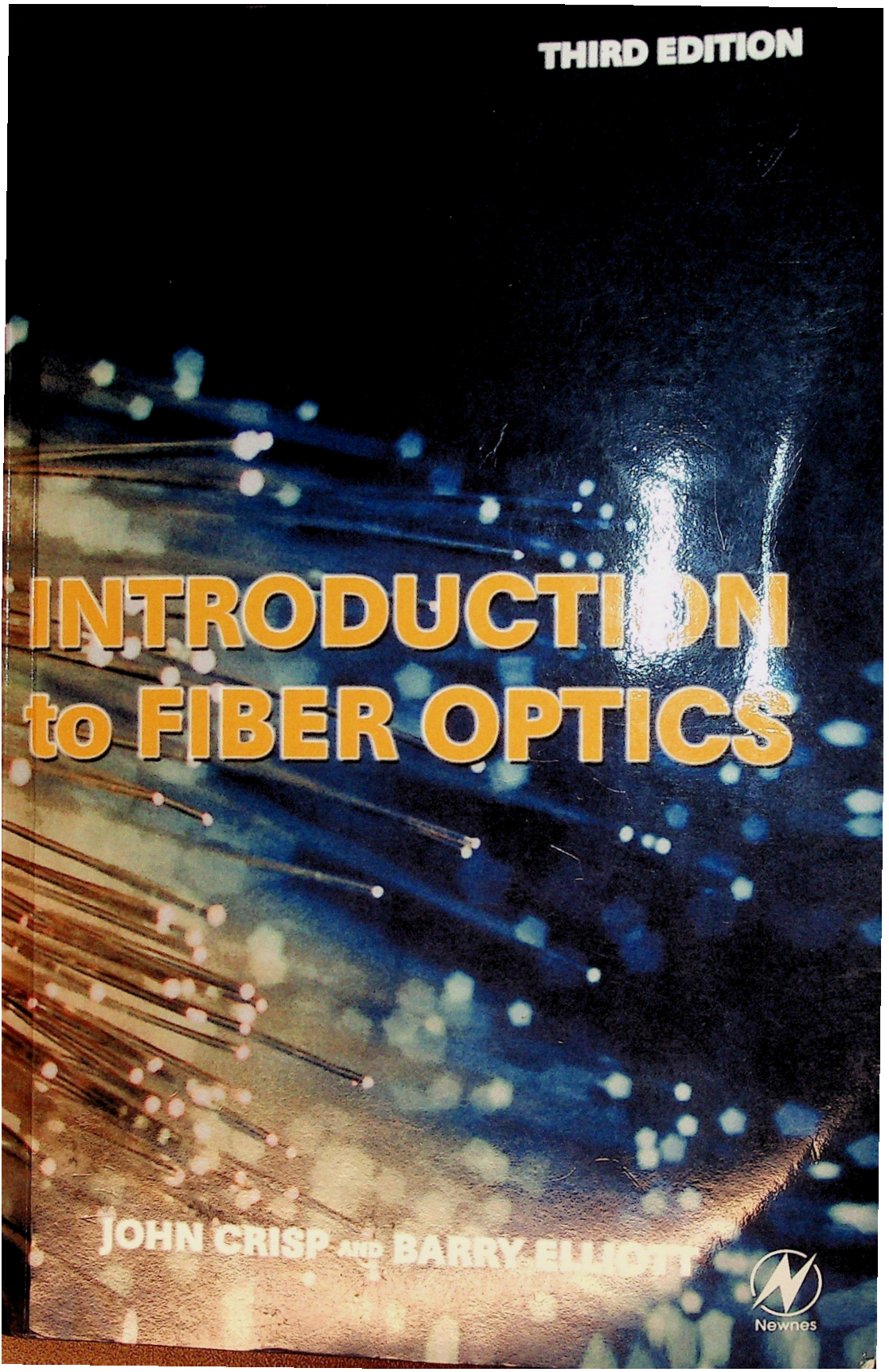


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Introduction to Fiber Optics

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8

Real cables

The optic fiber manufacturers provide the primary coated optic fiber. At this stage, the fiber is easily broken between finger and thumb and is typically only 250 μm in diameter.

The cable manufacturers then enclose the optical fiber (or fibers) in a protective sleeve or sleeves. These sleeves are often referred to as *jackets*, or *buffers* – the exact terminology differs a little according to manufacturer. Once enclosed, the assembly is then referred to as a *cable*.

The cost of installing the cable on site is much greater than the cost of the optic fiber alone, so it makes good sense to provide plenty of spare system capacity to allow for failures or expansion in the traffic to be carried. Extra fibers that are installed but not used do not deteriorate, so they can be left until required and are sometimes called *dark*, *spare* or *redundant* fibers. Nowadays, traffic that decreases in volume is a rare event indeed.

Although we could insist on buying a cable containing almost any number of fibers, it is generally less expensive and easier to buy standard sizes.

Small cables usually have a fiber count of 1, 2, 4 or 8.

Medium size cables have counts increasing in multiples of 6 or 8 to give typical sizes of 12, 18, 24, 30 and 36.

Larger cables increase in steps of 12 to give 48, 60, 72, etc.

The degree of protection depends on the conditions under which the cable is to operate. Some cables will live a luxurious life – warm, dry and undisturbed asleep in a duct in an air-conditioned office, while others are outside in the real world. These may well be submerged in water or solvents, attacked by

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rodents, at sub-zero temperatures or being crushed by earthmovers on a construction site.

Strength members

If we pull a length of fiber through a duct, the outer cover would stretch and the pulling load would be taken by the glass fiber, which would break. To prevent this the cable is reinforced by adding strength members. These are strong, low stretch materials designed to take the strain. The strength members used are usually fibers of aramid yarn, best known by their brand name of Kevlar (® Dupont Inc.), for light duty cable. For heavy duty cables we might expect to see fiber glass rods or steel wires. Kevlar is a very fine, yellow, silky fiber which is, weight for weight, about four times stronger than steel. It resists crushing and being pierced which makes it popular for another of its applications – bulletproof clothing. Unfortunately, it stretches too much to replace steel altogether and is also quite expensive.

Basic choice of cable design

There are two distinctly different methods used to protect the optic fibers. They are referred to as *loose tube* and *tight buffer* designs. We will have a look at these in a moment. There is a tendency for tight-buffer cables to find employment within buildings and loose-tube designs to be used externally. This is not a 'golden rule', just a bias in this direction.

Loose-tube construction

A hollow polymer tube surrounds the optic fiber as can be seen in Figure 8.1. The internal diameter of this tube is much greater than the diameter of the optic fibers that simply lie inside it. There is room for more than one fiber and as many as twenty-four optic fibers can run through the same tube. Heavy duty versions are available with hundreds of fibers shared amongst dozens of tubes.

