CHAPTER

8

Cabling

About This Chapter

Cabling is not glamorous, but it is a necessity for virtually all communication uses of fiber optics. A cable structure protects optical fibers from mechanical damage and environmental degradation, eases handling of the small fibers, and isolates them from mechanical stresses that could occur in installation or operation. The cable makes the critical difference in determining whether optical fibers can transmit signals under the ocean or just within the confines of an environmentally controlled office building.

This chapter discusses the major types of fiber-optic cable you are likely to encounter. You will see what cables do, where and why different types are installed, what cables look like on the inside, how cables are installed, and what happens to fibers in cables.

Cabling Basics

Fiber-optic cables resemble conventional copper cables externally, and they use similar materials and jacketing technology. Polyvinyl chloride (PVC) sheaths are common on both fiber-optic cables and coaxial cables used inside buildings, but fiber cables are often brightly colored, whereas coax usually has a black jacket. Polyethylene (PE) is used to protect both metal and fiber outdoor cables against the environmental rigors of underground burial or aerial installation.

Important differences are hidden inside the cable. Fiber cables do not require the electrical insulation needed to isolate copper wires. Optical cables can be designed without any internal metal elements to produce nonconductive or *all-dielectric cables* that are immune to ground-loop problems and resistant to lightning strikes. Fiber cables usually are smaller because fibers are small and each one has the capacity of many wire pairs.

The mechanical differences between glass fibers and copper wires lead to major differences between optical and metal cables. Pull gently on a fiber, and it stretches lightly then springs back to its original length. Pull a fiber hard enough and it breaks (at a weak point or surface flaw). Pull a copper wire, applying less stress than that needed to break the fiber, and the metal stretches by more than 20% and does not spring back to its original length. In mechanical-engineering terms, fiber is elastic because it contracts back to its original length, and copper is inelastic because it stays stretched.

Fibers must be isolated from tension, which can cause breakage or long-term reliability problems.

As you learned in Chapter 5, glass fibers are strong. Manufacturers proof-test fibers under stress of 100,000 pounds per square inch, or 0.7 giganewton per square centimeter. (The usual units are thousands of pounds per square inch, kpsi, one of the few cases where Imperial units are widely used in fiber optics.) The test normally is performed as the plastic-coated fiber is wound onto the shipping reel, so weaker fibers should not make it out of the plant.

Although the strength per unit area is very high for glass fibers, you should remember that a strong tug applies a large force per unit area across the small diameter of a fiber. What counts in assessing strength is the cross-section of the glass, not the thicker diameter of the plastic-coated fiber. A standard 125-μm fiber has a cross-sectional area of only 0.000019 square inch (0.00012 square centimeter), so a 2-lb (1-kg) force applied along the fiber corresponds to the 100 kpsi stress test.

Fibers are plastic coated as well as proof-tested; the coating protects the fiber surface from handling damage and environmental moisture. The cable structure isolates the fibers from excessive strain, both during installation and in service, such as when they are hanging from outdoor poles. The cable structure applies tension to strength members that run the length of the cable, either through the center or in another layer, depending on the application. As described later, these strength members may be metallic or nonmetallic.

Reasons for Cabling

Cabling packages optical fibers for protection and ease of handling, and cabled fibers are used for most communication applications. Bare fibers are used in sensors and in a few communication applications such as the fiber-optic guided missile described in Chapter 28. As you will learn later in this chapter, certain fibers can be blown into hollow tubes that guide and protect the fibers. These structures function much like cables and have advantages in some applications.

Ease of Handling

Cables make fibers easier to handle.

One major reason for cabling fibers is to make them easier to handle both singly and collectively.

Physically, single glass optical fibers resemble monofilament fishing line, except the fibers are stiffer. Protective plastic coatings raise the outer diameter of standard communication fibers to 250–900 μm, making them easier to handle than bare fibers. Reduced-cladding fibers are only 165 μm in diameter with the plastic coating, which makes them hard to handle.

Most communication systems require at least two fibers, each carrying signals in the opposite direction. Generally, multiple fibers follow the same path along much of their routes and are grouped in a single multifiber cable, which serves as a single easy-to-see and easy-to-handle structure. Some of these cables contain dozens of fibers, some hundreds, and the largest cables contain over a thousand fibers.

Individual fibers in a multifiber cable usually are color-coded or marked in ways that make them easy to identify. The color-coding is on a thin plastic layer that covers the plastic coating of the fiber. This coding is vital in helping cable installers keep track of connections. Color-coding also makes fibers more visible on a work surface than do clear-plastic coatings.

Cables also serve as mounting points for connectors and other equipment used to interconnect fibers. If you take that function too much for granted, try butting two bare fibers together with your hands and finding some way to hold them together permanently.

Protection from Damaging Forces

Another major goal of cabling is to prevent physical damage to the fiber during installation and use by forces applied intentionally or unintentionally. The two major concerns are stress or tension applied along the length of the cable, and crushing forces applied across the cable's diameter. The ability of cables to withstand these forces varies widely with cable design.

Cables prevent physical damage to fibers during installation and use.

The most severe stresses intentionally applied along the length of a cable come during installation. Many cables are pulled into place through underground ducts outdoors or through conduits within buildings. Pulling gear is attached directly to strength members on cable jackets, isolating the fibers from the force needed to pull the entire cable into place. Aerial cables also may be pulled into place. An alternative approach that reduces stress along the length of the cable is to blow lightweight cables along the length of a duct or conduit.

Cables encounter much less static stress once they are installed, although aerial cables hanging from supports must be able to support their own weight. In cold environments, the cables must also be able to support snow and ice adhering to them.

Static fatigue is a significant issue because glass fibers age very quickly if stretched much. This makes it important to isolate fibers from mechanical loads, so elongation during manufacture and installation is no more than 0.1% to 0.2%.

Cables also can experience short-duration dynamic forces along their lengths. Most of these are unintentional, such as tree limbs falling on aerial cables. Cables can provide reasonable protection against light branches or overweight crows landing on them, but they can be broken by severe shocks. Falling trees and telephone poles snap aerial cables; careless backhoe operators dig up and break underground cables. Even cables inside buildings are vulnerable to damage if someone yanks or trips on them.

Crush resistance is another important cable specification, measuring how well they can withstand force applied from the sides. Requirements differ widely. Ordinary intrabuilding cables are not made to be walked on, but a few have been made for installation under carpets. Deep-sea submarine cables must withstand the pressure of several kilometers of seawater above them.

Crush resistance is how well cables withstand crushing force applied from the side.

Cables can be armored to withstand unusual stresses. For example, the portions of submarine cables near shore are armored to protect them against damage from fishing trawlers and boat anchors. Buried cables must withstand a different type of crushing force applied in a small area: the teeth of gophers, who gnaw anything they can get their teeth around. The front teeth of gophers and other rodents grow continually, so they instinctively gnaw on objects they find underground. This is one case where the small size of fiber cables is undesirable, because it makes them just bite-sized for gophers. To prevent such damage, cables buried in areas where burrowing rodents live typically are sheathed in steel armor and built to larger sizes than gophers like to munch.

