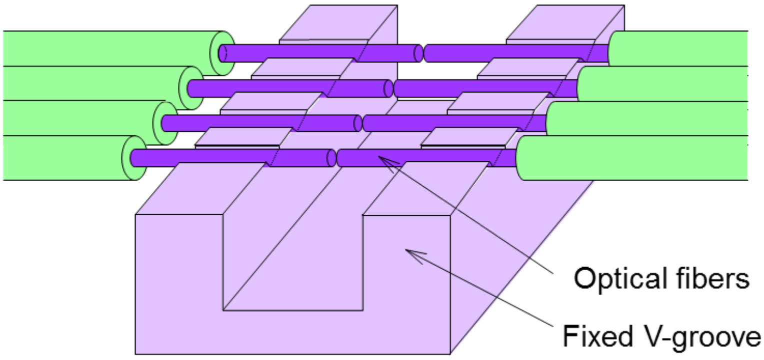
14.2 Aligning Method: Passive

The optical fiber is aligned prior to arc discharge so that joint attenuation will be as low as possible.

In the passive method the fixed V-groove can guide the optical fiber precisely and smoothly while it is being fed while the surface tension assists in the final alignment.

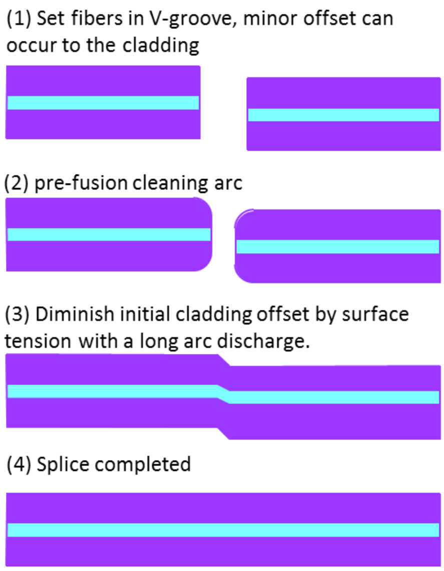
The splicer observes the fiber cladding. The core as such needs to be concentric to the cladding for a low attenuation splice.

The arc discharge melts both fiber ends to form continuous fiber.



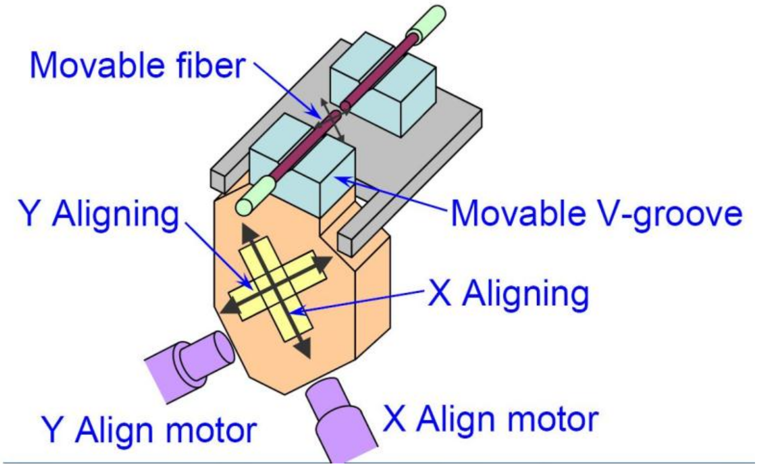
Typical results from a fixed vee groove splice are 0.05dB.

To diagrammatically show the alignment of concentric core fiber in a fixed grove splicer, (1) the fibers will have a small axis offset which is checked to be within tolerance (typically less than 7um), (2) the cleaning arc cleans the fiber ends, (3) the fibers are fed forward while a long arc is produced, as the fiber touch the surface tension of the molten glass causes the fiber ends to come into alignment (4).

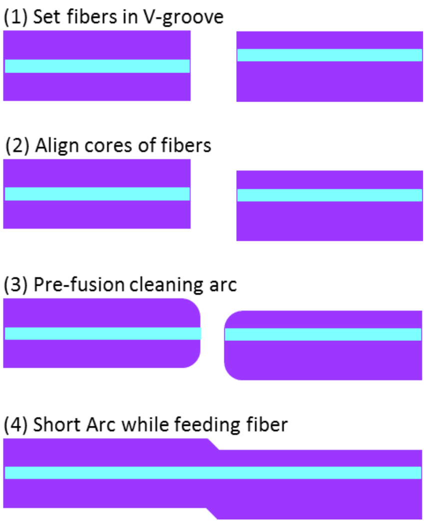


14.3 Aligning Method: Active

Movable V-grooves can align the fiber for either core or cladding alignment. The splicer identifies the fiber core and cladding and aligns them accordingly. The arc discharge is narrow and heating time is short so that alignment is not effected by the surface tension that is produced in the molten phase.



The process in active alignment splicing when the core is eccentric to the cladding involves (1) the fiber being set in the vee grooves, (2) identification of the core (or cladding in the case of cladding alignment programs for MM and bend insensitive fibers). (3) a cleaning arc, (4) a short arc that fuses the fiber s together without the surface tension having an effect on the splice.