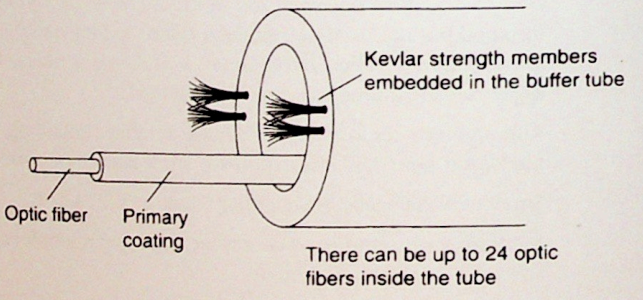


Figure 8.1 Loose-tube construction

The main feature is that the optic fiber is thus free to move about as it wishes. The benefit of this is that its natural springiness allows the optic fiber to take the path of least strain and allows the fiber to expand and contract with changes of temperature. Figure 8.2 shows how the fiber is able to take the route with the

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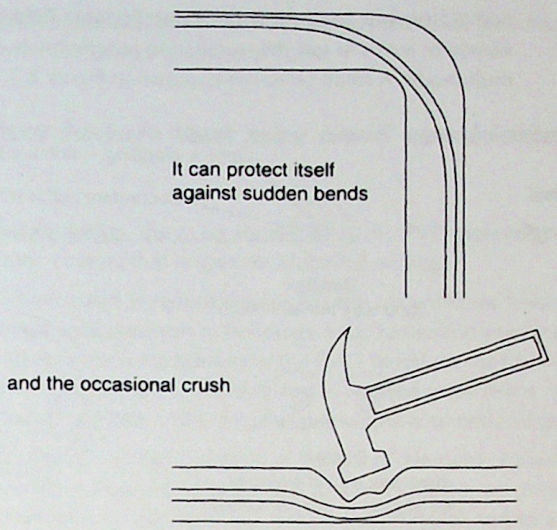


Figure 8.2
Some benefits of loose-tube construction

largest radius of curvature and help to protect itself from bending losses. Under normal, non-stress conditions the optic fiber(s) tend to snake lazily about inside the buffer tube and this results in the optic fiber itself being slightly (about 1%) longer than the buffer tube. This has the further advantage that the cable can be stretched by about 1% during installation without stressing the optic fiber (Figure 8.3).

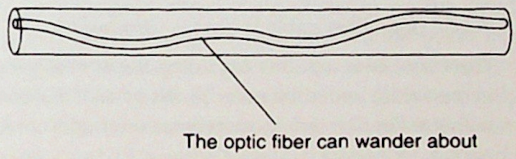


Figure 8.3
The optical fiber is up to 1% longer than the tube

Tight-buffer construction

In this case, a jacket is fitted snugly around the optic fiber in the same way that electrical cables are coated in plastic. This provides protection while allowing flexibility. This form of construction (shown in Figure 8.4) is normally, but again

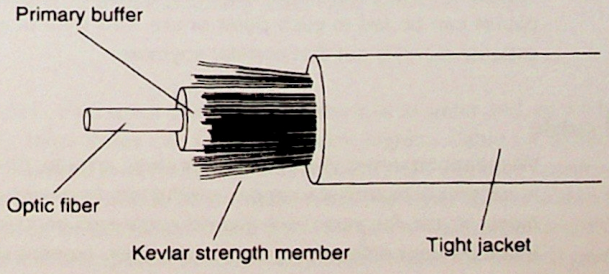


Figure 8.4
Tight-buffer construction

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not exclusively, used for indoor installations. Tight-jacketed cables come in a variety of forms to suit the installation requirements and may be single mode or multimode. A small selection is shown in Figure 8.5.

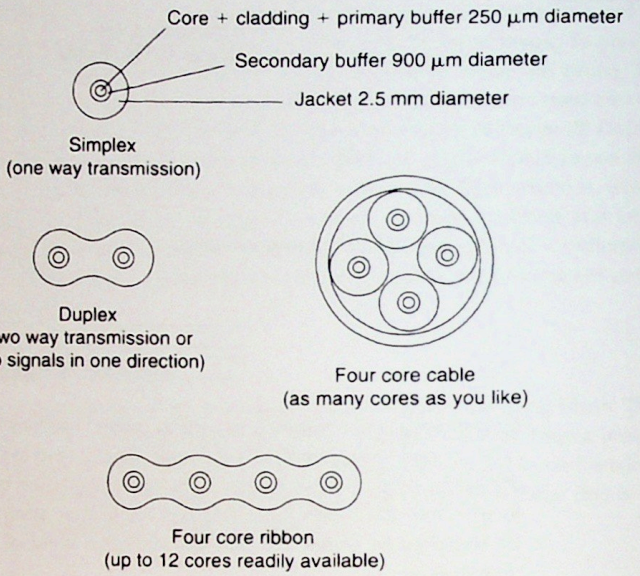


Figure 8.5 Tight-jacketed cables (strength members omitted for clarity)

Plastic optic fiber cable is always tight buffered.

There are three options regarding the strength members. They can be placed immediately under the outer jacket or added around each individual optic fiber within their own jacket, sometimes referred to as a *sub-jacket*.

Heavier cables often have an additional strength member in the center.

Breakout cable

The advantage of the latter approach is that the outer jacket can be stripped off leaving us with individual cables, each with its own strength members. This type is called *breakout cable*. The main cable is installed, perhaps as far as an office space via ceiling ducts and then, by stripping off the outer jacket, the individual cables can be fed to each point of use. This style of cable however is seen as expensive and is not that popular anymore.

Hybrid cable

We cannot transmit electrical power along an optic fiber and so in some cases it is necessary to include copper conductors to power repeaters or other instruments at the far end. Such *hybrid cable* can be custom built and may well include many different types of optic fiber, power cables of different voltage,

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copper coaxial cables and anything else that you feel like. The resulting cable can be bulky, heavy and very, very expensive.

Cable design – other factors that may need considering

Fire precautions

For use within buildings, the outer sheath is usually PVC (polyvinyl chloride) – the same plastic coating that is used for electrical wiring.

The PVC is often treated to reduce the fire hazards. As we know from the publicity surrounding smoke detectors in buildings, toxic fumes and smoke are an even greater hazard than the fierce burning of the PVC. To reduce the fire risk, the PVC is treated to reduce the rate of burning and is referred to as flame retardant. In addition, to reduce the other risks, it is available with low smoke and gas emission.

Chlorine (i.e. the 'C' in PVC) is from a branch of elements called halogens, which also contains fluorine, bromine and iodine. Halogens are often added to hydrocarbon plastics to aid flexibility, reduce flammability and to act as stabilizers and give a number of other benefits. PVC is a classic example of a halogenated plastic.

Over the last ten years the toxicity caused by the halogen-laden smoke from burning PVC has become apparent. The smoke is extremely toxic and acidic. This has led to the development of ranges of PVC-free cables sheathed in 'zero-halogen' materials and bearing names such as LSF (low smoke and fume), LFH (low fire hazard) and LSOH (low smoke, zero halogen) and any number of other abbreviations. Unfortunately there is no standard or regulated terminology used in the industry for this range of products and the buyer needs to display some *caveat emptor* when confronted with manufacturers' claims and should ask exactly what IEC or CENELEC standards the cables actually conform to. More definitions can be obtained from www.ThePhysicalLayer.com. LSOH cables have taken about 15% of the European market for indoor data cables and command price premiums of 20 to 50% over their PVC counterparts.

Different rules apply in America where the National Electrical Code defines strictly applied codes for General Purpose, Riser and Plenum grades of cables. The relevant American standards are defined by the UL organization such as UL910 for plenum grade cables. A plenum in this context means an architectural space where air is forced, or allowed, to move, e.g. a ceiling void used as the return path for air-conditioning (Elliott and Gilmore, 2002).