Cables are made stiff to keep fibers from being bent too tightly. This practice also helps prevent fibers from developing tiny microcracks, caused by surface nicks, which can lead to fiber breakage.

Many cables are now designed for quite specific applications, such as within air spaces in buildings or for aerial suspension from poles. Figure 8.1 shows a few representative examples. You'll learn about the structures that make up these cables and their specific applications later in this chapter.

Protection from Environmental Degradation

Cabling helps protect fibers from moisture.

Cabling also protects fibers from the more gradual degradation caused by the surrounding environment. Cables are designed to withstand specific conditions, making it important to match the cable to the working environment. The utmost care must be taken in the harshest environments.

FIGURE 8.1
A sampling of cable designs. (Courtesy of Corning Cable Systems)

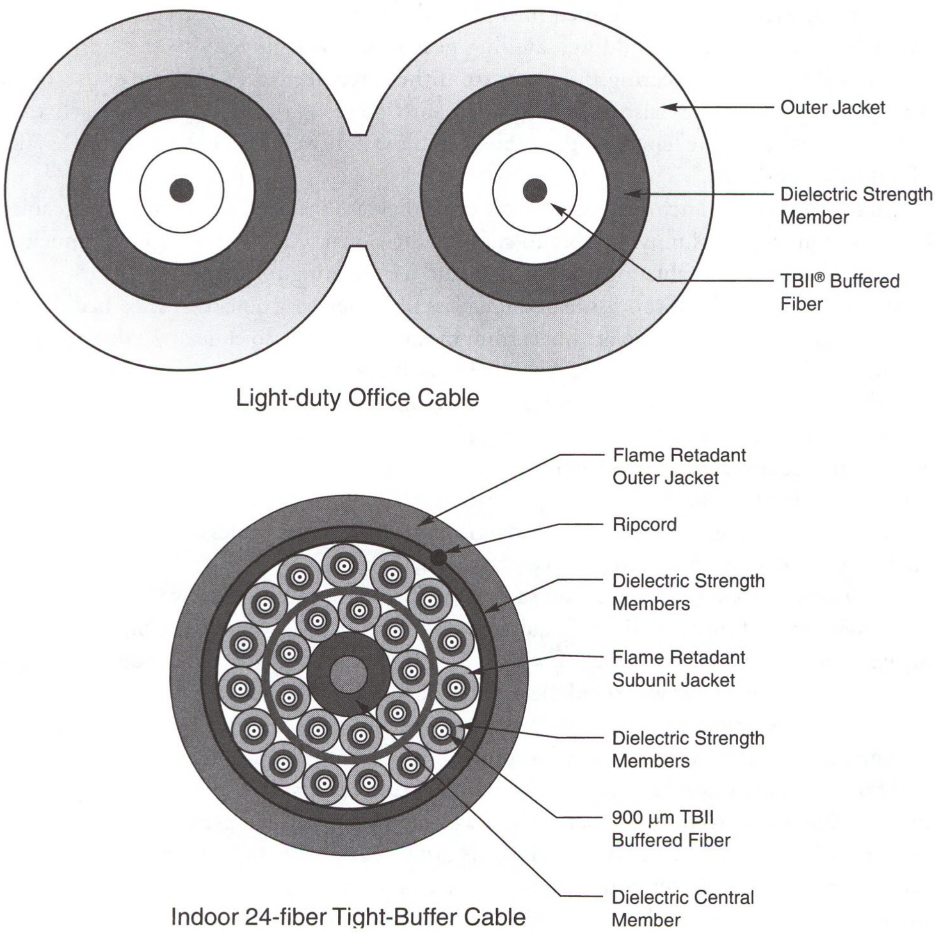
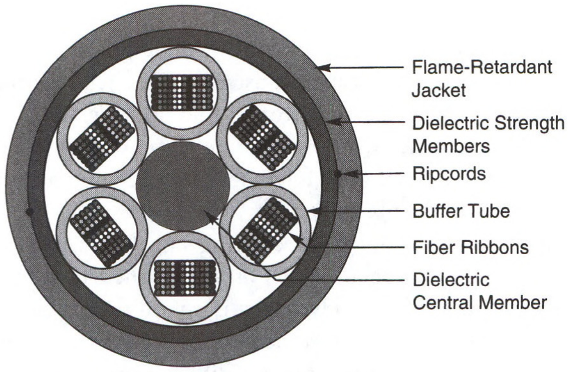
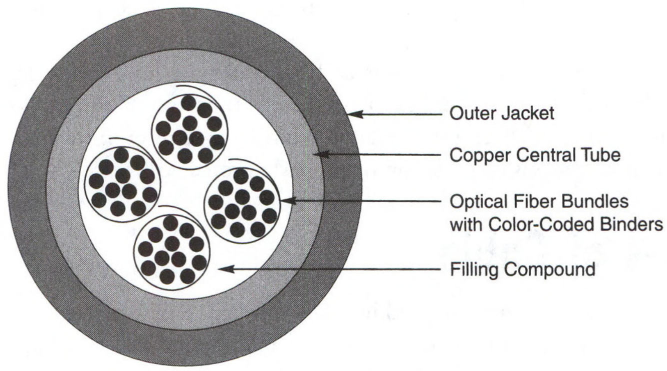


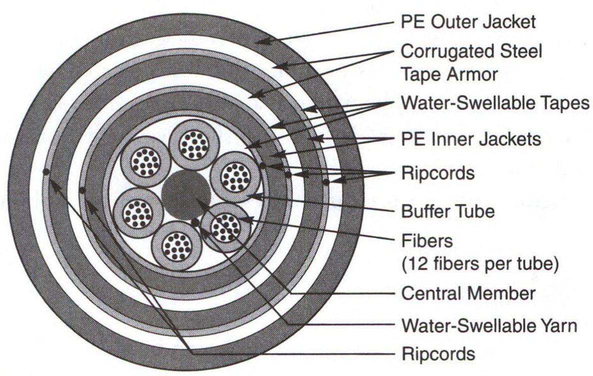
FIGURE 8.1
Continued



432-fiber Ribbon Cable for Indoor Use



Armored Cable for Installation in Roads and Sidewalks



Multi-armored Cable for Direct Burial

Long-term exposure to moisture can degrade fiber strength and optical properties. Most cables designed for an uncontrolled (i.e., outdoor or underground) environment include barriers to keep moisture out. Aerial cables must withstand temperature extremes, from blazing heat on hot, sunny summer days to freezing cold in the winter. The combination of cold and moisture presents an added danger—freezing of moisture inside the cable. Because water expands when it freezes, it can exert forces that produce microbends, increase losses, and even cause microcracks in the fibers.