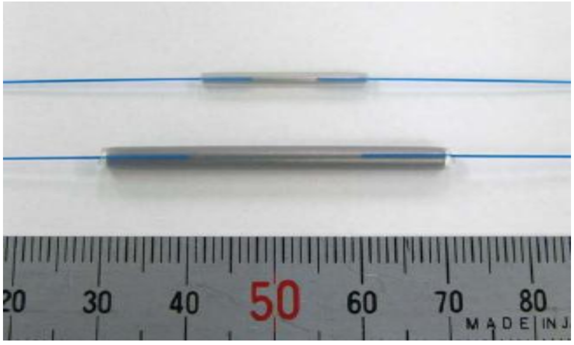
Merits of Fusion Splice include:

- Makes reliable **permanent connections (fusion)** of the fibers
- Achieves the **lowest loss** among any other connection
- Extremely **low reflection loss**
- **Convenient** for connecting all types of fiber from single fibers to ribbon fibers
- The complete splice is very **compact.**

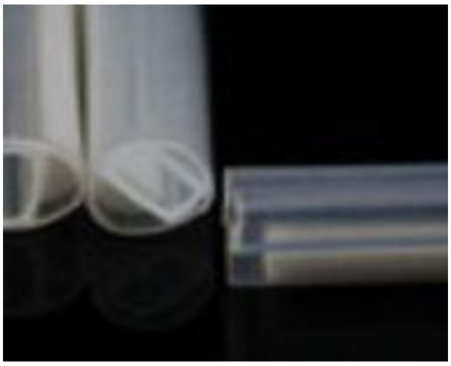
14.4 Splice protectors

The splice protector is an essential part of providing a reliable long-term splice, the splice protector mechanically protects the spice from bending and breaking at the untempered zone.

Single fiber splice protector



Ceramic type ribbon splice protector



Ceramic ribbon splice protector

Plastic & adhesive type splice protector

14.5 Fusion Splicers

Various types of splicers are available, depending on the application as to the choice of the system.

They can be grouped as follows:

- Large fiber splicing
- High strength splicing
- Core alignment with fiber rotation
- Core alignment
- Active cladding alignment
- Cladding alignment

14.5.1 Large fiber splicing

The LDF splicer will usually be able to do core alignment and be able to cover fibers from 400um to 1200um, although these are not common.

14.5.2. High Strength Splicing

The high strength splicer has special chucks that enable the fiber to be clamped by its buffer while the preparation is done with next to no contact or stress applied to the fiber.

14.5.3 Core Alignment with fiber rotation

The fiber rotation function allows Polarization-maintaining fiber to be spliced while maintaining the alignment of the stress members.

14.5.5 Core Alignment

The Core Alignment splicer can identify the core and align the fibers accordingly.

14.5.6 Active cladding alignment

Active Cladding alignment is not able to see the core but is able to align the cladding and is able to deliver typical losses of 0.03dB.

14.5.7 Cladding Alignment (Fixed Vee Groove)

Cladding alignment splicing is the only way multiple fibers can be spliced. It totally relies on the quality of the fibers delivered for good results.

This chart compares machine type against a function.

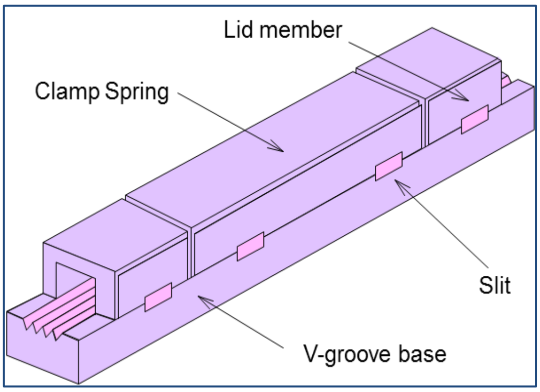
Model	 S123 Series	 S153A	 S178A	 S183PMII	 S184PM
Aligning method	Passive	Active	Active	Active	Active
Aligning	Clad	Clad	Core	Core	Core
Fiber Count	1 to 12※	Single	Single	Single	Single
Clad Diameter [um]	125	80 to 150	80 to 150	80 to 500	80 to 1200
Dissimilar Splicing	No	No	Yes	Yes	Yes
High Strength	No	No	No	Yes	Yes
PM Fiber Splicing	No	No	No	Yes	Yes
Application	OSP	OSP	OSP/OEM	OEM	OEM

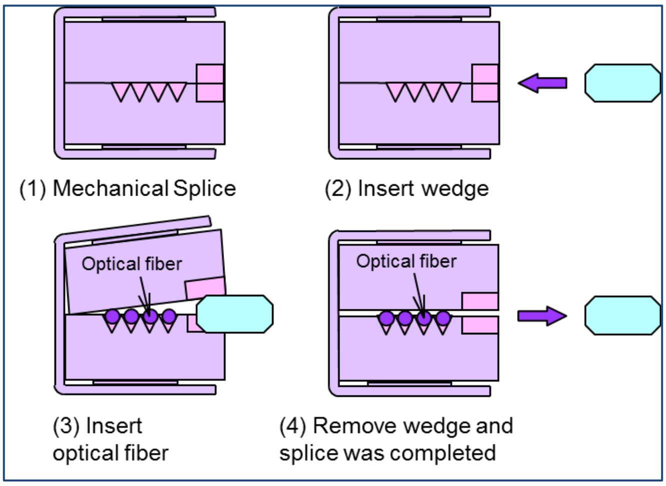
14.6 Typical flow of the splicing process

