Lennie Lightwave's
Guide To Fiber Optics

Contents

Lennie Supports The Educational Efforts of [The Widernet Project](#) From The University of Iowa

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The Fiber Optic Association, Inc. FOA www.foa.org

Who's Lennie?
Lennie Lightwave has been involved in fiber optics since he first went to "Fiber U" - the Fotec fiber optic installer conference way back in 1993. Lennie is now working with The Fiber Optic Association (FOA), the international professional society of fiber optics, to help train today's new fiber optic technicians.

Lennie's Guide is the result of more than 30 years of experience in fiber optics from Lennie and his friends, including training tens of thousands of techs to help them get started in fiber optics. It's intended to be a place to start, a basic guide that will teach you the jargon and basics of fiber technology and practices.

When you are finished with Lennie's Guide, you might want to get one of the FOA textbooks, *The FOA Reference Guide to Fiber Optics, The FOA Reference Guide to Outside Plant Fiber Optics, FOA Reference Guide to Premises Cabling* or the *FOA Reference Guide To Fiber Optic Network Design.*

What Do People Say About "Lennie"?
"I am a 30 year veteran of the "Bell System" with many years of experience with design of OSP Systems and also had 15 years as a product Rep. for AT&T/Lucent with responsibility of representing their fiber cable and apparatus products in the Northwest. In all those years I have not seen a better guide that takes the basics of fiber optics and puts it into an easily understandable format ..... that includes the "famous Bell Labs" fiber guru's." DS

What is fiber optics?

Picture sending signals zipping along from one location to another in the form of light guided through thin fibers of glass or plastic. These signals can be analog or digital - voice, data or video information and fiber can transport more information longer distances in less time than any copper wire.
It's powerful and fast, fast, fast!

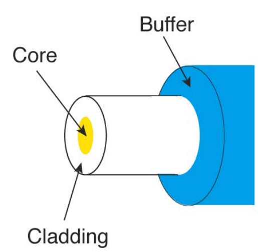
Jargon

First get to know the language - the "jargon" - here's a list of terms you should get to know:

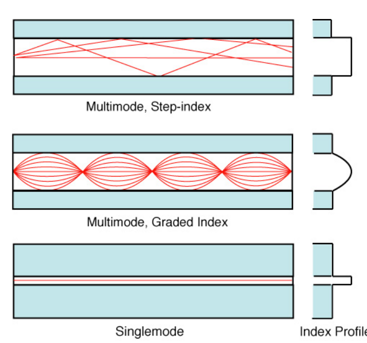
Metric System: Fiber Optics, as a international technology, utilizes the metric system as the standard form of measurement.
Several of the more common terms:
Meter: 39.37 inches.
Kilometer: 1000 meters / 3,281 feet / 0.62 miles.
Micron: 1/1,000,000th of a meter. 25 microns equal 0.001 inch. This is the common term of measurement for fibers.
Nanometer: One billionth of one meter. This term is commonly used in the fiber optics industry to express wavelength (or color) of transmitted light.

Let's Start With Fiber

Optical Fiber: Thin strands of highly transparent glass or sometimes plastic that guide light.
Core: The center of the fiber where the light is transmitted.
Cladding: The outside optical layer of the fiber that traps the light in the core and guides it along - even through curves.



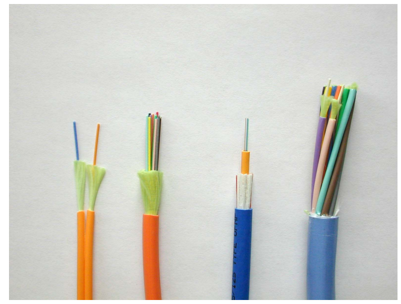
Buffer coating or primary coating: A hard plastic coating on the outside of the fiber that protects the glass from moisture or physical damage.
Mode: A single electromagnetic field pattern (think of a ray of light) that travels in fiber.
Multimode fiber: has a bigger core (almost always 62.5 microns - a micron is one one millionth of a meter - but sometimes 50 microns) and is used with LED sources at wavelengths of 850 and 1300 nm for short distance, lower speed networks like LANs.
Singlemode fiber: has a much smaller core, only about 9 microns, and is used for telephony and CATV with laser sources at 1300 and 1550 nm. It can go very long distances at very high speeds.



Both multimode and singlemode fiber have an outside diameter of 125 microns - about 5 thousandths of an inch - just slightly larger than a human hair.

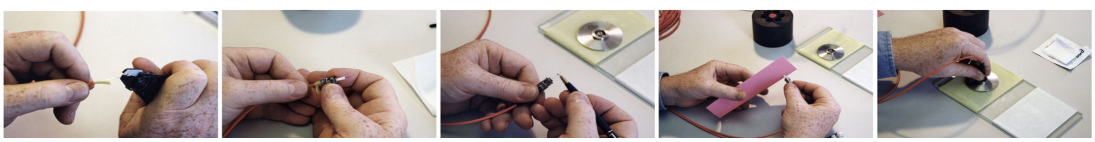
Plastic optical fiber (POF): is a large core (about 1mm) multimode fiber that can be used for short, low speed networks. POF is used in consumer HiFi and a new for car communication systems called MOST.