A significant long-term concern for fibers carrying signals at 1300 to 1650 nm is preventing the accumulation of hydrogen, which as you learned in Chapter 5 has a large absorption peak centered on 1380 nm. Hydrogen is rare in the air, but it can accumulate in a cable that carries electric currents. Electric currents decompose water molecules and some plastics, and the resulting hydrogen gas can diffuse into the glass. Small concentrations of hydrogen can disrupt transmission in the 1350–1450 nm region, and higher concentrations can cause absorption across a broader range. Modern cable designs should avoid hydrogen accumulation.

In all other circumstances, however, fiber undergoes no serious degradation if properly cabled. Nearly three decades have passed since the first fiber-optic systems were installed, and cable design has been greatly refined; but long-term monitoring of some early systems has shown no serious degradation of properly protected fibers.

Types of Cable

Cables are designed for particular environments.

A single type of fiber may be used in many different environments, but cables are designed for specific requirements. Look through a cable catalog and you'll see a long list of different types of cable, which vary in internal structure and the number of fibers they contain. Cables must meet fire and electrical safety codes, which ban indoor installation of materials that catch fire easily or release toxic gases.

Cable manufacturers use modular design, which they adapt and assemble into cables for particular needs. They have families of cables that can incorporate all the major types of fiber used for communications. They often assemble cables from subunits, such as ribbons, which can contain various numbers of fibers. In short, cable manufacturers build cables to fit customer requirements.

A variety of factors enter into their choices. We'll start by looking at environmental considerations.

Types of Environments

The major types of environments for optical cable can be loosely classified as follows:

- Inside devices (e.g., inside a telephone switching system or computer).
- Intraoffice or horizontal (e.g., across a room, usually to individual terminals or work groups).
- Intrabuilding or riser (e.g., up wiring risers or along elevator shafts between floors in a structure; typically between distribution nodes on each floor that serve multiple users).

- Plenum installations (i.e., through air spaces in a building; must meet special codes).
- Interbuilding or campus links (short exterior connections; link distribution nodes in separate buildings).
- Drop cables, which carry signals from outdoor cables to homes or businesses.
- Blown-fiber cables, in which fibers are blown into previously installed hollow tubes.
- Chemical-resistant cables for industrial environments.
- Temporary light-duty cables (e.g., remote news gathering at sports events).
- Aerial cables (e.g., strung from utility poles outdoors). May be supported by lashing to support wires or other cables.
- All-dielectric self-supporting cables.
- Cables installed in plastic ducts buried underground.
- Direct-burial cables (i.e., laid directly in a trench or plowed into the ground).
- Submarine cables (i.e., submerged in ocean water or sometimes fresh water).
- Instrumentation cables, which may have to meet special requirements (e.g., withstand high temperatures, corrosive vapors, or nuclear radiation).
- Composite cables, which include fibers and copper wires that carry signals (used in buildings). Note the differences from hybrid cables, as follows.
- Hybrid power-fiber cables, which carry electric power (or serve as the ground wire for an electric power system) as well as optical signals.

These categories are not exhaustive or exclusive, and some are deliberately broad and vague. Instrumentation, for example, covers cables used to log data collected while drilling to explore for oil or other minerals. Special cables are needed to withstand the high temperatures and severe physical stresses experienced within deep wells. There is some overlap among categories; composite cables, for example, may also be classed as intraoffice cables.

Cable Design Considerations

A variety of considerations go into cable design, starting with the physical environment and the services being provided. They lead to a wide variety of cable types on the market. The most important considerations are summarized next.

Cables used inside buildings must meet fire and electrical codes.

- Intradevice cables should be small, simple, and low in cost, because the device containing them protects the cables.
- Intraoffice and intrabuilding cables must meet the appropriate fire and electrical codes. The National Electric Code (issued by the National Fire Protection Association) covers fiber cables that contain only fibers and

Table 8.1 Cable specifications under U.S. National Electric Code

Cable Type	Description	Designation	UL Test
General-purpose (horizontal)—fiber only	Nonconductive optical fiber cable	OFN	Tray/1581
General-purpose (horizontal)—hybrid (fiber/wire)	Conductive optical fiber cable	OFC	Tray/1581
Riser/backbone—fiber only	Nonconductive riser	OFNR	Riser/1666
Riser/backbone—hybrid	Conductive riser	OFCR	Riser/1666
Plenum/overhead—fiber only	Nonconductive plenum	OFNP	Plenum/NFPA 262
Plenum/overhead—hybrid	Conductive plenum	OFCP	Plenum/NFPA 262

cables that contain both fibers and copper wires. The primary concern is fire safety, because many cable materials are flammable, and some release toxic gases when they burn. Table 8.1 lists cable types and fire-safety tests specified by Underwriters Laboratories. Outdoor cables that do not meet these requirements can run no more than 50 ft (15 m) within a building before terminating in a cable box or being spliced to an approved indoor cable. Indoor/outdoor cables are available that meet indoor requirements and can withstand outdoor conditions, although they are not as rugged as heavy-duty outdoor cables.

- *Plenum cables* are special intrabuilding cables made for use within air-handling spaces, including the spaces above suspended ceilings, as well as heating and ventilation ducts. They are made of materials that retard the spread of flame, produce little smoke, and protect electronic equipment from damage in fires, called "little smoke, no halogen" (LSNH) materials. (Halogens produce toxins.) Cables meeting the NFPA 262 specification can be run through air spaces without special conduits. The special materials are expensive and are less flexible and less abrasion-resistant than other cable materials, but installation savings and added safety offset the extra cost.
- Fiber count depends on the number of terminals served. Individual terminals may be served by a two-fiber duplex cable that looks like the zip cord used for electric lamps. Other types are round or oval in cross section and the largest contain over a thousand fibers. Multifiber cables often terminate at patch panels or communications "closets" where they connect to cables serving individual terminals.

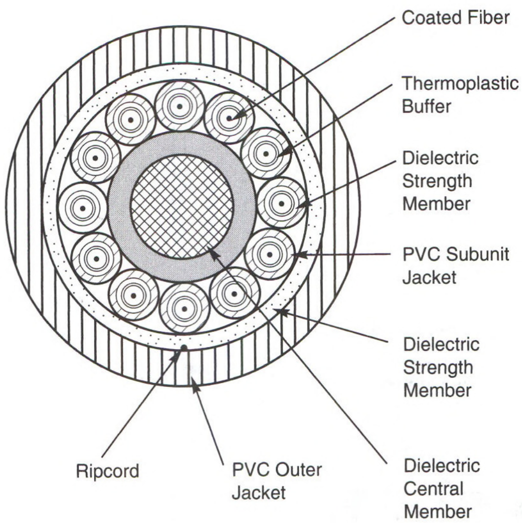


FIGURE 8.2
Breakout cable. (Courtesy of Corning Cable Systems)

- Breakout or fanout cables are intrabuilding cables in which the fibers are packaged as single- or multifiber subcables. This allows users to divide the cable to serve users with individual fibers, without the need for patch panels. Figure 8.2 shows an example.