Step	Name	Tools	Process description
1	Stripping	Mechanical, with or without thermal, chemical, or hot air.	The removal of the buffering protecting the bare fiber.
2	Cleaning	IPA with cloth or tissue, IPA and ultrasonic, chemical free cloth,	The process of cleaning the surface of the bare fiber prior to splicing.
3	Cleaving	Cleaver	Process to prepare the end face of the bare fiber prior to fusing.
4	Splicing	Fusion splicer	Process of aligning and fusing the fiber.
5	Protecting	Heat shrink sleeve	Heat shrinking the splice protector over the splice and bare fiber.

14.7 The Mechanical Splice

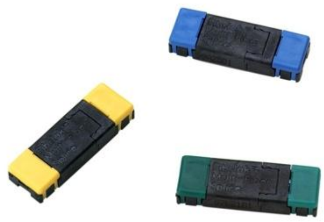
A mechanical splice is the method of mechanical alignment of two optical fibers. The fibers are stripped, cleaned and cleaved with a precise designated length. The alignment requires precise V-grooves that guide optical fiber and index matching oil. No power is required and it is suitable for breakdowns requiring a quick recovery.



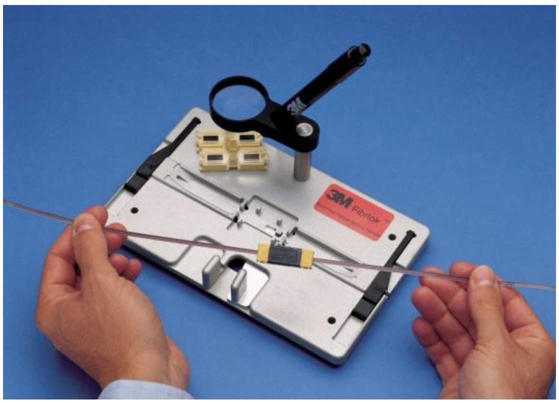


Single fiber mechanical fiber

Multi fiber mechanical fiber



Ribbon fiber mechanical splice jib



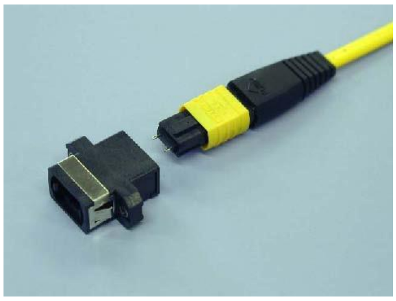
15. Types of connectors

Connectors offer easy and reliable jointing of optical fibers. They are used to make the connection between optical fiber and equipment at the telecommunication exchange, central offices, data centers and field devices.