Terms that describe fiber optic cable:



Cable: Fiber needs protection to survive all the places it gets installed and it's the cable that provides it. Cables may have from one to hundreds of fibers inside.
Jacket: The tough outer covering on the cable. Cables installed inside buildings must meet fire codes by using special jacketing materials.
Strength members: Aramid fibers (Kevlar is the duPont trade name) used to pull the cable. The term is also used for the fiberglass rod in some cables used to stiffen it to prevent kinking.
Armor: A metallic lay on the cable that discourages rodents from chewing through it.

Termination:
Connector: A non-permanent device for connecting two fibers or fibers to equipment where they are expected to be disconnected occasionally for testing or rerouting. It also provides protection to both fibers. (Parts for an ST connector are shown.)



Splice: a permanent joint between two fibers
Mechanical Splice: A splice where the fibers are aligned created by mechanical means
Fusion Splice: A splice created by welding or fusing two fibers together
Fusion Splicer: An instrument that splices fibers by fusing or welding them, typically by electrical arc.
Hardware: Terminations and Splices require hardware for protection and management: patch panels, splice closures, etc.

Fiber Performance Specifications
Terms you use when you want to take your measurements:
Attenuation: The reduction in optical power as it passes along a fiber, usually expressed in decibels (dB). See optical loss
Bandwidth: The range of signal frequencies or bit rate within which a fiber optic component, link or network will operate.
Decibels (dB): A unit of measurement of optical power which indicates relative power. A -10 dB means a reduction in power by 10 times, -20 dB means another

10 times or 100 times overall, -30 means another 10 times or 1000 times overall and so on.
dB: Optical power referenced an arbitrary zero level
dBm: Optical power referenced to 1 milliwatt
Micron (μm): A unit of measure used to measure wavelength of light.
Nanometer (nm): A unit of measure used to measure the wavelength of light (meaning one one-billilonth of a meter)
Optical Loss: The amount of optical power lost as light is transmitted through fiber, splices, couplers, etc, expressed in dB.
Optical Power: is measured in "dBm", or decibels referenced to one miliwatt of power. while loss is a relative reading, optical power is an absolute measurement, referenced to standards. You measure absolute power to test transmitters or receivers and relative power to test loss.
Scattering: The change of direction of light after striking small particles that causes loss in optical fibers and is used to make measurements by an OTDR
Wavelength: A term for the color of light, usually expressed in nanometers (nm) or microns (m). Fiber is mostly used in the infrared region where the light is invisible to the human eye.

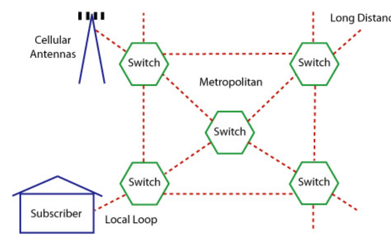
Terms that describe the tools you will need for installation and termination:
Jacket Slitter or Stripper: A cutter for removing the heavy outside jacket of cables

Fiber Stripper: A precise stripper used to remove the buffer coating of the fiber itself for termination. There at three types in common use, called by their trade names: "Miller Stripper", "No-Nik" and "Micro Strip."
Cleaver: A tool that precisely "breaks" the fiber to produce a flat end for polishing or splicing.
Scribe: A hard, sharp tool that scratches the fiber to allow cleaving.
Polishing Puck: for connectors that require polishing, the puck holds the connector in proper alignment to the polishing film.
Polishing Film: Fine grit film used to polish the end of the connector ferrule.
Crimper: A tool that crimps the connector to the aramid fibers in the cable to add mechanical strength.

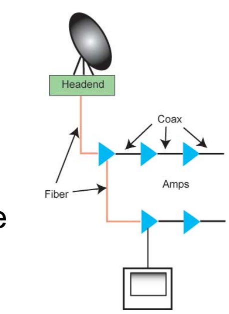
Terms that describe test equipment you will need:
Optical Power Meter: An instrument that measures optical power from the end of a fiber
Test Source: an instrument that uses a laser or LED to send an optical signal into fiber for testing loss of the fiber
Optical Loss Test Set (OLTS): A measurement instrument for optical loss that includes both a meter and source

Reference Test Cables: short, single fiber cables with connectors on both ends, used to test unknown cables.
Mating Adapter: also called splice bushing or coupler, allows two cables with connectors to mate.
Fiber Tracer: An instrument that allows visual checking of continuity and tracing for correct connections
Visual Fault Locator: A device that allows visual tracing and testing of continuity.
Microscope: used to inspect the end surface of a connector for flaws or dirt.
OTDR: An instrument that uses backscattered light to find faults in optical fiber and infer loss from only one end of the cable.