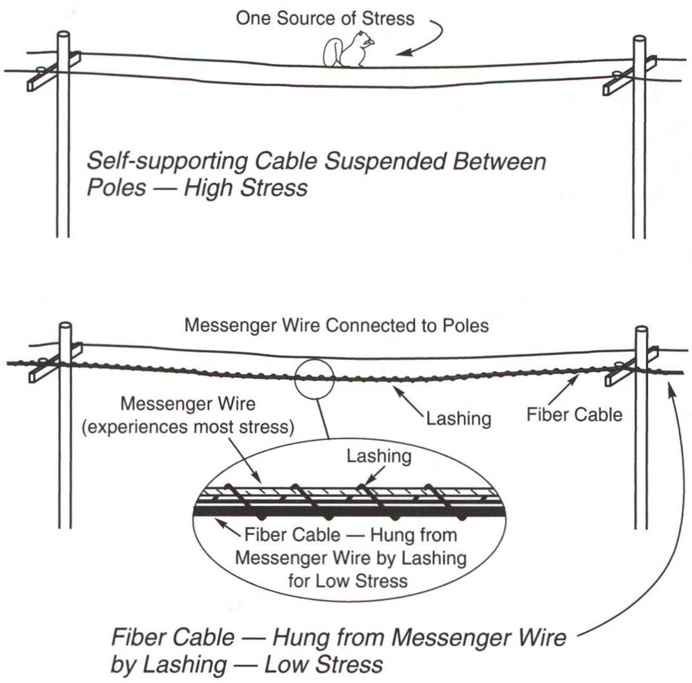
> Breakout cables are intrabuilding cables with fibers packaged into subcables.

- Composite or hybrid cables include both fibers and copper wires to deliver different communication services or communication and power to the same point. For example, the fiber may connect a workstation to a local area network while the wires carry voice telephone service to the same user.
- Temporary light-duty cables are portable and rugged enough to withstand reasonable wear and tear. They may contain only a single fiber (e.g., to carry a video feed from a camera) and should be durable enough to be laid and reused a few times.
- Outdoor cables are designed to survive harsh outdoor conditions. Most are strung from overhead poles, buried directly in the ground, or pulled through underground tubes called ducts, but a few in protected areas are exposed to surface conditions. Most have polyethylene jackets, which keep out moisture and withstand temperature extremes and intense sunlight. However, polyethylene does not meet indoor fire codes, so such cables can run only short distances indoors, typically to equipment bays from which indoor cables fan out.

> Outdoor cables can withstand harsher environments than intrabuilding cables but do not meet the same fire and building codes.

- Aerial cables are made to be strung from poles outdoors and typically also can be installed in underground ducts. They normally contain multiple fibers, with internal stress members of steel or synthetic yarn that protect the fibers from stress. Figure 8.3 shows two types of aerial installations, which normally use different types of cables. One suspends the cable

FIGURE 8.3
Aerial cable installations.



between adjacent poles, supported by internal strength members or by a strength member packaged parallel to the fiber unit, which hangs below in what is called a "figure-8" cable. The other approach is to run a strong "messenger wire" between poles and lash the fiber cable to it by winding a supporting filament around both. Lashing supports the fiber cable at more frequent intervals and reduces the stress applied along its length, which can be large if the only supports are at the poles. Many aerial fiber cables are designed only for lashing, not to withstand the high stress of suspension between poles.

- All-dielectric cables contain no metal elements, either to conduct electricity or to serve as strength members. These cables use nonconductive strength members, such as fiberglass yarns or glass-reinforced plastic (GRP) strength rod. The all-dielectric construction prevents lightning surges and ground-loop problems, so they are widely used outdoors, particularly in lightning-prone areas.
- Armored cables are similar to outdoor cables but include an outer armor layer for mechanical protection and to prevent rodent damage. Steel or all-dielectric central members may be used. They can be installed in ducts or aerially, or directly buried underground (which requires extra protection against the demanding environment of dirt). Normally, the armor is surrounded inside and out with polyethylene layers that protect it from corrosion and cushion the inside from bending damage.

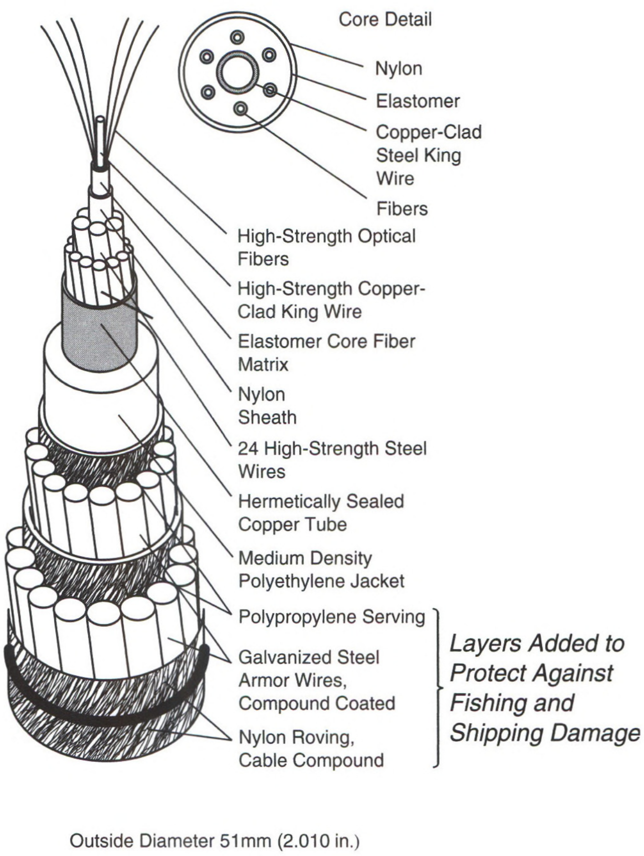


FIGURE 8.4
Fiber-optic submarine cable. (Courtesy of TyCom Ltd.)

- Submarine cables can operate while submerged in fresh or salt water. Those intended to operate over relatively short distances—no more than a few kilometers—are essentially ruggedized and waterproof versions of direct-burial cables. Cables for long-distance submarine use are more elaborate, as shown in Figure 8.4. Some parts of submarine cables are buried under the floor of the river, lake, or ocean, largely to protect them from damage by fishing trawlers and boat anchors. The multilayer design shown in Figure 8.4 can withstand ocean floor pressures; the outer armor is not needed on the deep-sea bed, where no protection is necessary against fishing trawlers and other boat damage.

Elements of Cable Structure

All fiber-optic cables are made up of common elements.

The diverse variety of fiber-optic cables are built from a common set of structural elements. Individual fibers are housed in one of three different elements—a tight buffer, a loose tube, or a ribbon. These structural elements can house one or more fibers, and they, in turn, are grouped together within the cable. The more fibers, the more levels of grouping are likely. Some of these internal assemblies may be called *subcables* or *breakouts* because they can be split from the main cable and strung to another point. Individual fibers within each group may be color coded, with the groups or subcables themselves, in turn, color coded so each fiber can be identified.

Multifiber cables usually are built around central strength members. Sometimes the central strength members are fillers; and sometimes ribbon cables, assembled with flat ribbons stacked in the center of the cable, are surrounded by strength members. Single- and dual-fiber cables typically are surrounded by strength members.