Moisture

Unfortunately, PVC is not completely impervious to water and, as we have seen previously, large losses can result from such ingress. Cable for external use is normally sheathed in polyethylene and is usually of loose tube construction. An additional precaution is to fill the loose tubes and other spaces within the cable with a silicon or petroleum based gel. This gel is waterproof and thixotropic and flows into any spaces. In severe conditions where the cable is permanently

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submerged even several layers of polyethylene are found not to be totally waterproof. In these conditions, an aluminum foil wrap is placed immediately under the outer jacket (Figure 8.6).

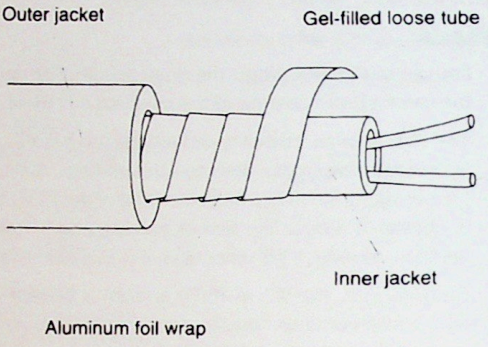


Figure 8.6 A waterproof cable (strength members omitted for clarity)

Ultraviolet protection

Sunlight and other sources of UV light tend to degrade many plastics, including standard polyethylene and PVC, in the course of time. In most cases, making the outer sheath from UV stabilized polyethylene is sufficient, but for extreme situations a metal-sheathed cable is used.

Hydrocarbons

Hydrocarbons are organic compounds of hydrogen and carbon and include solvents, oils, benzene, methane and petroleum. Polyethylene provides poor protection against hydrocarbons and more exotic materials such as nylon or PTFE (Teflon) may be used. For the ultimate in protection against these agents, a lead inner sheath can be added under the polyethylene outer layer.

Radiation

Optical fibers, especially multimode, are sensitive to ionizing radiation, e.g. X-rays, gamma rays, electron beams, etc. The fibers tend to go dark and hence the attenuation rises. Fibers that are expected to withstand radiation, such as in nuclear power plant monitoring, in close proximity to X-ray sources, in space craft or even military systems expected to survive a nuclear Armageddon, must either be protected by lead sheathing or picked from specialist ranges of radiation 'pre-hardened' fibers.

Locating the correct fiber

In multi-core cables, the buffers are usually colored to reduce the chance of incorrect connection during installation.

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Typical colors used for the first 12 fibers are listed below.

Fiber number	*Color*
1	blue
2	orange
3	green
4	brown
5	slate
6	white
7	red
8	black
9	yellow
10	violet
11	rose
12	aqua

When we come to the 13th fiber we start at blue again but we add a thin black stripe called a tracer. The 14th fiber would be orange with a black tracer. What color would we use for the fiber number 20? Now, there's a problem. Using the above method, we would expect black with a black tracer. We break from the sequence and use black with a yellow tracer. Another method, used in loose tube cables, is to wrap individual bundles of fibers with different colored threads.

Mechanical damage

Mechanical support and strength members are not the same even though, in some cases, both functions can be performed by the same elements. Strength members are present to prevent the cable being excessively stretched but mechanical damage can involve other forms of abuse such as being crushed or cut.

In light duty cables as used in buildings, both functions can be achieved by a layer of Kevlar or similar material placed under the outer jacket (Figure 8.7).

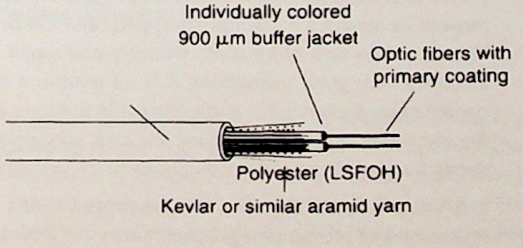


Figure 8.7 Light duty indoor distribution cable

We may also provide some localized protection such as when the fiber is fed under a carpet, for instance. It will be walked on and crushed by furniture being moved. A protective strip is shown in Figure 8.8 and is very similar to those used to protect electrical wiring.

In situations beyond the ability of Kevlar, the normal form of protection is to add a layer, or several layers, of metallic tape or galvanized wire under the outer sheath as in Figure 8.9.

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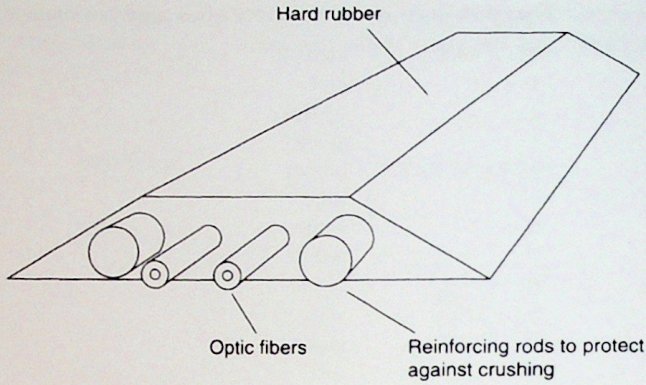


Figure 8.8
A form of localized protection

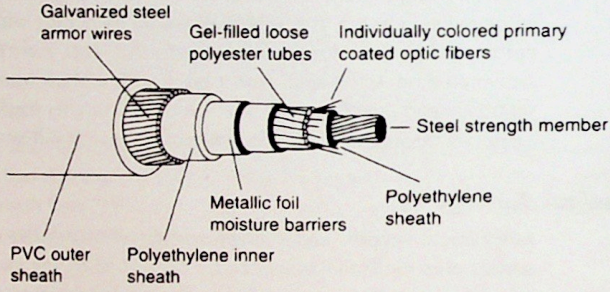


Figure 8.9
An external direct burial cable

The cable may have to survive crushing forces from surface traffic or earth movement or perhaps being picked up by a mechanical digger. It may be laid across a river or indeed an ocean. In the latter case, the cable is initially buried but for most of its distance it is simply dropped onto the ocean floor to take its chance. The enormous cost of location, recovery and repair make extra mechanical protection a very good investment. It is, of course, a matter of judgment as to the degree of protection that a particular cable requires. Adding further protection has the inevitable result of increasing the size and weight which will mean that the strength members would need upgrading to prevent damage during installation.

It is worth mentioning that the galvanized wires, added for additional crush resistance and protection against abrasion, are wound around the cable in a spiral. The result of this wrapping technique is that this additional layer does little to assist the strength members, and certainly could not replace them. As we know, if we pull on a spiral, such as a spring, it gets longer. Applied to a cable, it would mean that pulling forces would cause the cable to lengthen until the fibers break.

The cost of the optic fiber within the outdoor cable is an insignificant part of the whole. It pays then to install considerable spare capacity in the form of extra optic fibers to allow for failures or expansion of the traffic carried in the future.

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The spare fibers do not degrade by laying around unused but to add an extra fiber after installation would mean laying a whole new cable.

Rodents

One form of mechanical damage which may need to be addressed in some situations is rodent damage. In both fiber and electrical cables they gnaw away until they either break through the optic fiber or they reach the live conductor and the cable takes its revenge.