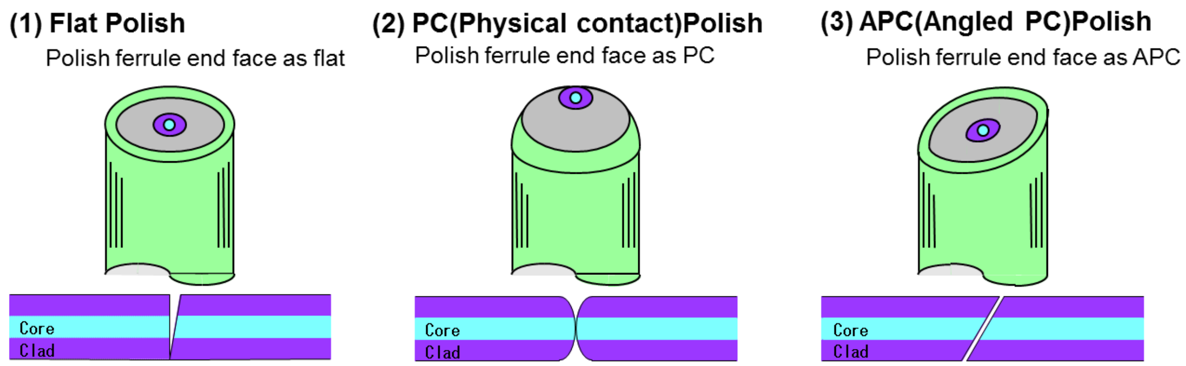
LC connector

SC-PC ribbon fanout

MPO and thru adaptor

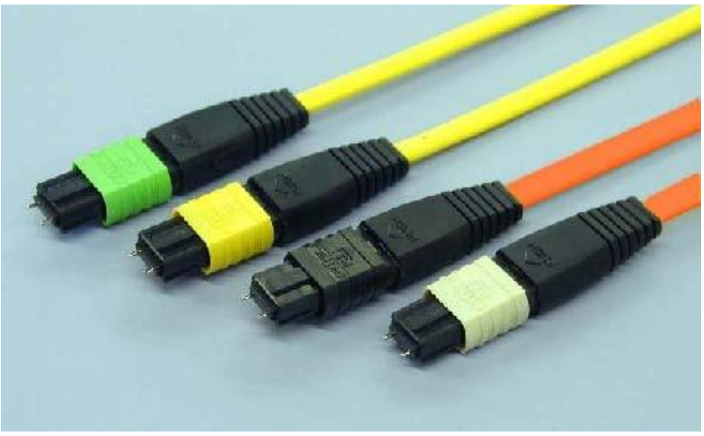


There are a huge range of connectors and types of finish that the connect face can have. The earliest connectors were Flat Polish, but they suffered from high insertion loss. These were improved with the PC (Positive Contact polish), but its weakness was high back reflection. This was again improved on with the APC (Angled PC) Polish connector.

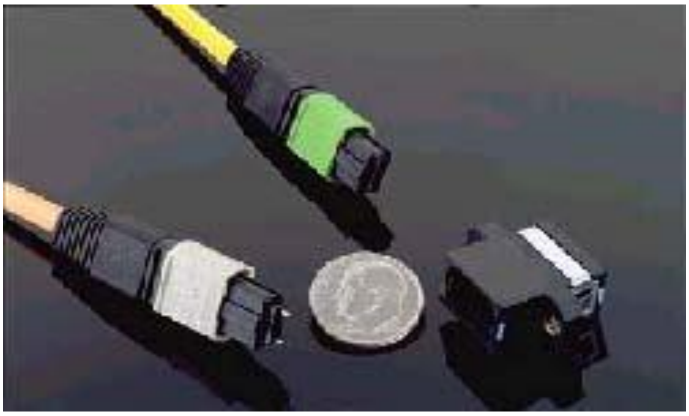


15.1 Ribbon fiber connectors

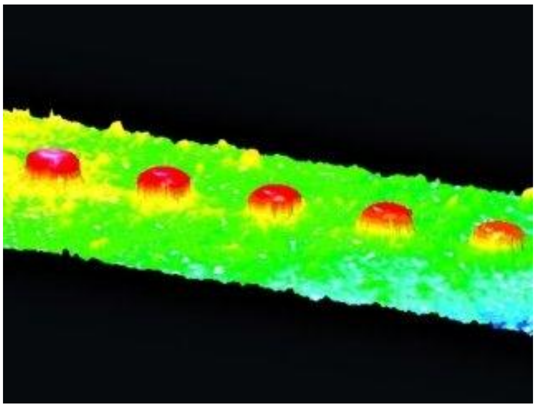
From left to right: MTP Angle polish, MTP SM, Multimode.

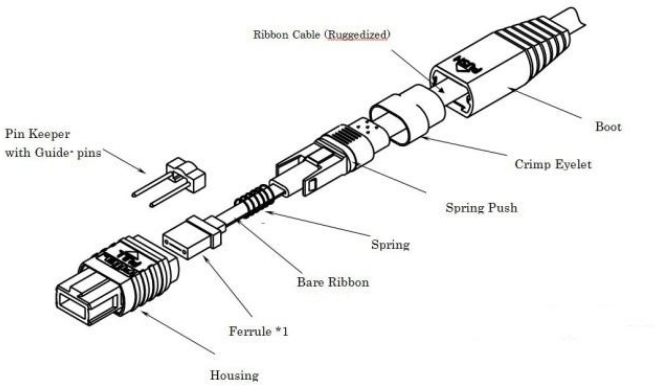


Multimode, MTP thru adaptor



Graphical high magnification from an interferometer



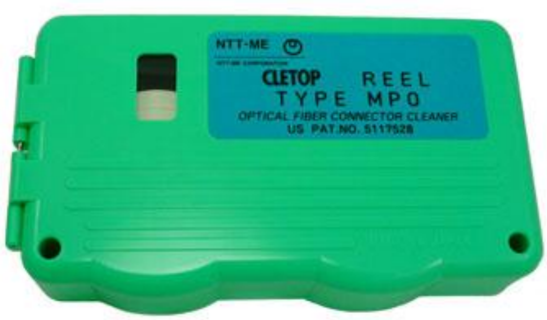


OptiTip Plug and receptacle (MPO)

Inspection showing 2 of 12 fibers as the probe scrolls across the face.