A *jacket* encloses the entire cable structure, sealing it from the environment. *Armor* provides additional mechanical protection, particularly where cables might be exposed to burrowing rodents or mechanical hazards. *Rip cords* embedded in the cable structure can split the jacket to access individual fibers or subcables. Electrical conductors deliver power where needed, or allow one cable to carry both electronic and fiber-optic signals.

Let's look at these structures in more detail.

Fiber Housings

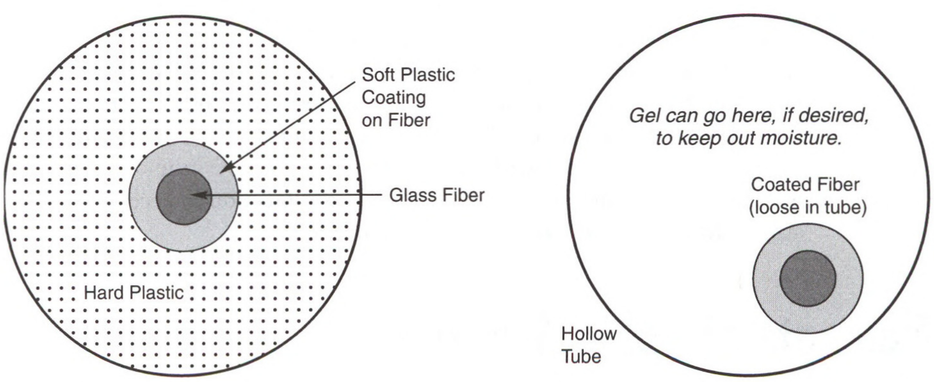
Fibers can be housed in tight buffers or loose tubes.

The two fundamental types of fiber housing are rigid jackets and loose tubes, both shown in Figure 8.5. Each type has its own advantages, applications, and variations.

Tightly buffered cables cover plastic-coated fibers with a thick buffer layer of harder plastic, making the fibers easier to handle. These buffered fibers can be packed tightly together in a compact cable structure, an approach widely used indoors. *Ribbon cables* are a variation in which several parallel fibers are encased in a flat outer buffer.

Loose-tube cables leave the plastic-coated fibers loose inside a flexible tube. For outdoor use, the tube usually is filled with a gel that prevents moisture from seeping inside. Multiple fibers can fit inside each tube. The loose-tube structure mechanically isolates the fibers from the cable structure, enabling the cable to handle thermal and other stresses encountered outdoors.

FIGURE 8.5
Tightly buffered and loose-tube structures for cables.



(a) Tightly Buffered Fiber (encased in hard plastic buffer)

(b) Loose Tube (with fiber inside a hollow tube, which may be filled with gel)

Blown fibers are a variation on the loose-tube design in which the tube is installed first, then fibers are blown along its length. Once the fibers are installed, they function as they would in a loose-tube cable.

Each cable type has its advocates, and the boundaries between their applications are not rigid: Tightly buffered cables can be built for outdoor applications, while loose-tube cables also are made for indoor use.

LOOSE-TUBE CABLE

The simplest loose-tube design contains a single plastic-coated fiber in a long tube, with inner diameter much larger than the fiber diameter. The fiber is installed in a loose helix, so it can move freely inside the tube. This design protects the fiber from stresses applied to the cable structure during installation or service, including the effects of changing temperature, which could cause bending loss or damage the fiber.

There are several variations on the loose-tube approach. Multiple fibers can run through the same tube, either individually or assembled into one or more ribbons. Individual fibers usually are color-coded. The tube does not have to be a physically distinct cylinder running the length of the cable. Alternatives include running grooves along the length of a solid cylinder encased in a larger tube, and pressing corrugated structures together and running fibers through the interstices. The end result is the same; the fiber is isolated from stresses applied to the surrounding cable structure.

Alternatively, fibers can be blown into a previously installed hollow tube that guides them along the cable route. When the fibers are in place, the unit functions as a loose-tube cable. The installation technique is described later.

Moisture-blocking gels can be messy, but they are widely used in outdoor loose-tube cables. Some older cables had similar gels or "grease" around the outside of each tube, filling the interstices of the cable. Cleaning was time-consuming and messy, so dry water-blocking materials are now used between tubes.

Loose-tube cables are filled with gels for outdoor use.

Loose-tube cables are preferred for outdoor environments where the cable may be stressed or exposed to moisture. They can be installed from poles, in ducts, or by direct burial. A single tube can contain many fibers, allowing high fiber densities in compact cables. The cables can also be made of flame-retardant materials to meet codes for indoor use, particularly where high fiber counts are needed.

TIGHTLY BUFFERED FIBER

A tightly buffered fiber is encased (after coating) in a plastic layer. The coating is a soft plastic that allows deformation and reduces forces applied to the fiber. The harder outer buffer provides physical protection.

Tightly buffered fibers are typically used indoors.

Tight buffering tolerances assure that the fibers are in predictable positions, making it easier to install connectors. The tight-buffer structure creates subunits that can be divided among many terminals, without using patch panels. Tight-buffer cables are smaller for small fiber counts than loose-tube cables, but the ability to pack many fibers into a single loose tube makes that advantage disappear as the fiber count increases.

A major advantage of tight-buffered cable for indoor use is its compatibility with materials that meet fire and electrical codes. Although losses may be somewhat higher than in loose-tube cables, indoor transmission distances are short enough that it's not a problem.

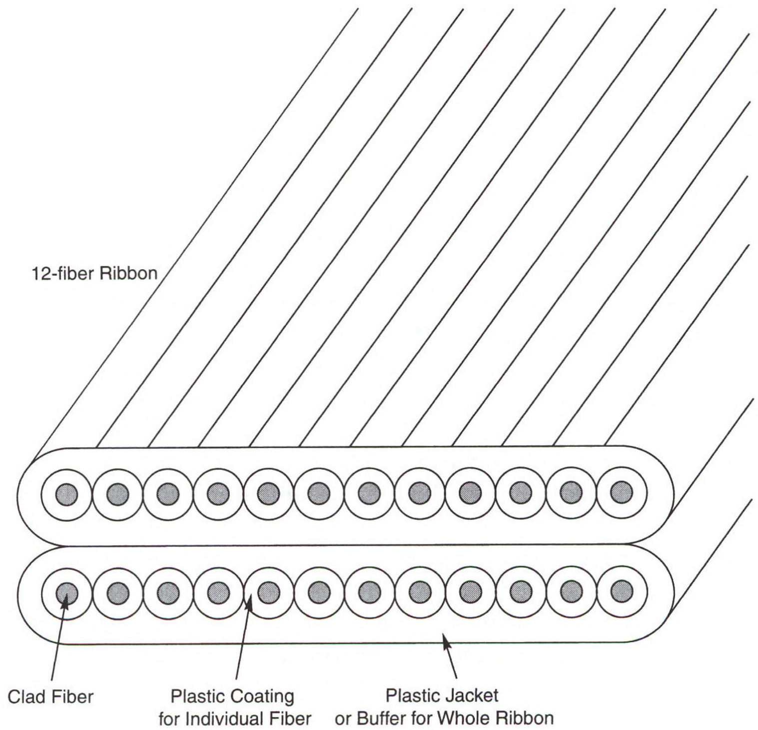
RIBBON CABLE

Many parallel fibers can be encased in plastic to form a ribbon around which cables can be built.