Rodent attack can be lessened by using a very hard plastic for the outer sheath or, more usually, relying on the layer of galvanized wire strands that was added for general mechanical protection. Nowadays a lower cost form of armoring is to use a corrugated steel tape. An alternative approach is to install the cable in a rodentproof duct.

Installation tension

As the name suggests, this is a measure of how hard we can pull the cable during installation without causing damage. The force is measured in Newtons (N). The quoted values start at about 100 N for lightweight internal cables and extend to 10 000 N or more for ruggedized cables.

So what does all this mean? How big is a Newton?

For those of us who enjoy the unlikely story of Sir Isaac Newton sitting under an apple tree, it may be interesting to know that to pick up an average sized eating apple he would have applied a force of about 1 N. An equally unscientific measure is achieved by taking off your jacket, rolling up your sleeves, taking a firm grip on the cable and pulling hard until you break out in a gentle sweat. We are now looking at a force in the region of 250 N. Slightly nearer the mark is to remember that about 10 N is needed to lift a 1 kg (2.2 lb) weight.

Both eating-apples and people come in a wide range of sizes. For this reason, the apparatus for pulling the cables is fitted with adjustable tension and mechanical fuses to prevent damage to the cable.

Weight

Expressed in kilograms per kilometer ($kg \cdot km^{-1}$). There is obviously a wide range of weights depending on the degree of protection built into the cable. Light duty indoor cable designs with the Kevlar strength members result in weights around $20\,kg \cdot km^{-1}$ and the armored external cables are in the order of $500\,kg \cdot km^{-1}$. Hybrid cables which include copper cores can be very much heavier.

Bending radius

To prevent damage to the cable and possible bending losses, the minimum bend radius is always quoted in the specification. One interesting point is that two different figures are stated – a tighter bend is allowed for long-term use since the cable is no longer under stress once installation is complete. For a lightweight cable the figures are about 50 mm for long-term use and 70 mm during installation,

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and for external armored cable the figures are around 175 mm and 350 mm respectively.

Temperature range

Three temperatures may be offered in a specification:

- ▷ installation range, typically 0°C to +60°C
- ▷ operating range, −30°C to +70°C
- ▷ storage range, −40°C to +80°C.

The installation range is the most restricted because the cable will be under stress during this time.

Typical examples

To bring it all together, here are two typical cables. The first is a lightweight internal tight-jacketed cable and the other is an external armored cable suitable for direct burial.

Lightweight internal cable – Figure 8.7

Cable diameter	4.8 mm
Minimum bending radius	
long term	40 mm
installation	60 mm
Installation tension	
long term	250 N
installation	800 N
Weight	19 kg · km^{-1}
Temperature range	
installation	0°C to +60°C
static operation	−10°C to +70°C
storage	−20°C to +80°C

External direct burial cable – Figure 8.9

Cable diameter	14.8 mm
Minimum bending radius	
long term	150 mm
installation	225 mm
Installation tension	
long term	600 N
installation	3000 N
Weight	425 kg · km^{-1}
Temperature range	
installation	0°C to +60°C
static operation	−10°C to +60°C
storage	−20°C to +70°C

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Installation of the cable

Most fiber is installed by traditional pulling techniques developed for copper cable. A pulling tape is inserted into the duct and is attached to the end of the optic fiber cable by a cable grip. This is a length of stainless steel braided wire terminated by an eye. As the tape is pulled, the tension increases and the braiding decreases in diameter, gripping the cable somewhat like a Chinese finger trap. The harder we pull, the tighter it gets. To reduce the friction experienced by the cable as it slides along the duct proprietary lubricants can be applied to the outside of the cable.

Blown fiber

This is an alternative technique available for distances up to about 2 km. It is unique in that it involves the installation of a cable empty of any optic fibers; these are added afterwards. This has three real advantages. It defers much of the cost since only the optic fibers actually required at the time need to be installed. It allows the system to be upgraded by the replacement of individual optic fibers and finally, as a bonus, the installation of the optic fiber is completely stress free.

The first step is to install the empty loose tube cable, which in itself is little more than an empty tube. The cable shown in Figure 8.10 contains seven tubes, each of 5 mm diameter in an outer jacket of 18 mm diameter. No commitment to use any particular number or types of fibers needs to be made at this stage in the proceedings.

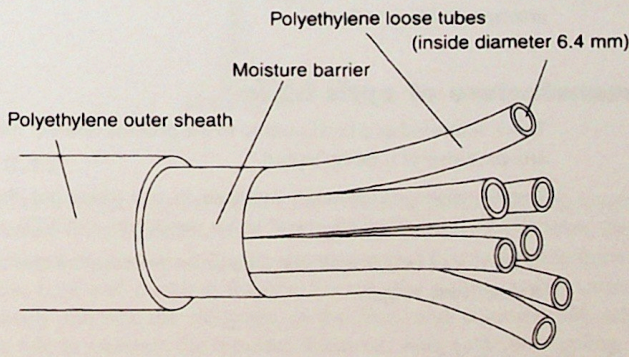


Figure 8.10 Blown fiber tubing – no fiber installed

The next stage is to blow in the fibers. This can be done the same day as the tube (also known as MicroDuct) is installed or ten years later.

There are two methods available. One is to blow in a group of individual fibers, up to 12, into the tube and the second method is to blow in a bunch of fibers preformed into a simple bundle. In each case the fibers or bundle of fibers have a very special anti-static, low friction coating applied by the manufacturer.

The advantages of individual fibers are that they can cope with numerous tight bends better than a larger bundle and being presented as individual fibers at the

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termination point they can be organized and terminated quicker. The advantages of a fiber bundle are that the larger, stiffer unit can go longer distances and the blowing machine can be simpler than the multi-fiber version. Blown fiber ribbon is also possible as is fiber already preterminated at one end.

In every case the blowing machine simply feeds the fibers into the tube but it is the application of a supply of compressed air that provides the motive power to move the fibers along the duct.

A small compressor, called a blowing head, is attached to the end of the loose tube and blows air through it. The fiber is then fed in through the same nozzle as the air and is supported by the air stream. The fiber is blown along the tube and happily round bends in the duct, like a leaf in the wind, at a rate of about two meters a second, a goodish walking pace. No stress is felt by the fiber as it is supported by the movement of the air all along its length.

Other fibers can be blown in at any time to suit the customer although you can't add fiber to an already populated duct. However the fibers are equally easy to remove if the fiber needs to be upgraded at a future date.

A group of microducts is called a multiduct and a typical installation would have a 7-tube multiduct installed, which is potentially an 84 fiber cable, although only twelve might be installed in the first instance to give the network its connectivity required from day one. This leaves an upgrade path of at least 72 fibers available for the building or campus in the future.

To maintain the value of installed microducts they must be sealed to prevent the ingress of dirt, water and insects which would seriously hamper any future attempts to blow in fiber!

The manufacture of optic fiber

This is intended as a brief outline to the process offered, more out of interest than any pretense of it being useful.

There are several different methods in use today but the most widespread is called the modified chemical vapor deposition (MCVD) process.

At the risk of oversimplifying a complex process, we can summarize the process in three easy stages.