Fiber Optic Networks



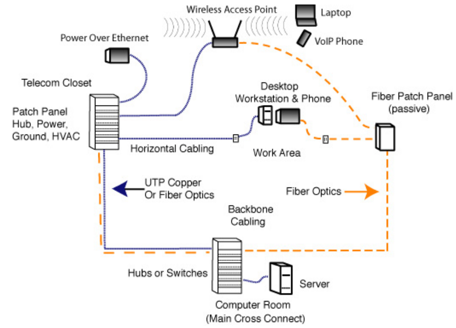
In the telcos, singlemode fiber is used to connect long distance switches, central offices and SLCs (subscriber loop carriers, small switches in pedestals in subdivisions or office parks or in the basement of a larger building). Practically every telco's network is now fiber optics except the connection to the home, and many are actively installing fiber to the home. Fiber to the home (FTTH) is now cost effective - especially since most homes want the high speed services that would justify fiber optics.



CATV companies "overbuild" with fiber. They lash fiber cable onto the aerial "hardline" coax used for the rest of the network or pull it in the same conduit underground. The fiber allows them to break their network into smaller service areas that prevent large numbers of customers from being affected in an outage, making for better service and customer relations. The fiber also gives them a return path which they use for Internet and telephone connections, increasing their revenue potential. CATV companies have their own FTTH called RFOG.

LANs (local area networks) use fiber optics primarily in the backbone but increasingly to the desk. The LAN backbone often needs longer distance than copper cable (Cat 5/5e/6) can provide and of course, the fiber offers higher bandwidth for future expansion. Most large corporate LANs use fiber backbones with copper wire to the desktop and lots of wireless access points connected on fiber or copper. Fiber to the desk can be cost effective if properly designed, with new systems being used based on FTTH components.

Lots of other networks use fiber. CCTV is often on fiber for its distance capability. Industrial plants use lots of fiber or distance and noise immunity. Utilities use it for network management, liking its immunity to noise also. The military uses it because it's hard to tap or jam. Airplanes use it for that reason too, but also like the lighter weight of fiber.



Designing Cable Networks

This is too big a topic for a overview! But we'll pass along some hints to make life easier. Better to see the FOA online reference guide or Fiber U for more links to design information.

First and foremost, visit the work site and check it out thoroughly. Know the "standards" but use common sense in designing the installation. Don't cut corners that may affect performance or reliability. Consider what are the possible problems and work around or prevent them. There is no substitute for common sense here!

Fiber's extra distance capability makes it possible to do things not possible with copper wire. For example, you can install all the electronics for a network in one communications closet for a building and run straight to the desktop with fiber. With copper, you can only go about 90 meters + patchcords (less than 300 feet), so you need to keep the electronics close to the desk. With fiber, you only need passive patch panels locally to allow for moves. Upgrades are easy, since the fiber is only loafing at today's network speed!

Is Copper Really Cheaper Than Fiber?

When it comes to costs, fiber optics is always assumed to be much more expensive than copper cabling. Whatever you look at - cable, terminations or networking electronics - fiber costs more, although as copper gets faster (e.g. Cat 6A) it gets more expensive, almost as much as fiber. So isn't it obvious that fiber networks are more expensive than copper? Maybe not! There is more to consider in making the decision. FTTH architecture is being adapted into the LAN and proving cheaper for many applicaitions.

Why Use Fiber?

If fiber is more expensive, why have all the telephone long distance and metropolitan networks been converted to fiber - and they are now starting on fiber to the home? And why are all the CATV systems converting to fiber too? Are their networks that different? Is there something they know we don't?

Telcos use fiber to connect all their central offices and long distance switches because it has thousands of times the bandwidth of copper wire and can carry signals hundreds of times further before needing a repeater – making fiber cost ~ 1-5% as much as copper or wireless. FTTH allows offering new services that require more bandwidth than copper wires and reduces maintenance. The CATV companies use fiber because it give them greater reliability and the opportunity to

offer new services, like phone service and Internet connections.
Both telcos and CATV operators use fiber for economic reasons, but their cost justification requires adopting new network architectures to take advantage of fiber's strengths. A properly designed premises cabling network can also be less expensive when done in fiber instead of copper. There are several good examples of fiber being less expensive, so lets examine them.

Industrial Networks
In an industrial environment, electromagnetic interference (EMI) is often a big problem. Motors, relays, welders and other industrial equipment generate a tremendous amount of electrical noise that can cause major problems with copper cabling, especially unshielded cable like Cat 5. In order to run copper cable in an industrial environment, it is often necessary to pull it through conduit to provide adequate shielding.
With fiber optics, you have complete immunity to EMI. You only need to choose a cable type that is rugged enough for the installation, with breakout cable being a good choice for it's heavy-duty construction. The fiber optic cable can be installed easily from point to point, passing right next to major sources of EMI with no effect. Conversion from copper networks is easy with media converters, gadgets that convert most types of systems to fiber optics. Even with the cost of the media converters, the fiber optic network will be less than copper run in conduit.

Long Cable Runs
Most networks are designed around structured cabling installed per EIA/TIA 568 standards. This standard calls for 90 meters (295 feet) of permanently installed unshielded twisted pair (UTP) cable and 10 meters (33 feet) of patchcords. But suppose you need to connect two buildings or more? The distance often exceeds the 90 meters by the time you include the runs between the buildings plus what you need inside each building.
By the time you buy special aerial or underground waterproof copper cable and repeaters, you will usually spend more than if you bought some outside plant fiber optic cable and a couple of inexpensive media converters. It's guaranteed cheaper if you go more than two links (180 meters.)