The arrangement of fibers in a ribbon cable shown in Figure 8.6 is in some ways a variation on the tightly buffered cable. Each ribbon is made by aligning several coated fibers parallel and touching each other, then coating them with a plastic buffer or jacket to form a single multifiber ribbon. While tightly buffered fibers are individual structures, the ribbon is a unit containing 4 to 36 fibers, which resembles the flat 4-wire cables used for household telephones. Figure 8.6 shows two 12-fiber ribbons stacked on top of each other; up to a dozen ribbons can be stacked to make an extremely dense block of fibers.

Ribbon cables can be used by themselves as the basis of a fiber cable, with a stack of ribbons at the core surrounded by a cable structure. Alternatively, one or more ribbons can be stacked inside loose tubes and assembled into a loose-tube fiber cable. Stacking ribbons can yield very high fiber counts, such as the 864-fiber cable shown in Figure 8.7, made by stacking a dozen 12-fiber ribbons inside each of six loose tubes.

FIGURE 8.6
Fibers in a ribbon cable.



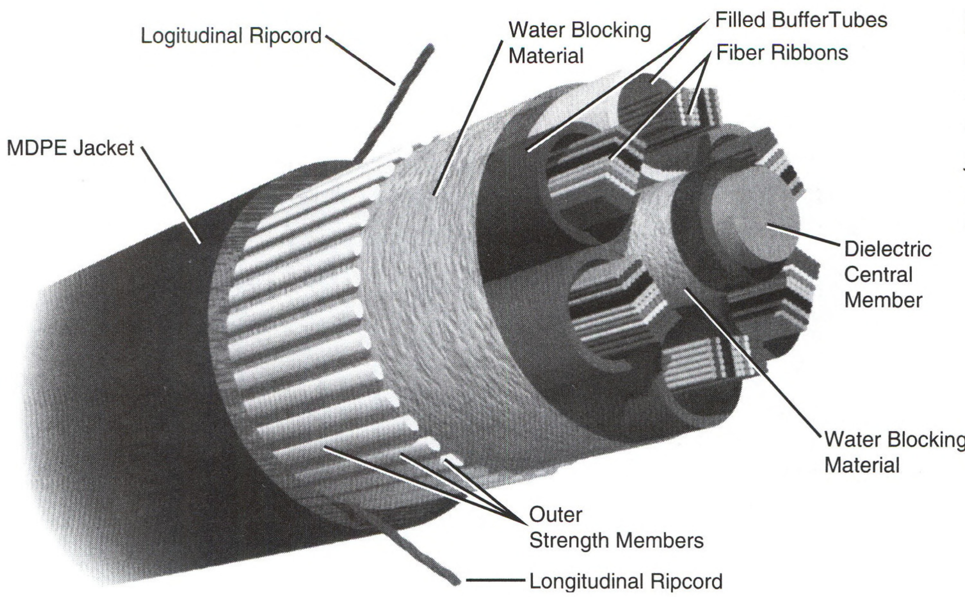


FIGURE 8.7
Stacking ribbons inside loose tubes can give very high fiber counts. (Courtesy of Pirelli Cable)

The simple structure makes a ribbon cable easy to splice in the field because each fiber is in a precisely predictable position. Multifiber connectors also can be installed easily on ribbon cables. The ribbons allow very dense packing of fibers, important for some applications. However, installation can cause uneven strain on different fibers in the ribbon, leading to unequal losses and other potential problems.

Fiber Arrangements in Cable

Fibers can be arranged in a cable in many different ways. The simplest cables are round with a single fiber at their center. *Duplex* (two-fiber) cables may either be circular or oval in cross section or be made like electrical zip cord, with two single-fiber structures bonded together along their length, as in Figure 8.1.

The more fibers in the cable, the more complex the structure. One common cable structure has six tightly buffered fibers wound loosely around a central member. The buffered fibers are wound so that they don't experience torsion in the cable. In loose-tube cables, the fiber count can be raised by putting multiple fibers in each tube. Groups of 8 or 12 fibers may also be wound around a central member.

Cables with more fibers are built up of modular structures. For example, a 36-fiber cable can be made from six loose-tube or tightly buffered subcables containing six fibers each, or from three 12-fiber ribbons. A dozen 12-fiber ribbons make a 144-fiber cable. Stacking together 18 loose-tube subcables, each containing a dozen fibers, makes the 216-fiber cable shown in Figure 8.8.

864-fiber cables are in use.

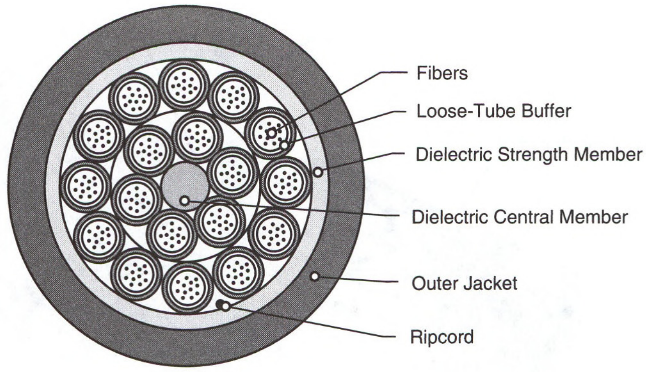


FIGURE 8.8
Modular cable containing 216 fibers, with 12 in each of 18 loose tubes. (Courtesy of Corning Cable Systems)

High fiber counts were rare in early installations, but they have become popular as fibers are used to distribute signals to more customers in large metropolitan areas. Cables with several hundred fibers are in use, and manufacturers now offer cables with up to 1,132 fibers.

Cabling Materials

Materials play an important role in cable properties.

The choice of materials plays a crucial role in determining characteristics of a cable. Designers usually face trade-offs among several factors. Fire safety is crucial for indoor cables, particularly those that run through air spaces, because some compounds used in outdoor cables produce toxins or catch fire easily. Moisture resistance and temperature tolerance are critical in most outdoor environments. Aerial cables must survive severe temperature extremes, sunlight, and wind loading; cable pulled through ducts must withstand surface abrasion as well as tension along its length. The major materials used in cabling are as follows:

- Polyethylene: Standard for outdoor cables because it resists moisture, it is stable over a wide temperature range, and resists abrasion. It does not meet indoor fire-safety rules, so only short runs are used indoors to reach service panels.
- Polyvinyl chloride (PVC): The most common material for indoor cables, it is available in different grades for various requirements. It is flexible, fire-retardant, and can be extruded easily during cabling, but it is not as durable or moisture-resistant as polyethylene.
- Polyvinyl difluoride (PVDF): A plastic used for plenum cables, it retards fire better than polyethylene and produces less smoke. It is less flexible and harder to extrude.
- Low smoke-no halogen (LSNH) plastics: Producing little smoke and very low levels of toxic halogen compounds, these materials are safest for cables used in enclosed spaces. These compounds have various names and may not be completely free of halogens (i.e., chlorine, fluorine, and bromine) because halogens reduce the flammability of plastics. These materials also

protect electronic equipment from corrosion and fire damage, but they are expensive and not as durable as PVC.