15.1.6 Ribbon splice on connector

15.1.7 MPO Cletop cleaner (plug only)

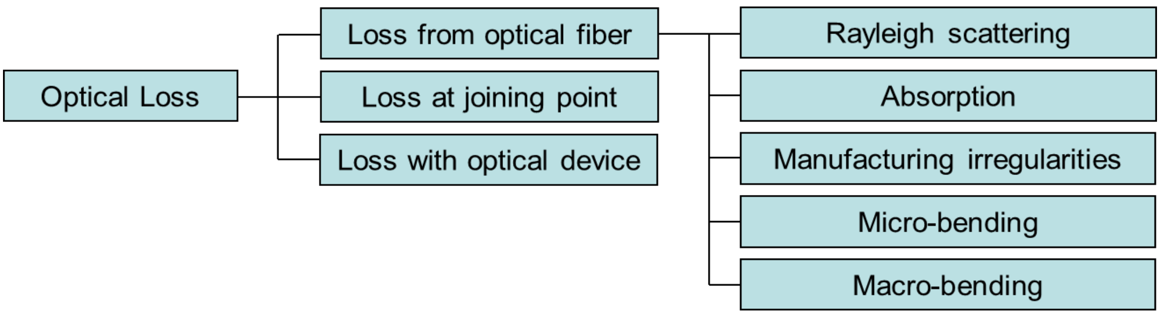


15.1.8 IBC MTP Cleaner (socket and plug)

16. Loss on optical fiber

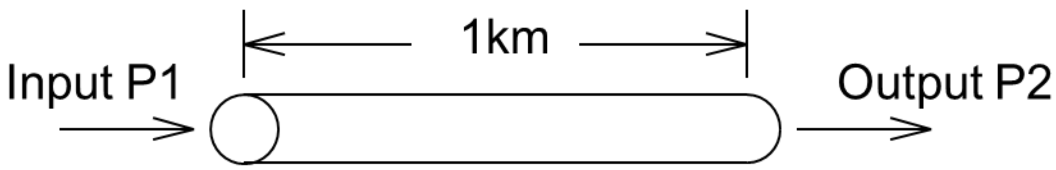
A fiber's loss is measured by how much light gets lost as the optical signal travels along the fiber. This can be influenced by a number of factors (image below).

- **Rayleigh scattering** - Scattering of light caused by index of refraction variations in the submicroscopic structure of the glass.
- **Absorption** -A physical mechanism in fibers that attenuates light by converting it in to heat
- **Manufacturing irregularities** - Such as geometric variations in core diameter or circularity, voids in the glass, defects at the core-cladding interface, and imperfect application of dopants, can cause scattering loss. However, these regularities are usually negligible in present day fibers.
- **Microbending** - Curvatures of the fiber that involve axial displacements of a few micrometers and spatial wavelength of a few millimeters. Microbends cause loss of light and consequently increase the attenuation of the fiber. Loss due to microscopic bends in the fiber.
- **Macrobending** - Macroscopic axial deviation of a fiber from a straight line, in contrast to microbending. Loss due to large bends in the fiber.
-



Loss on optical fiber is represented by Decibel [dB], the unit that expresses the ratio of two powers and given by -10 log (P2/P1).

α (called alpha) = -10 log (P2/P1) [dB]



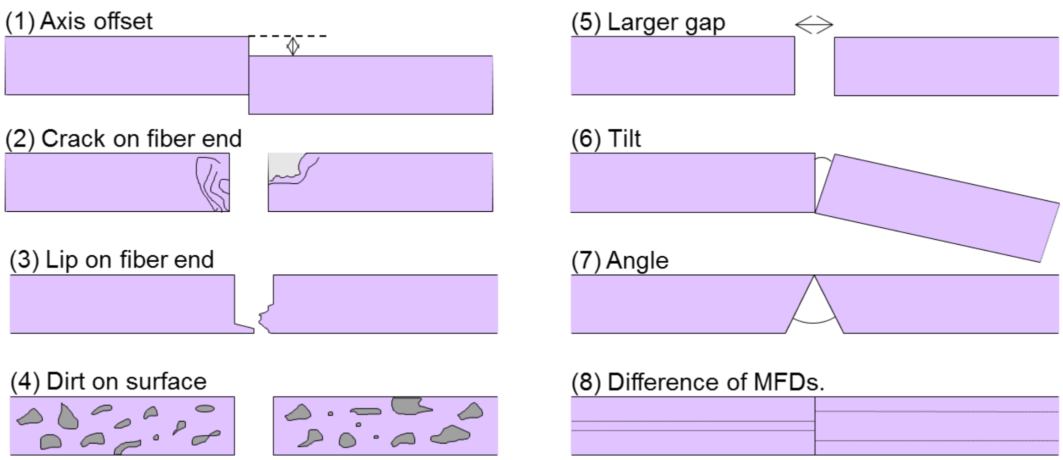
Type of glass	P1	P2	dB/km
Window glass	1	$1/10^{100}$	1000.0
Optical Lens	1	$1/10^{10}$	100.0
Optical fiber in 1970s	1	$1/10^{2}=1/100$	20.0
SI @ 850mm	1	$1/10^{0.5} = 1/3.98$	6.0
GI @ 850mm	1	$1/10^{0.27} = 1/1.86$	2.7
SM @ 1310mm	1	$1/10^{0.05} = 1/1.12$	0.5
DSF @ 1550mm	1	$1/10^{0.025} = 1/1.06$	0.26

16.1 Factor of Splice loss

Optical fiber connections rely on the core having a suitable alignment and contact of the core, with quality terminations that are clean and connected. If these factors are met the result will be a low loss often well below 0.5dB.

Various aspects that are factor of splice loss are listed below. No. 1 to No 7 are extrinsic factors. No. 8 is an intrinsic factor.