Stage 1 – Figure 8.11

A hollow silica tube is heated to about 1500°C and a mixture of oxygen and metal halide gases is passed through it. A chemical reaction occurs within the gas and a glass *soot* is formed and deposited on the inside of the tube. The tube is rotated while the heater is moved to and fro along the tube and the soot transforms a thin layer of silica glass. The rotation and heater movement ensures that the layer is of constant thickness. The first layer that is deposited forms the cladding and by changing the constituents of the incoming gas the refractive index can be modified to produce the core. Graded index fiber is produced by careful continuous control of the constituents.

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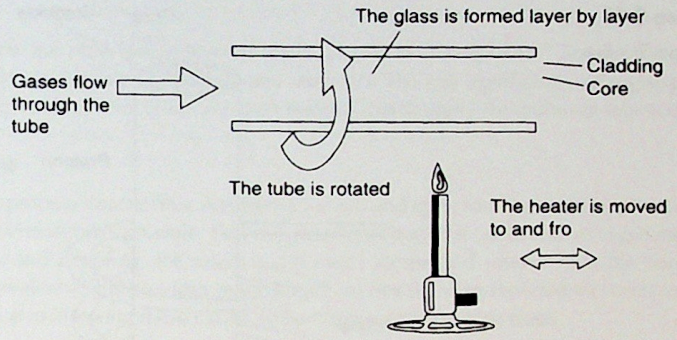


Figure 8.11 Stage 1 – the core and cladding are formed inside the tube

Stage 2 – Figure 8.12

The temperature is now increased to about 1800°C and the tube is collapsed to form a solid rod called a preform. The preform is about 25 mm in diameter and a meter in length. This will produce about 25 km of fiber.

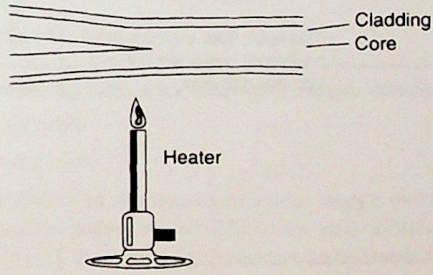


Figure 8.12 Stage 2 – further heating collapses the tube

Stage 3 – Figure 8.13

The preform is placed at the top of a high building called a pulling tower and its temperature is increased to about 2100°C. To prevent contamination, the atmosphere is kept dry and clean. The fiber is then pulled as a fine strand from the bottom, the core and cladding flowing towards the pulling point. Laser gauges continually monitor the thickness of the fiber and automatically adjust the pulling rate to maintain the required thickness. After sufficient cooling, the primary buffer is applied and the fiber is drummed.

Advantages of optic fibers

The fact that optic fibers do not use copper conductors, and even the strength members need not be metallic, gives rise to many advantages.

Immunity from electrical interference

Optic fibers can run comfortably through areas of high level electrical noise such as near machinery and discharge lighting.

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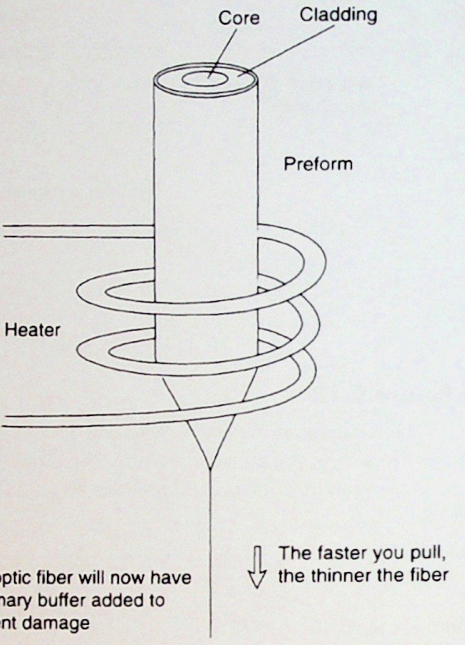


Figure 8.13
Stage 3 – the fiber is drawn

No crosstalk

When copper cables are placed side by side for a long distance, electromagnetic radiation from each cable can be picked up by the others and so the signals can be detected on surrounding conductors. This effect is called *crosstalk*. In a telephone circuit it results in being able to hear another conversation in the background. Crosstalk does not trouble optic fibers even if they are closely packed.

Glass fibers are insulators

Being an insulator, optic fibers are safe for use in high voltage areas. They will not cause any arcing and can be connected between devices which are at different electrical potentials, hence no earth loop currents.

The signals are carried by light and this offers some more advantages.

Improved bandwidths

Using light allows very high bandwidths. Bandwidths of several Gigahertz are available on fibers whereas copper cables are restricted to hundreds of Megahertz.

Security

As the optic fibers do not radiate electromagnetic signals, they offer a high degree of security as discussed in Chapter 6.

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Low losses

Fibers are now available with losses as low as $0.2\,dB \cdot km^{-1}$ and hence very wide spacing is possible between repeaters. This has significant cost benefits in long distance telecommunication systems, particularly for undersea operations.

Size and weight

The primary coated fiber is extremely small and light, making many applications like endoscopes possible. Even when used as part of a cable with strength members and armoring, the result is still much lighter and smaller than the copper equivalents. This provides many knock-on benefits like reduced transport costs and also allowing more cables to be fitted within existing ducts.

Only a single fiber is required

One fiber can send a signal whereas copper requires two wires, one of which is needed as a return path to complete the electrical circuit.

Quiz time 8

In each case, choose the best option.

1 A cable containing both optic fiber and copper conductors is called:

(a) an armored cable

(b) a dehydrated cable

(c) tight-jacketed cable

(d) a hybrid cable

2 A white fiber with a black tracer is most likely to be fiber number:

(a) 18

(b) 16

(c) 14

(d) 12

3 Spiral galvanized wires are sometimes added to a cable to:

(a) conduct electricity

(b) allow the cable to stretch more to relieve stress

(c) improve crush resistance

(d) allow the fibers to be upgraded as necessary

4 Blown fiber allows:

(a) easy removal of the fibers to clean the ducts

(b) the diameter of the fiber to be increased by filling it with compressed air

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(c) easy removal of any water in the fiber

(d) easy replacement of any damaged fiber

5 Within buildings:

(a) both tight-buffered and loose-jacketed cables are used

(b) only loose-jacketed cables are used

(c) only armored cables can be used

(d) only tight-buffered cables are used

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10

Fusion splicing

Fusion splicing is the most permanent and lowest loss method of connecting optic fibers. In essence, the two fibers are simply aligned then joined by electric arc welding. The resulting connection has a loss of less than 0.05 dB, about 1% power loss. Most fusion splicers can handle both single mode and multimode fibers in a variety of sizes but, due to the losses involved, we can only splice multimode to multimode or single mode to single mode. There are also splicers that can automatically splice multicore and ribbon cable up to 12 fibers at a time.

Preparation of the fiber

The fibers must first be stripped, cleaned and cleaved as we have seen in Chapter 9. To allow spare fiber for easy access and to allow for several attempts, a length of at least five meters of jacket should be removed. The primary buffer is only stripped to about 25 mm. The exact length is determined by the fusion splicer in use.

The quality of the cleave is of paramount importance. However much money we spend on buying the most sophisticated splicing apparatus, it will all be wasted if we cannot cleave the fiber accurately. Both cleavers and splicers come in a range of prices with splicers being the more expensive by a factor of at least ten and sometimes a hundred. It is never a good idea to save money by buying an inadequate cleaver – it is always better to buy the cleaver you have confidence in, then, if necessary, recover the money by buying a slightly cheaper version of the splicer. Most splicers nowadays measure the accuracy of the cleave and if found wanting, the fiber is rejected until you have redone it to a satisfactory standard. Most splicers consider an end angle of better than about 3° as satisfactory.