- High-strength dielectric compounds: Aramid yarn, known by the trade name Kevlar™, was used for dielectric strength members in cables until shortages developed recently. (Kevlar is used in military and police body armor.) Other compounds are now used.

Other Structural Elements

Fibers and their buffers are not the only structural elements of cables. Many—but not all—fiber-optic cables include other components to provide strength and rigidity.

Many cables contain central members to make them rigid and strength members to withstand tensile forces.

Many cables are built around central members made of steel, fiberglass, or other materials. These run along the center of the cable and provide the rigidity needed to keep it from buckling, as well as a core to build the cable structure around. A central member may be overcoated with plastic or other material to match cable size requirements and to prevent friction with other parts of the cable. Small indoor cables containing few fibers generally lack central members, but they are common in outdoor cables, and in indoor cables with high fiber counts.

The structure containing the fibers surrounds central members in cables that contain central members. Otherwise this structure is at the center of the cable. This structure also contains the supporting structures, such as tubes containing groups of fibers.

Strength members provide tensile strength along the length of cables that are subjected to tension during or after installation. A strength member may be at the core of the cable, or may be a layer between the cable jacket and the fibers, as shown in Figure 8.9. Some cables have both inner and outer strength members. Tension is applied directly to the strength member when a cable is pulled into a duct.

The outer jacket is a plastic layer that covers the cable structure, protecting the fibers from abrasion, moisture, and other damage. Its composition depends on the application.

Buried and underwater cables require armor.

Underwater and buried cables are among the types that require one or more layers of protecting armor. Typically for buried cables, steel is wound around an inner plastic sheath.

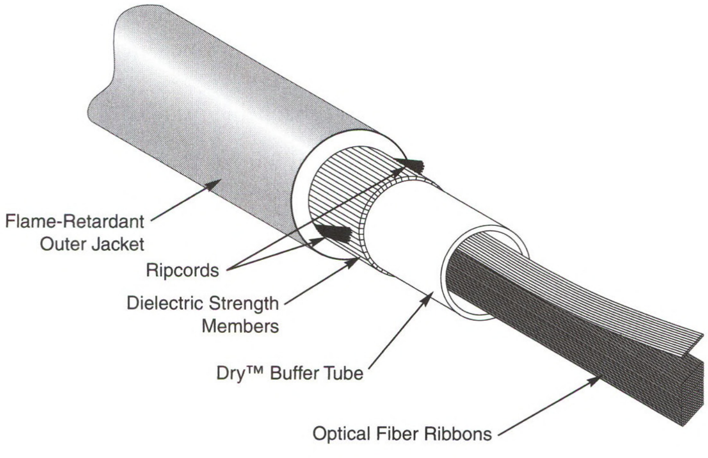


FIGURE 8.9
Strength members are wound around the buffer tube, which holds ribbon fibers in a plenum cable that does not have a central strength member. (Courtesy of Corning Cable Systems)

An outer plastic sheath is then applied over the armor to prevent corrosion. The metal armor helps protect against crushing damage, rocks, and rodents. Underwater cables in shallow waters may have multiple layers to protect against damage from shipping and fishing operations, as shown in Figure 8.4.

Blown-in Fibers

Fibers can be blown through microducts instead of installing normal cables.

Traditionally, cables are installed as finished units, containing both fibers and protective structures. An alternate approach is to install hollow microducts—typically about 5 mm in diameter—then to blow fibers through them. Forcing air through the microduct carries the fiber along with it, pulling all along its length so it doesn't damage the fiber.

The process uses conventional single- or multimode fibers coated with a blowable coating, designed to be dragged along by air forced through the microducts. The air can carry the coated fibers around bends, and over distances of more than 1000 feet (300 meters), usually within a building or between adjacent buildings.

The use of blown fibers is a two-stage process. The flexible microducts that carry the fibers must be installed first, then the fiber is blown through them. The major attraction is that the fibers need not be blown in at once, and that fibers can be replaced easily, like cables in underground ducts. Thus you could install the microducts when renovating a building, and blow in the fibers later, when you know transmission requirements. If a fiber was damaged, you could pull it out and blow in a replacement. With the proper equipment, fibers can be blown into place very quickly.

From a functional standpoint, blow-in fibers behave like loose-tube cables without a filler in the tubes. Materials used in the plastic tubes are chosen to meet the appropriate fire and electrical codes. While blown fibers are not widely used, the technology is available.

Cable Installation

Special techniques are used to install different types of cable.

Cable installation is a specialized task, and the detailed procedures are beyond the scope of this book. Most methods for installing optical cables have been adapted from those used for copper cables. Outdoor cables are laid along rights of way leased or owned by telecommunications carriers, such as along a railroad or highway, which are well marked after the cables are installed.

The basic approaches depend on the type of cable being installed.

- Submarine cables are laid from ships built for that purpose. Typically they are buried in a trench dug on the sea floor at depths of less than about 200 meters (600 feet), and laid directly on the ocean floor in deep ocean basins.
- Direct-buried cables normally are laid in a deep, narrow trench dug with a cable plow, which is then covered with dirt.
- Cable ducts are plastic tubes laid in trenches dug for the purpose, then covered over. Duct sizes and flexibility vary; some are only an inch or two and can be wound on large spools; others are a few inches in diameter and rigid. The ducts typically are directly covered by soil, but sometimes

may be encased in concrete to add structural integrity and prevent service disruptions. The ducts are installed without cables inside. Duct routes may be direct between endpoints, or may be routed through a series of underground access points at manholes.

- Cables can be installed in ducts by threading a pull line through the ducts, attaching it to the cable, then pulling the cable through with the pull line. If manholes or other access points are available along the route, cable runs are pulled between them.
- Cables can be blown into place along the length of a duct, just as fibers can be blown into a microduct. As with blown fibers, the air applies force along the length of the cable, minimizing the chance of damage. This technique is easy and has become very popular for outside plant.
- Self-supporting aerial cables may be suspended directly from overhead poles. Other aerial cables can be suspended from messenger wires, strong steel wires strung between poles. If a messenger wire is used, the cable is lashed to it with a special lashing wire running around both the cable and the messenger wire, or sometimes wound around it. This is a common installation for many overhead fiber cables because it minimizes strength requirements.
- Plenum cables are strung through interior air spaces.
- Interior cables may be installed within walls, through cable risers, or elsewhere in buildings. Installation is easiest in new construction. Only special cables designed for installation under carpets should be laid on the floor where people walk.
- Temporary light-duty cables are laid by people carrying mobile equipment that requires a broadband (typically video) connection to a fixed installation.