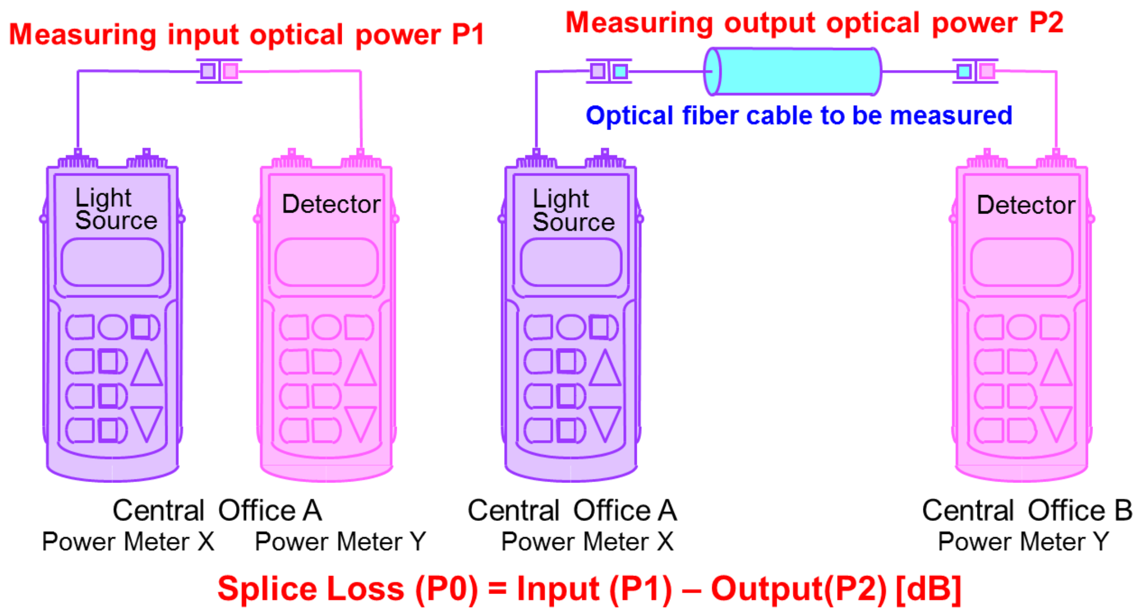
Factor of splice loss



16.2 Measuring methods

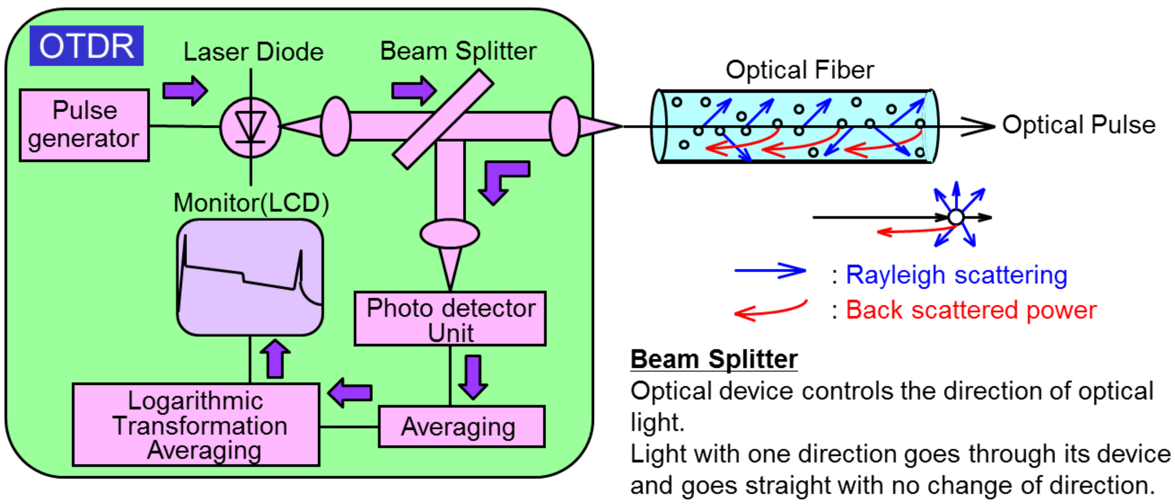
16.2.1 Power Meter

Measuring how much optical power over a given length of cable will establish the attenuation of the link under test, this is done with either absolute values or referenced values as shown below.