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Protecting the fiber

Splice protector

In the preparation phase, we have stripped the fiber of all its mechanical and waterproof protection. Once the fiber has been spliced, some protection must be restored since the splicing process will have reduced the fiber strength to less than 30% of its former value.

This is achieved by a device called a splice protector. It consists of a short length (about 60 mm) of heat-shrink sleeving enclosing some hot-melt glue and a stainless steel wire rod as seen in Figure 10.1.

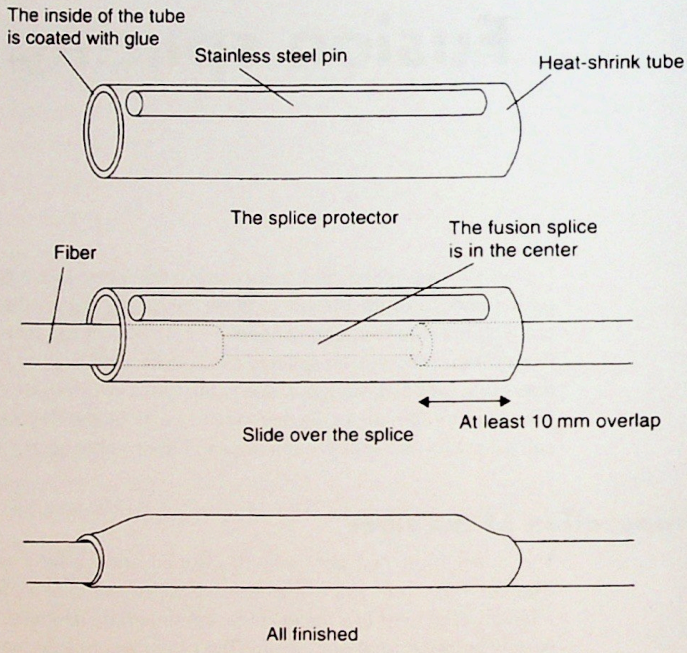


Figure 10.1 Don't forget the splice protector

Prior to joining the fiber, the splice protector is slid onto the fiber. After the splice is completed, the protector is centered over the splice and heated, usually in a purpose-built oven although a hot-air gun can be used. The oven is a simple tray with a lid, a heater and a timer, which are normally built-in features of the splicers. The hot-melt glue keeps the protector in position whilst the stainless steel rod provides proof against any bending that may occur. The outer sleeve offers general mechanical and water protection to replace the buffer that has been removed. To ensure that the fiber is fully protected along its length, at least 10 mm of the protector must overlap the primary buffer at each end of the splice.

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Enclosures (termination enclosures)

After the splice is completed, we are left with a length of fiber deprived of its outer jacket. The fiber must be protected from mechanical damage, and from water. This is achieved by an enclosure (Figure 10.2). The design, and cost, of the enclosures depend on the environment in which the fiber is going to live.

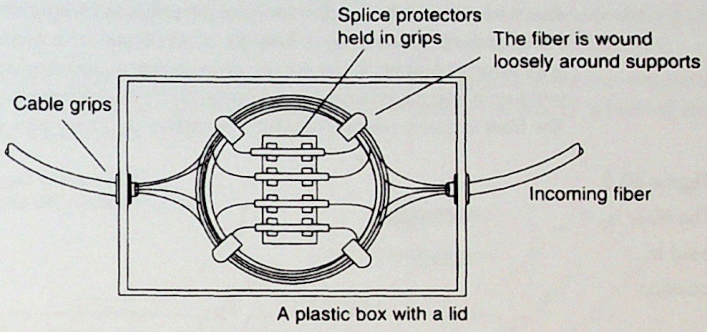


Figure 10.2 A very simple splice enclosure

Obviously something to protect fiber under water has to be superior to a plastic box in an air-conditioned office.

The significant feature is a means of ensuring that the fiber is well supported within the container in such a way that bending loss is avoided. This is done by having something to wind the fiber around, like a reel which, if enclosed, is referred to as a cassette, or at least a few clips to support the fiber and the splices. Single mode fiber is very sensitive to handling within the enclosure (bend radius infringements, microbending, etc.) whereas multimode is slightly more forgiving.

They are readily available in different sizes to hold everything from four to hundreds of fibers. Each fiber must be identified; otherwise a simple job could become a real nightmare. This is achieved by attaching labels to the fibers or splice protectors and by using colored splice protectors.

There are some other factors to consider which may not immediately spring to mind such as:

- ▷ security of the data: with the outer jacket removed a simple live fiber detector can be clipped onto the fiber and all the data being passed can be copied
- ▷ access to an enclosure is the easy way to sabotage a communication system
- ▷ there is also a problem with light, again with no jacket and as bends are inevitable, there is a risk of light entering the system so the container should be lightproof
- ▷ unpleasant environments: salt spray, acids, high temperatures, crushing and all sorts of other nasties
- ▷ access for repairs or for testing purposes.

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We stripped off five meters of outer jacket to enable the fiber to be lifted out of the enclosure with enough spare fiber to be easily connected to test equipment or a fusion splicer.

Holding and moving the fibers in the splicer

The fibers are held in vee-grooves cut into steel or ceramic blocks (Figure 10.3). As usual, cleanliness is all-important. The fiber is cleaned and cleaved then the vee-groove is cleaned by a lint-free cloth, tissue or a 'cotton bud' moistened with isopropyl alcohol. Do not use compressed air cleaners as any contamination will turn it into a grit blaster and damage the critical dimensions of the vee-groove. The fiber is gently pressed into the vee-groove by a magnetic or gravity clamp.

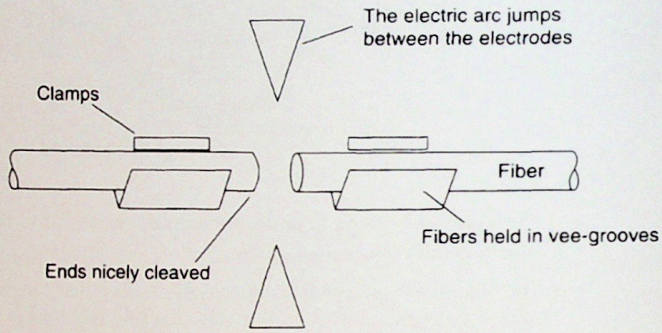


Figure 10.3 The fiber is held in position

Once the fibers are safely clamped into their vee-grooves, they are moved, vee-grooves and all, until the fibers are aligned with each other and positioned directly under the electrodes from which the electric arc will be produced. We are aiming to achieve positioning with an accuracy of better than 1 μm.

In the least accurate splicers, suitable only for multimode fibers, this can be achieved by simple micro gears operated manually. More precision is required for single mode fibers since the core is so much smaller. A 1 μm error in positioning an 8 μm core causes a lateral misalignment of 12.5% whereas the same error on the larger 62.5 μm core in a multimode fiber would represent a lateral misalignment of less than 2%.