Cable Changes and Failure

Cabling can cause minor changes in fiber properties, particularly attenuation. The major reason for these changes is microbending, which depends on the fiber's local environment and on stresses applied to it. These stresses generally are negligible for cables in protected or stable environments, such as inside buildings or in buried duct. Aerial cables are subject to the most extreme variations, because they are exposed to conditions from summer sun to winter ice. Repeated heating and cooling can cause microbending because the glass fiber and the cable materials do not expand and contract with temperature at the same rate. Tightly buffered fibers generally are considered more vulnerable to microbending losses, but in well-made cables the differences are quite small.

Microbending can cause changes in fiber attentuation after cabling.

Telephone companies were very cautious before beginning their massive conversion to fiber-optic cables, conducting extensive tests and field trials to evaluate the reliability of fiber. Engineers were instinctively wary of glass, but many tests have shown that fiber cables are very durable under normal conditions. Although poor installation can damage fibers, fibers or cables rarely fail in properly installed systems unless physical damage occurs.

Most cable failures are due to physical damage.

Gophers and other burrowing rodents are natural enemies of all buried cables. Their front teeth grow continually, and they instinctively gnaw on anything they can get their incisors around, including cables. Gophers are a serious problem in some areas in the United States, and cables buried in those areas should be armored and otherwise designed to deter gopher attack. The U.S. Fish and Wildlife Service even developed a standardized "gopher test" in which a cable was run through a gopher cage and left in place for seven days to test its resistance to the gnawing rodent. Cables buried in some areas must meet these rodent-proof standards. (Cables containing obsolete fibers are sometimes called "gopher bait" because they are of little use for telecommunications.)

Human activity is responsible for most other damage to buried cables. The archetypical example is a backhoe digging up and breaking a buried cable, an event industry veterans call "backhoe fade." Construction damage by careless contractors is a serious problem but the subject of some jokes. One telecommunications company runs its long-distance cables alongside natural-gas pipelines, where it posts warnings, which one top manager summarized as "you dig, you die."

Aerial cables are vulnerable to many other types of damage, from errant cranes to falling branches and heavy loading with ice and snow. All kinds of cables can be—and are—cut by mistake by maintenance crews. Light-duty indoor cables can be damaged by closing doors or windows on them; the fibers can be broken without causing obvious damage to the outside of the cable. Tripping over a cable is not likely to break the cable, but it could snap the fibers inside, or jerk the cable out of a connector at one end. (In general, connectors are the weakest points of short cables.)

Fibers do not always break at the exact point where the cable is damaged. When stressed along their lengths, fibers tend to break at weak points, which may be a short distance away from the obvious damage to the cable. The break points can differ among fibers in a multifiber cable, so you might have to go a ways from the break before you find the ends of all fibers. As with copper cables, physical damage to the cable does not invariably sever fibers.

What Have You Learned?

1. Fibers can break at inherent flaws and develop microcracks under tension, so they must be protected from stretching forces.
2. Cabling packages fibers for protection and easier handling.
3. Cables must resist crushing as well as isolate the fiber from tension along its length.
4. Cables protect fibers from heat, cold, and moisture. The designs chosen vary widely, depending on environmental conditions.
5. Indoor cables must meet fire and electrical safety codes. The major impact of these codes is on composition of the plastics used in the cable structure.
6. Cables can carry from one over 1000 fibers.
7. Important structural elements in a cable are the housing for the fiber, strength members, jacketing, and armor. Armor is used only in certain environments where physical damage is a threat.

8. Outdoor cables may be hung from poles, pulled or blown through ducts, or buried directly in the ground.
9. Fibers can be enclosed in a loose tube, a tight plastic buffer, or a ribbon.
10. The physical arrangement of fibers in the cable depends on the number of fibers and how they are to be distributed in the installation.
11. Much cable damage occurs when a sudden force is applied, such as when a backhoe digs up a buried cable.

What's Next?

In Chapter 9, we will examine the light sources used with fiber-optic cables.

Further Reading

Bob Chomycz, *Fiber Optic Installer's Field Manual* (McGraw-Hill, 2000)

Jim Hayes, *Fiber Optics Technician's Manual* (Delmar, 1996)

Questions to Think About

1. The design of fiber-optic cables evolved from the design of electrical cables for similar applications. What is one common problem with aging electrical cables that does not affect fiber-optic cables?
2. What is one problem with fiber-optic cables *not* present with electronic cables?
3. Why make one cable with 1000 fibers rather than 10 with 100 fibers?
4. A cable weighs 300 kilograms per kilometer, with poles placed 50 meters apart on the road. A flock of twenty 0.5-kilogram crows perch on the cable to watch the scenery. By what percentage do they increase the weight of the cable span?
5. An ice storm coats the cable with a 1-cm layer of ice. Assume for simplicity that the cable is 2 cm in diameter, and that ice weighs 1 gram/cubic centimeter. How much weight does the ice add to a 50-meter span of the cable?
6. What is the main difference between the structures of indoor and outdoor cables?

Chapter Quiz

1. What part of a cable normally bears stress along its length?
   a. the fiber
   b. the plastic coating of the fiber

c. a strength member
d. metallic armor
e. all of the above

2. Cables cannot protect fibers effectively against
a. gnawing rodents.
b. stresses during cable installation.
c. careless excavation.
d. static stresses.
e. crushing.

3. Light-duty cables are intended for use
a. within office buildings.
b. in underground ducts.
c. deep underground where safe from contractors.
d. on aerial poles where temperatures are not extreme.

4. The special advantages of plenum cables are what?
a. They are small enough to fit in air ducts.
b. They meet stringent fire codes for running through air spaces.
c. They are crush resistant and can run under carpets.
d. They have special armor to keep rodents from damaging them.

5. Outdoor cables are *not* used in which of the following situations?
a. suspended overhead between telephone poles
b. tied to a separate messenger wire suspended between overhead poles
c. inside air space in office buildings
d. pulled through underground ducts

6. A loose-tube cable is
a. a cable in which fibers are housed in hollow tubes in the cable structure.
b. a cable for installation in hollow tubes (ducts) underground.
c. cable for installation in indoor air ducts.
d. used underwater.
e. none of the above

7. Which of the following are usually present in direct-burial cables but *not* in aerial cables?
a. strength members
b. outer jacket
c. armor
d. fiber housing

8. In what type of cable installation can the cable be blown into place?

a. direct burial

b. underground duct

c. military field systems

d. submarine cable

9. The main cause of differences in properties of a fiber before and after cabling is

a. microbending.

b. temperature within the cable.

c. application of forces to the fiber.

d. damage during cabling..

10. The most likely cause of failure of cabled fiber is

a. hydrogen-induced increases in attenuation.

b. corrosion of the fiber by moisture trapped within the cable.

c. severe microbending losses.

d. physical damage to the cable.