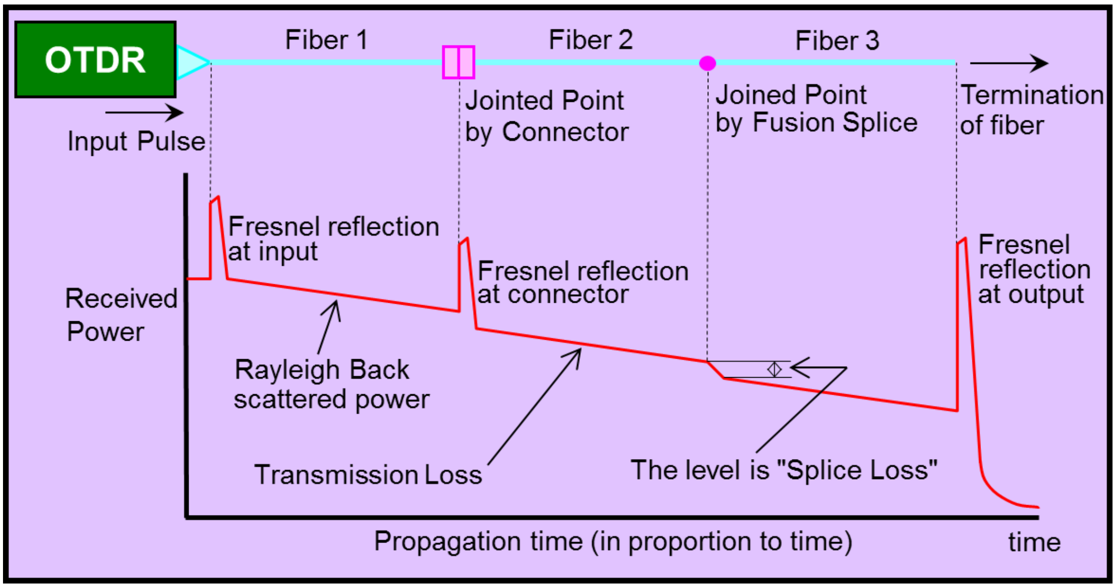


16.2.2 OTDR

OTDR stands for Optical Time Domain Reflect meter. An optical pulse is sent down a fiber. The resulting power reflected back to the input is displayed as a function of distance or time on a screen (LCD). The instrument is useful for measuring fiber loss, splice loss and determining the location of faults or breaks.

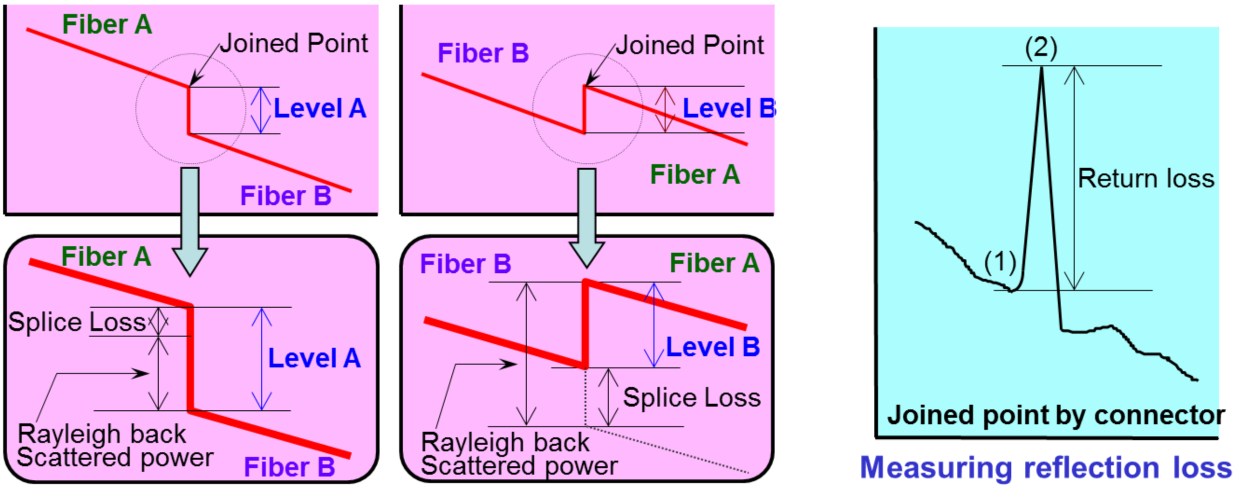


The laser power that is launched at the connector (Fresnel reflection) and the power along the fiber producing back scattering reaches the OTDRs detectors at the time as the function of distance. This enables the OTDR to show the length of a fiber based on its refractive index. We can see splices, macro bends, fiber attenuation, length, breaks, reflection and insertion loss of connectors or mechanical splices.



16.3 The splice measurement

A splice appears like steps on the trace. Its step includes the actual splice loss and the power of back scatter level. By also measuring the splice point from the opposite direction we can account for "loss-gainers" and determine an accurate reading of the splice as calculated by averaging both values.