The extra precision is provided by using stepper motors or piezo-electric drive blocks. A stepper motor is an electric motor that behaves in a different manner to a 'normal' electric motor. We usually picture electric motors spinning round as power is applied. Stepper motors, instead, turn a set number of degrees and then lock in that position. The amount it turns can be precisely controlled by digital input signals and, in conjunction with a gear train, is able to provide extremely accurate alignment of the fibers.

A piezo drive makes use of the property of some crystals to extend or contract when voltages are applied across them. This property is reciprocated because when those same crystals have force applied across them, voltages appear across the affected faces.

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Observing the alignment

All fusion splicers are fitted with some means to observe the fiber positioning and the condition of the electrodes. This is achieved by either a microscope or by a CCD camera (CCD = charge coupled device – a semiconductor light sensor) and a liquid crystal display (LCD). The trend is towards CCD cameras since they are more pleasant to use and have the safety advantage of keeping our eyes separated from the infrared light, which can, of course, cause irreparable damage to the eyes if we accidentally observe an active fiber through the microscope.

The optic system always allows viewing from two angles as fibers can otherwise hide one behind the other and appear to be aligned. One way of achieving this is shown in Figure 10.4.

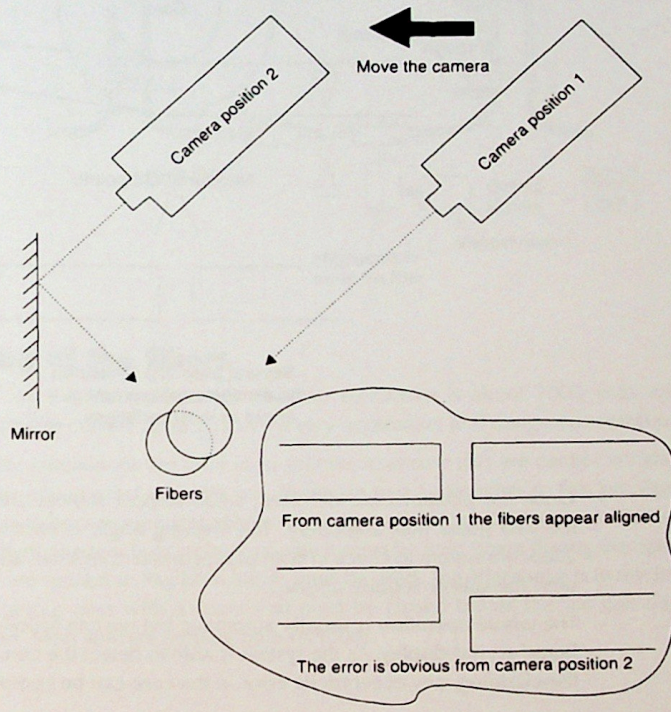


Figure 10.4
Observing the fiber positions

Automatic positioning

There are two methods.

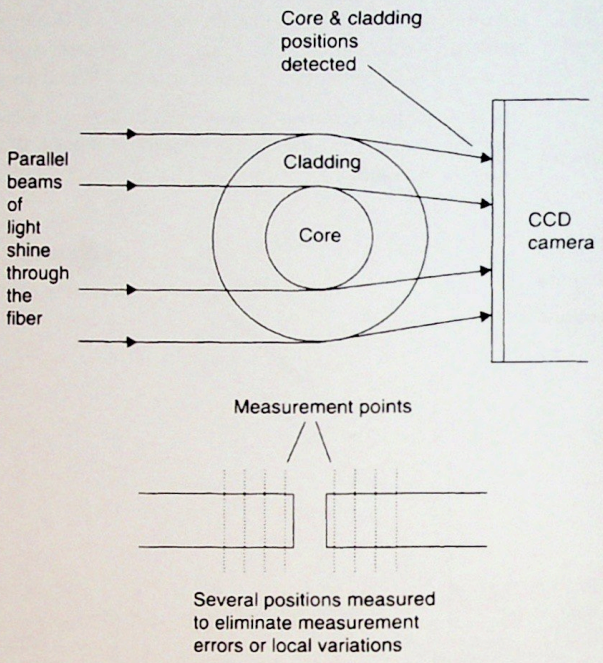
PAS – the profile alignment system – Figure 10.5

This is the standard method of aligning the fibers in modern fusion splicers. The idea is very simple. A light is shone through the fiber and is detected by a CCD

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camera. The change of light intensity at the edge of the cladding and at the core, due to the changes in refractive indices, allows the system to detect their positions. Several readings are taken from each fiber and averaged out to reduce any slight errors.

Figure 10.5
PAS – detecting the position of the fiber



Once the positions are detected, small stepper motors are activated to bring the two fibers into alignment. The viewing angle is switched through 90° to allow the system to check in both planes and further small adjustments are made until the splicer is quite satisfied.

The whole operation is usually automatic but we can follow the process on the liquid crystal display. As the system is able to detect the core position as well as the cladding, any eccentricity error in the core can be compensated for.

LID – light injection and detection system – Figure 10.6

This system makes use of bend loss, the light leakage that occurs when moderately tight bends are introduced into a fiber. Remember that the light can go into the fiber at a bend as well as being able to escape from it.

A bend is introduced at the input side of the splicer and light is injected into the fiber through the primary buffer. The light travels down the fiber and jumps the gap into the other fiber. A similar bend in the other length of fiber allows light to escape.

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A stepper motor or piezo drive is used to move one of the fibers horizontally and the output light is monitored to detect the point of maximum light transfer. This means that the cores are aligned, at least in one plane. The fiber is then moved in the vertical plane until, once again, the point of maximum light transfer is discovered. The whole process is repeated once or twice making finer and finer adjustments until it homes in on the point of best light transfer. Once this has been achieved, the fibers are spliced.

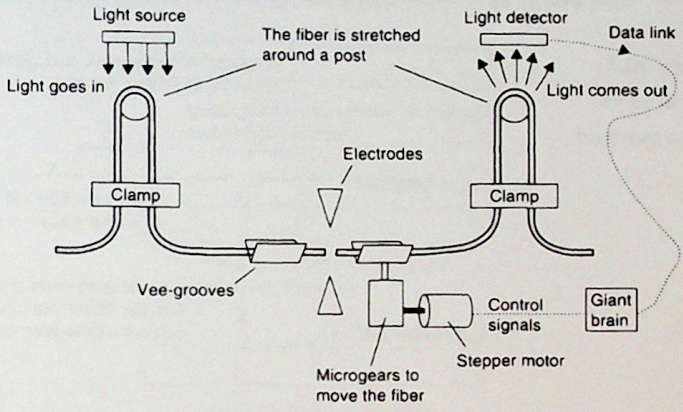


Figure 10.6 A simplified LID system

Fusion splicing of the fibers

The arc that occurs between the two electrodes is about 7000 volts with an adjustable current up to 25 mA – a very unpleasant and dangerous combination.

Safety precautions are built in to splicers to ensure that we cannot accidentally come into contact with the arc. There are two approaches to this problem, the first is to be sure we know where our fingers are before the arc starts. This is done by involving two buttons both of which must be held down during the operation and are spaced so that both hands must be used. The alternative is to enclose the dangerous area with a cover that must be closed before the arc can be energized. Most splicers employ both methods.