Centralized Fiber LANs
When most contractors and end users look at fiber optics versus Cat 5e cabling for a LAN, they compare the same old copper LAN with fiber directly replacing the copper links. The fiber optic cable is a bit more expensive than copper and terminations are a little more too, but the big difference is the electronics which are $200 or more per link extra for fiber.
However, the real advantage of fiber comes if you use a centralized fiber optic network - shown on the right of the diagram above. Since fiber does not have the 90 meter distance limitation of UTP cable, you can place all electronics in one location in or near the computer room. The telecom closet is only used for passive connection of backbone fiber optic cables, so no power, UPS, ground or air conditioning is needed. These auxiliary services, necessary with Cat 5 hubs,

cost a tremendous amount of money in each closet.
In addition, having all the fiber optic hubs in one location means better utilization of the hardware, with fewer unused ports. Since ports in modular hubs must be added in modules of 8 or 16, it's not uncommon with a hub in a telecom closet to have many of the ports in a module empty . With a centralized fiber system, you can add modules more efficiently as you are supporting many more desktop locations but need never have more than a one module with open ports.

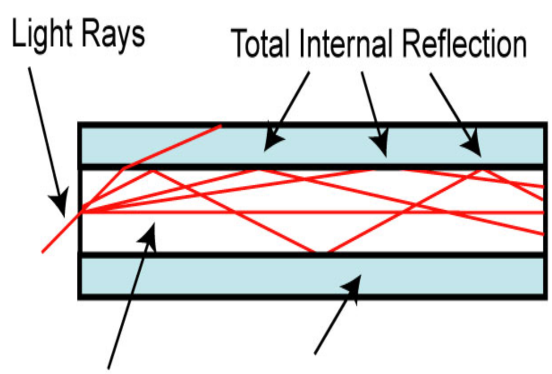
High Speed Networking
It was more than a year after 10 Gigabit Ethernet (GbE) became available on fiber optics that it finally become available on copper and then it took 5 times as much power to run. In order to get high speeds to work over copper, the electronics must be very complicated, and consequently as expensive as fiber.

Bottom Line
So when it comes to costs, looking at the cabling component costs may not be a good way to analyze total network costs. Consider the total system and you may find fiber looks a lot more attractive.

Optical Fiber

The usual fiber specifications you will see are size, attenuation and bandwidth. While manufacturers have other specs that concern them, like numerical aperture (the acceptance angle of light into the fiber), ovality (how round the fiber is), concentricity of the core and cladding, etc., these specs do not affect you.

Fiber Itself
Fiber Optics, as we said, is sending signals down hair-thin strands of glass or plastic fiber. The light is "guided" down the center of the fiber called the "core". The core is surrounded by a optical material called the "cladding" that traps the light in the core using an optical technique called "total internal reflection." The core and cladding are usually made of ultra-pure glass, although some fibers are all plastic or a glass core and plastic cladding. The fiber is coated with a protective plastic covering called the "primary buffer coating" that protects it from moisture and other damage. More protection for all the fibers is provided by the "cable" which has the fibers and strength members inside an outer covering called a "jacket".

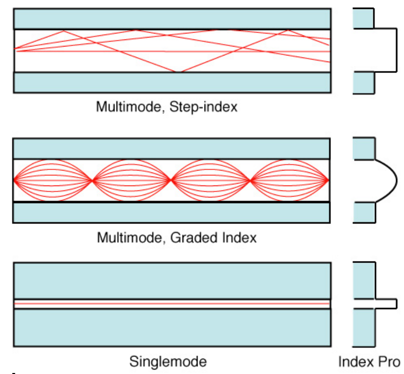


Multimode & Singlemode Fibers
Multimode & Singlemode fiber are the two types of fiber in common use. Both fibers are 125 microns in outside diameter - a micron is one one-millionth of a meter and 125 microns is 0.005 inches- a bit larger than the typical human hair.

Multimode fiber has light traveling in the core in many rays, called modes. It has a bigger core (almost always 62.5 microns, but sometimes 50 microns) and is used with LED sources at wavelengths of 850 and 1300 nm (see below!) for slower local area networks (LANs) and lasers at 850 and 1310 nm for networks running at gigabits per second or more.

Singlemode fiber has a much smaller core, only about 9 microns, so that the light travels in only one ray. It is used for telephony and CATV with laser sources at 1300 and 1550 nm.

Plastic Optical Fiber (POF) is large core (about 1mm) fiber that can only be used for short, low speed networks.



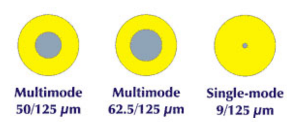
Step index multimode was the first fiber design but is too slow for most uses, due to the dispersion caused by the different path lengths of the various modes. Step index fiber is rare - only POF uses a step index design today.