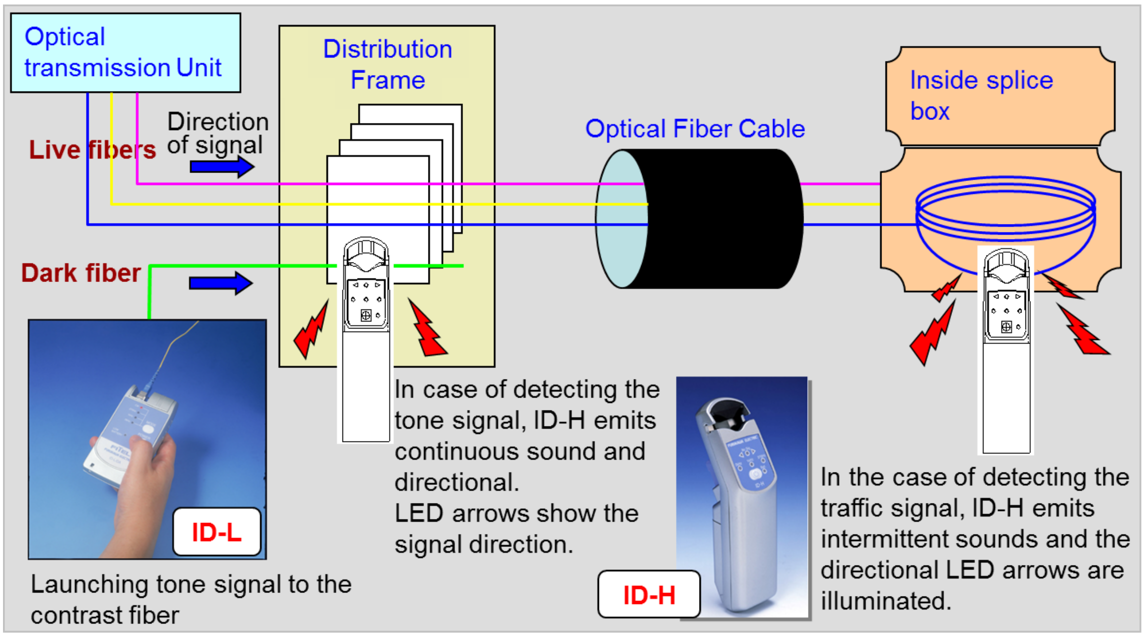
Measuring splice loss

Splice Loss = (Level A + Level B) / 2 [dB]

Measuring reflection loss

16.4 Traffic or Fiber identifier

The Traffic or Fiber Identifier is used to determine if the correct fiber has been selected, if the fiber has traffic or is dark. Most traffic identifiers can be used on both single fiber and ribbon fiber. The image below shows the typical application.



17. Tooling relative to ribbon fiber and cable

The following tools give an insight to common items/tools relevant to ribbon fiber and cable. Keep in mind there are fiber cables and applications that will require more specialised tooling.

17.1 Strippers

Strippers are used to remove the buffer and expose the cladding.

Fitel S218R

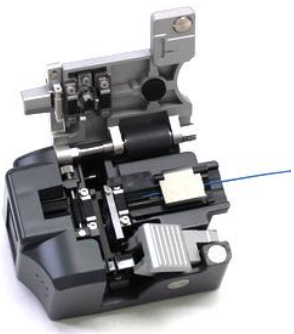
Micro Strip M4T

Forte Automated Ribbon stripper

17.1 Cleaver

The cleaver is a critical tool; if the cleaver is not delivering the desired cleave angles or is requiring a lot of repeat attempts, productivity goes down.

Fitel S325 Cleaver

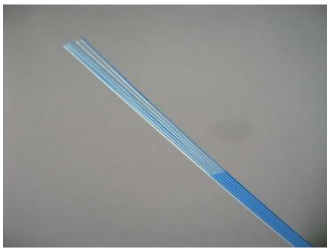


17.2 Deribbonizer

If you are required to join lose 250um fiber to ribbon the S220 will skim the top and bottom layer off the ribbon.

Fitel S220 De-Ribbonizor

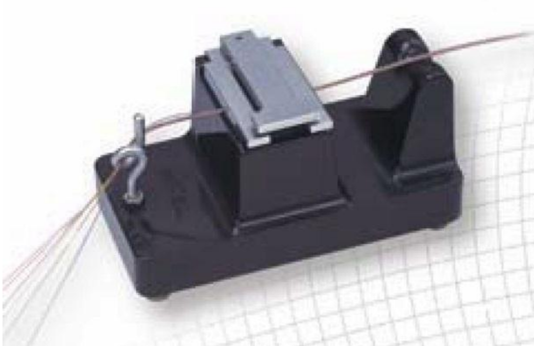
Fiber after top and bottom film is removed



17.3 Ribbonizer

If you have loses 250um fiber that you are required to join to ribbon, the ribbonizer holds the fiber in position while the adhesive is applied.

Fitel S612 Ribbon former, converting loose fibers into ribbon



17.4 Separator

Splitting 12 fibers into other configurations

Fitel S233 Ribbon Slitter, precisely splits the ribbon into preferred lots, i.e. 6 + 6, 8 + 4, etc.

17.5 Splice protectors

The two most common types of slice protectors are ceramic and silica; the silica versions are often ground to a more precise finish.

17.6 Cable jacket strippers

The tools are wide and varied; with every different cable type another tool can be required.

Mid Span jacket cutter **General Jacket stripper** **Large tube cutter**

Mid Span Tube access

Please refer to the associated Resource CD for accompanying documents and material.

Special thanks to the suppliers who provided Cable, Enclosures, Racks, Equipment and Tools:

3M, AusOptic International, Corning, Prysmian, TE and Warren and Brown.

Acknowledgement of resource material:

3M, Corning, Draka, forte, Fujikura, Furukawa Electric Co, FIA, JDSU, Jeff Hetch, Micro Electronics NTT, Norland Products, Prysmain, Sumitomo, Simcoa Operations, TE , US Connect, Wikapidia.