Prefuse

The first stage of the fusing process is to align the fibers with an end gap equal to one fiber diameter and apply a short, relatively low power arc. This is called a prefuse. Its purpose is to clean and dry the end surfaces of the cleaves so that nothing untoward gets trapped inside the splice. It can remove very slight tangs from the cleave but don't expect miracles, it won't repair a poorly prepared fiber.

Main fuse

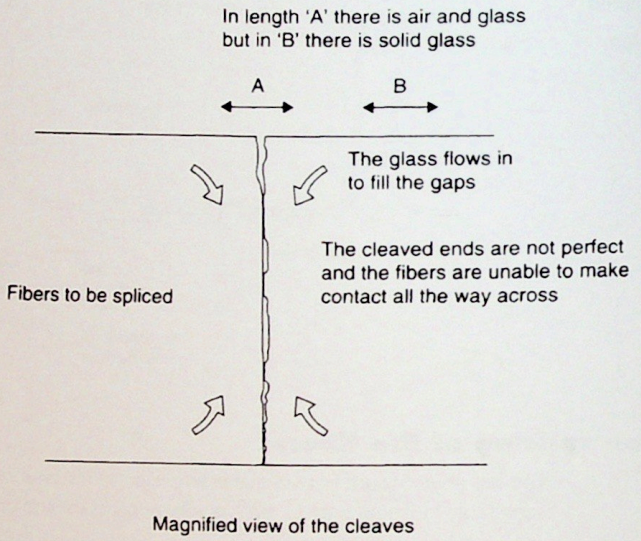
The fibers are then brought together and some additional end pressure is applied. The additional pressure allows the fibers to move towards each other slightly as

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they melt. How far they move, called the *overfeed*, *autofeed* or *stuffing distance*, is critical. Too much or too little and the splice will not be satisfactory.

The reason for introducing the overfeed is illustrated in Figure 10.7. In the figure, the cleaved end of the fiber is shown greatly magnified and, even with a good cleaver, the surface is never completely smooth. When two fibers are brought together there are some small air gaps present which means that within the area marked A there is actually less glass than in a similar length, shown as B. When the electric arc melts the end of the fiber, the glass tends to collapse inwards, filling the air gaps. This produces some waisting as shown in 'Splicing disasters!' (see Figure 10.9).

Figure 10.7
The need for some overfeed



The main fusing arc is more powerful and lasts for a longer period of time, between 10 and 20 seconds.

If the splicer is fitted with a microscope, it is important to check in the instruction book to see if the fiber can be viewed during splicing. The arc emits ultraviolet light and as the microscope concentrates the light there is a danger of suffering from arc-eye, a temporary or permanent damage to the eyes. This is the result of electric arc welding without eye protection. Most viewing microscopes have a UV filter (and an infrared filter) to prevent eye damage, but check the manual first. This is another advantage of choosing one with a CCD camera and monitor.

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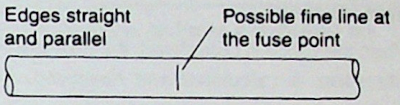
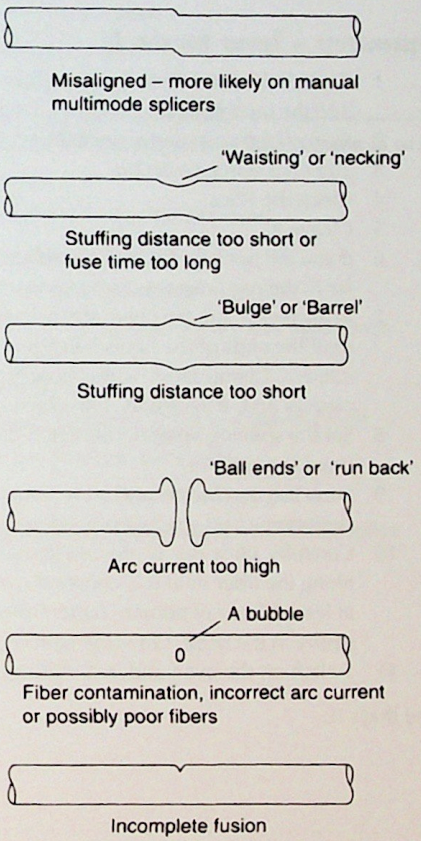


Figure 10.8
This is what we hope to see

Once fusing is completed have a good look at the splice. If it is difficult to see where the splice is, then it's probably a good one (Figure 10.8). We are looking for the outer edges of the cladding to be parallel, just like a new continuous length of fiber. Sometimes a small white line appears across the core but this is not important and can be ignored. See Figure 10.9 for all the disasters.

Figure 10.9
Splicing disasters!



Setting up the splicer

Different types of fibers require particular values of arc current and lengths of time since this determines the temperature to which the fiber rises. There are several automatic programs installed as well as user-defined settings that we can employ in the light of experience.

The equipment is powered by nicad batteries giving up to 300 splices per charge, somewhat less (50 or so) if the oven is used to shrink the splice protector.

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Automatic splice testing

When the splice is completed, the fiber positions are rechecked and an estimated splice loss is calculated and displayed. Although the estimate is reasonably accurate, it is only an estimate and not a measurement. To be really certain, the loss must be measured and this must be done after the splice protector has been fitted, just in case the splice is damaged during this operation. Testing is described in Chapter 15.

Some splicers also provide a tensile test – just a gentle pull of 200 grams or so. It won't damage the fiber but will test the mechanical integrity of the splice.

Practical summary – how to do it

1 Consult the instruction books of the splicer and the splice protector to find the recommended stripping lengths of the primary buffer.
2 Strip off the outer jackets and the required length of the primary buffer.
3 Slip on a splice protector.
4 Clean the fiber.
5 Cleave it.
6 If you are not familiar with the splicer, read the handbook. They all differ in the requirements for loading and positioning the fiber.
7 In a typical case, the fibers are inserted into the vee-grooves and moved until the ends of the fibers meet guide lines visible through the lens or camera. Clamp them in position. Have a look at the standard of the cleaves and, if necessary, take the fiber out and try again.
8 Set the splicing program to match the fiber in use. The handbook will provide guidance.
9 Press the start button and leave it to it. The program will run through its positioning and splicing procedure, and then stop.
10 Carefully lift it out of the vee-grooves and slide the splice protector along the fiber until it is centered over the splice. Make sure you have at least 10 mm of primary buffer inside the splice protector and place it gently in the oven. On some splicers, even this is done for you.
11 Switch on the oven and in a minute or two it will switch off.

And that's it.

Quiz time 10

In each case, choose the best option.

1 Too much overfeed whilst splicing will cause:

(a) waisting

(b) a bubble being formed due to air being trapped inside the fiber

(c) a bulge in the fiber

(d) runback

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2 The main fusing arc is likely to have a duration of:

(a) 15 s

(b) 62.5 ns

(c) 10–20 minutes

(d) less than a second

3 PAS stands for:

(a) position adjustment system

(b) profile alignment standard

(c) plane alignment system

(d) profile alignment system

4 For viewing the splicing process, a CCD camera is preferable to a microscope because:

(a) higher magnification can be achieved

(b) better resolution is possible

(c) there is no risk of eye damage

(d) a CCD camera can operate at very low light levels

5 A splice protector:

(a) provides more flexibility at the mechanical joint

(b) is not needed inside an enclosure

(c) protects against unauthorized copying of data

(d) provides mechanical protection to the fusion splice

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