Graded index multimode fiber uses variations in the composition of the glass in the core to compensate for the different path lengths of the modes. It offers hundreds of times more bandwidth than step index fiber - up to about 2 gigahertz.

Singlemode fiber shrinks the core down so small that the light can only travel in one ray. This increases the bandwidth to almost infinity - but it's practically limited to about 100,000 gigahertz - that's still a lot!

Size Matters

Fiber, as we said, comes in two types, singlemode and multimode. Except for fibers used in specialty applications, singlemode fiber can be considered as one size and type. If you deal with long haul telecom customers, you may have to work with manufacturers on specialty singlemode fibers.



Multimode fibers originally came in several sizes, optimized for various networks and sources, but the data industry standardized on 62.5 core fiber in the mid-80s (62.5/125 fiber has a 62.5 micron core and a 125 micron cladding.) After the introduction of gigabit and 10 gigabit networks, an old fiber has been revived. The 50/125 fiber was used from the late 70s with lasers for telecom applications before singlemode fiber became available again, re-engineered for high bandwidth use with 850 nm VCSEL sources. It offers higher bandwidth with the laser sources used in the gigabit LANs and can go longer distances.

CAUTION:

You cannot mix and match fibers! Trying to connect singlemode to multimode fiber can cause 20 dB loss - that's 99% of the power. Even connections between 62.5/125 and 50/125 can cause loss of 3 dB or more - over half the power.

Fiber Types and Typical Specifications			
Core/Cladding	**Attenuation**	**Bandwidth**	**Applications/Notes**
Multimode Graded-Index			
(microns)	@850/1300 nm	@850/1300 nm	
62.5/125 OM1	3/1 dB/km	160/500 MHz-km	Once most common LAN fiber
50/125 OM2	3/1 dB/km	500/500 MHz-km	Laser-rated for GbE LANs
50/125 OM3	3/1 dB/km	2000/500 MHz-km	Optimized for 850 nm VCSELs
50/125 OM4	3/1 dB/km	3500/500 MHz-km	Optimized for 850 nm VCSELs
100/140	3/1 dB/km	150/300 MHz-km	Obsolete
Singlemode			
	@1310/1550 nm		
8-9/125	0.4/0.25 dB/km	HIGH! ~100 Terahertz	Telco/CATV/long high speed LANs
Multimode Step-Index			
	@850 nm	@850 nm	
200/240	4-6 dB/km	50 MHz-km	Slow LANs & links
POF (plastic optical fiber)			
	@ 650 nm	@ 650 nm	
1 mm	~ 1 dB/m	~5 MHz-km	Short Links & Cars

Fiber Optic Cables

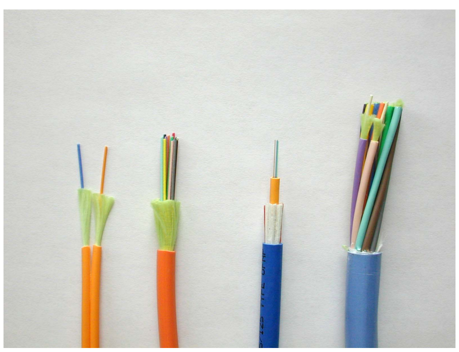
Fiber optic "cable" refers to the complete assembly of fibers, strength members and jacket. Fiber optic cables come in lots of different types, depending on the number of fibers and how and where it will be installed. Choose cable carefully as the choice will affect how easy it is to install, splice or terminate and, most important, what it will cost!

Choosing a cable - what hazards will it face?

Cable's job is to protect the fibers from the hazards encountered in an installation. Will the cables be exposed to chemicals or have to withstand a wide temperature range? What about being gnawed on by a woodchuck or prairie dog? Inside buildings, cables don't have to be so strong to protect the fibers, but they have to meet all fire code provisions. Outside the building, it depends on whether the cable is buried directly, pulled in conduit, strung aerially or whatever. Your best bet is to contact a few cable manufacturers (two minimum, three preferred) and give them the specs. They will want to know where the cable is going, how many fibers you need and what kind (singlemode or multimode or both in what we call "hybrid" cables.) You can also have a "composite" cable that includes copper conductors for signals or power. The cable companies will evaluate your requirements and make suggestions. Then you can get competitive bids.

Since the plan will call for a certain number of fibers, consider adding spare fibers to the cable - fibers are cheap! That way, you won't be in trouble if you break a fiber or two when splicing, breaking-out or terminating fibers. And request the end user consider their future expansion needs. Most users install lots more fibers than needed, especially adding singlemode fiber to multimode fiber cables for campus or backbone applications.

Cable Types



Cables (L>R): Zipcord, Distribution, Loose Tube, Breakout

Simplex and zip cord: Simplex cables are one fiber, tight-buffered (coated with a 900 micron buffer over the primary buffer coating) with Kevlar (aramid fiber) strength members and jacketed for indoor use. The jacket is usually 3mm (1/8 in.) diameter. Zipcord is simply two of these joined with a thin web. It's used mostly for patch cord and backplane applications, but zipcord can also be used for desktop connections.

Distribution cables: They contain several tight-buffered fibers bundled under the same jacket with Kevlar strength members and sometimes fiberglass rod reinforcement to stiffen the cable and prevent kinking. These cables are small in size, and used for short, dry conduit runs, riser and plenum applications. The fibers are double buffered and can be directly terminated, but because their fibers are not individually reinforced, these cables need to be broken out with a "breakout box" or terminated inside a patch panel or junction box.

Breakout cables: They are made of several simplex cables bundled together. This is a strong, rugged design, but is larger and more expensive than the distribution cables. It is suitable for conduit runs, riser and plenum applications. Because each fiber is individually reinforced, this design allows for quick termination to connectors and does not require patch panels or boxes. Breakout cable can be more economic where fiber count isn't too large and distances too long, because is requires so much less labor to terminate.

Loose tube cables: These cables are composed of several fibers together inside a small plastic tube, which are in turn wound around a central strength member and jacketed, providing a small, high fiber count cable. This type of cable is ideal for outside plant trunking applications, as it can be made with the loose tubes filled with gel or water absorbent powder to prevent harm to the fibers from water. It can be used in conduits, strung overhead or buried directly into the ground. Since the fibers have only a thin buffer coating, they must be carefully handled and protected to prevent damage.

Ribbon Cable: This cable offers the highest packing density, since all the fibers are laid out in rows, typically of 12 fibers, and laid on top of each other. This way 144 fibers only has a cross section of about 1/4 inch or 6 mm! Some cable designs use a "slotted core" with up to 6 of these 144 fiber ribbon assemblies for 864 fibers in one cable! Since it's outside plant cable, it's gel-filled for water blocking.

Armored Cable: Cable installed by direct burial in areas where rodents are a problem usually have metal armoring between two jackets to prevent rodent penetration. This means the cable is conductive, so it must be grounded properly.

Aerial cable: Aerial cables are for outside installation on poles. They can be lashed to a messenger or another cable (common in CATV) or have metal or aramid strength members to make them self supporting.

Even More Types Are Available: Every manufacturer has it's own favorites, so it's a good idea to get literature from as many cable makers as possible. And check out the little guys; often they can save you a bundle by making special cable just for you, even in relative small quantities.

Cable Design Criteria

Pulling Strength: Some cable is simply laid into cable trays or ditches, so pull strength is not too important. But other cable may be pulled thorough 2 km or more of conduit. Even with lots of cable lubricant, pulling tension can be high. Most cables get their strength from an aramid fiber (Kevlar is the duPont trade name), a unique polymer fiber that is very strong but does not stretch - so pulling on it will not stress the other components in the cable. The simplest simplex cable has a pull strength of 100-200 pounds, while outside plant cable may have a specification of over 800 pounds.

Water Protection: Outdoors, every cable must be protected from water or moisture. It starts with a moisture resistant jacket, usually PE (polyethylene), and a filling of water-blocking material. The usual way is to flood the cable with a water-blocking gel. It's effective but messy - requiring a gel remover (use the commercial stuff - it's best- -but bottled lemon juice works in a pinch!). A newer

alternative is dry water blocking using a miracle powder - the stuff developed to absorb moisture in disposable diapers. Check with your cable supplier to see if they offer it.
Fire Code Ratings: Every cable installed indoors must meet fire codes. That means the jacket must be rated for fire resistance, with ratings for general use, riser (a vertical cable feeds flames more than horizontal) and plenum (for installation in air-handling areas. Most indoor cables us PVC (polyvinyl chloride) jacketing for fire retardance. All premises cables must carry identification and flammability ratings per the NEC (National Electrical Code) paragraph 770.

NEC Rating	Application
OFNG or OFCG	general purpose
OFNR or OFCR	riser rated cable for vertical runs
OFNP or OFCP	plenum rated cables for use in air-handling plenums
OFN-LS	low smoke density

Cables without markings should never be installed indoors as they will not pass inspections! Outdoor cables are not fire-rated and can only be used up to 50 feet indoors. If you need to bring an outdoor cable indoors, consider a double-jacketed cable with PE jacket over a PVC UL-rated indoor jacket. Simply remove the outdoor jacket when you come indoors and you will not have to terminate at the entry point.

Choosing A Cable
With so much choice in cables, it is hard to find the right one. The table below summarizes the choices, applications and advantages of each.

Cable Type	Application	Advantages
Tight Buffer Simplex & Zipcord	Premises	Makes rugged patchcords
Distribution	Premises	Small size for lots of fibers, inexpensive
Breakout	Premises	Rugged, easy to terminate, no hardware needed
Loose Tube	Outside Plant	Rugged, gel or dry water-blocking
Armored	Outside Plant	Prevents rodent damage
Ribbon	Outside Plant	Highest fiber count for small size

Installing Fiber Optic Cable

Installation methods for both wire cables and optical fiber cables are similar. Fiber cable can be pulled with much greater force than copper wire if you pull it correctly. Just remember these rules:

- Do not pull on the fibers, pull on the strength members only! The cable manufacturer gives you the perfect solution to pulling the cables, they install special strength members, usually duPont Kevlar® aramid yarn or a fiberglass rod to pull on. Use it! Any other method may put stress on the fibers and harm them. Most cables cannot be pulled by the jacket. Do not pull on the jacket unless it is specifically approved by the cable manufacturers and you use an approved cable grip.
- Do not exceed the maximum pulling load rating. On long runs, use proper lubricants and make sure they are compatible with the cable jacket. On really long runs, pull from the middle out to both ends. If possible, use an automated puller with tension control or at least a breakaway pulling eye.
- Do not exceed the cable bend radius. Fiber is stronger than steel when you pull it straight, but it breaks easily when bent too tightly. These will harm the fibers, maybe immediately, maybe not for a few years, but you will harm them and the cable must be removed and thrown away!
- Do not twist the cable. Putting a twist in the cable can stress the fibers too. Always roll the cable off the spool instead of spinning it off the spool end. This will put a twist in the cable for every turn on the spool! If you are laying cable out for a long pull, use a "figure 8" on the ground to prevent twisting (the figure 8 puts a half twist in on one side of the 8 and takes it out on the other, preventing twists.) And always use a swivel pulling eye because pulling tension will cause twisting forces on the cable.
- Check the length. Make sure the cable is long enough for the run. It's not easy or cheap to splice fiber and it needs special protection. Try to make it in one pull, possible up to about 2-3 miles.

Conduit and Innerduct: Outside plant cables are either installed in conduit or innerduct or direct buried, depending on the cable type. Building cables can be installed directly, but you might consider putting them inside plenum-rated innerduct. This innerduct is bright orange and will provide a good way to identify fiber optic cable and protect it from damage, generally a result of someone cutting it by mistake! The innerduct can speed installation and maybe even cut costs. It can be installed quickly by unskilled labor, then the fiber cable can be pulled through in seconds. You can even get the innerduct with pulling tape already installed.

Cable Plant Hardware - fitting the pieces of the puzzle together!

These various enclosures, cabinets, racks and panels are used to protect and organize splice and termination points. The network designer should know the type of network, support systems, the routes to be taken. Then the connection/splice locations can be determined and the hardware planned.
There are lots of rules to follow, of course (the EIA/TIA 569 has something to say about all this).
Here are some examples of fiber optic hardware:
Breakout kits: They allow you to separate and protect individual fibers in a loose tube cable so it can be terminated.
Splice enclosures - for long cable runs outside, the point where cables are spliced, sealed up and buried in the ground, put in a vault of some kind or hung off a pole.
Splice panels- connect individual fibers from cables to pigtails
Patch panels - provides a centralized location for patching fibers, testing, monitoring and restoring cables.
Racks and cabinets: enclosures for patch panels and splice panels. Usually these also include cable management - without this the cables start looking like spaghetti flying everywhere in a short time! There are tons of hardware and tons of manufacturers who make them. Be sure to choose panels that have the connections behind locked doors, since the biggest problem we see is connectors broken by people messing around in communications closets! Fiber doesn't need maintenance or inspection. Lock 'em up and only unlock it when you have to move something!

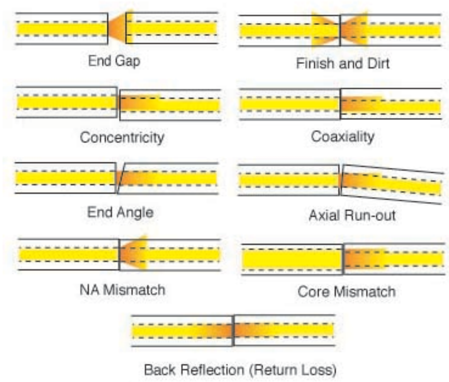
Termination – Connectors and Splices

Installers terminate fiber optic cable two ways - with connectors or splices. Connectors mate two fibers to create a temporary joint and/or connect a fiber to a piece of network gear. Splices create a permanent joint between the two fibers. Terminations must be of the right style, installed in a manner that makes them have low light loss, good physical strength and protection against dirt or damage. No area of fiber optics has been given greater attention than termination. Manufacturers have come up with over 80 styles of connectors and about a dozen ways to install them. There are two types of splices and many ways of implementing the splice. Fortunately, only a few types are used for most applications.
Different connectors and splice termination procedures are used for singlemode and multimode connectors, so make sure you know what the fiber will be before you specify connectors or splices!

Connectors

We'll start our section on termination by considering connectors. Since fiber optic technology was introduced in the late 70s, numerous connector styles have been developed. Each new design was meant to offer better performance (less light loss and back reflection), easier and/or termination and lower cost. Of course, the marketplace determines which connectors are ultimately successful.

Connector and Splice Loss Mechanisms
Connector and splice loss is caused by a number of factors. Loss is minimized when the two fiber cores are identical and perfectly aligned, the connectors or splices are properly finished and no dirt is present. Only the light that is coupled into the receiving fiber's core will propagate, so all the rest of the light becomes the connector or splice loss.



End gaps cause two problems, insertion loss and return loss. The emerging cone of light from the connector will spill over the core of the receiving fiber and be lost. In addition, the air gap between the fibers causes a reflection when the light encounters the change n refractive index from the glass fiber to the air in the gap. This reflection (called fresnel reflection) amounts to about 5% in typical flat polished connectors, and means that no connector with an air gap can have less than ~0.3 dB loss. This reflection is also referred to as back reflection or optical return loss, which can be a problem in laser based systems. Connectors use a number of polishing techniques to insure physical contact of the fiber ends to minimize back reflection. On mechanical splices, it is possible to reduce back reflection by using non-perpendicular cleaves, which cause back reflections to be absorbed in the cladding of the fiber.

The end finish of the fiber must be properly polished to minimize loss. A rough surface will scatter light and dirt can scatter and absorb light. Since the optical fiber is so small, typical airborne dirt can be a major source of loss. Whenever connectors are not terminated, they should be covered to protect the end of the ferrule from dirt. One should never touch the end of the ferrule, since the oils on one's skin causes the fiber to attract dirt. Before connection and testing, it is advisable to clean connectors with lint-free wipes moistened with isopropyl alcohol.

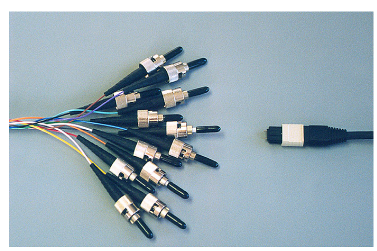
Two sources of loss are directional; numerical aperture (NA) and core diameter. Differences in these two will create connections that have different losses depending on the direction of light propagation. Light from a fiber with a larger NA will be more sensitive to angularity and end gap, so transmission from a fiber of larger NA to one of smaller NA will be higher loss than the reverse. Likewise, light from a larger fiber will have high loss coupled to a fiber of smaller diameter, while one can couple a small diameter fiber to a large diameter fiber with minimal loss, since it is much less sensitive to end gap or lateral offset.

These fiber mismatches occur for two reasons. The occasional need to interconnect two dissimilar fibers and production variances in fibers of the same nominal dimensions. With two multimode fibers in usage today and two others which have been used occasionally in the past and several types of singlemode fiber in use, it is possible to sometimes have to connect dissimilar fibers or use systems designed for one fiber on another. Some system manufacturers provide guidelines on using various fibers, some don't. If you connect a smaller fiber to a larger one, the coupling losses will be minimal, often only the fresnel loss (about 0.3 dB). But connecting larger fibers to smaller ones results in substantial losses, not only due to the smaller cores size, but also the smaller NA of most small core fibers.

Guide to Fiber Optic Connectors
Check out the "spotters guide" below and you will see the most common fiber optic connectors. (All the photos are to the same scale, so you can get an idea of the relative size of these connectors. A bigger selection of connector types, including some of the obsolete ones, is on the FOA online reference guide – www.foaguide.org)

SC (left) is a snap-in connector that is widely used in singlemode systems for it's excellent performance. It's a snap-in connector that latches with a simple push-pull motion. It is also available in a duplex configuration.

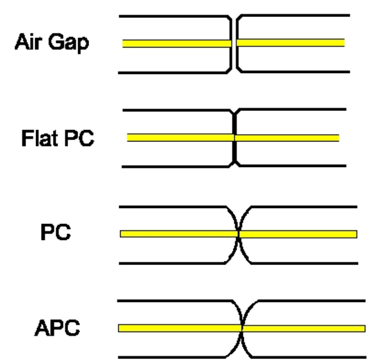
ST (center, an AT&T Trademark) is still one of the most popular connector for multimode networks, like most buildings and campuses. It has a bayonet mount and a long cylindrical ferrule to hold the fiber. Most ferrules are ceramic, but some are metal or plastic. And because they are spring-loaded, you have to make sure they are seated properly. If you have high loss, reconnect them to see if it makes a difference. The ST/SC connectors have the same ferrule size - 2.5 mm or about 0.1 inch - so they can be mixed and matched to each other using hybrid mating adapters. This makes it convenient to test, since you can have a set of multimode reference test cables with ST or SC connectors and adapt to the other connector.
LC (right) is a newer design connector that uses a 1.25 mm ferrule, half the size of the ST. Otherwise, it's a standard ceramic ferrule connector, easily terminated with any adhesive. Good performance, highly favored for singlemode.



The ST is still one of the most popular multimode connector because it is inexpensive and easy to install. The SC connector was specified as a standard by the early EIA/TIA 568A specification, but its higher cost limited its popularity. However, newer SCs are much better in both cost and installation ease, so it has been growing in use. Singlemode networks use LC or SC connectors in about the same proportion as ST and SC in multimode installations. EIA/TIA 568 allows any fiber optic connector as long as it has a FOCIS (Fiber Optic Connector Intermateability Standard) document behind it.

MPO is a multifiber connector for 12 or 16 fibers in a row. Its main use is for preterminated cable assemblies. It is mainly used in a 12 fiber configuration but 24 fiber versions are available.

Connector Ferrule Shapes & Polishes
Fiber optic connectors can have several different ferrule shapes or finishes, usually referred to as polishes. early connectors, because they did not have keyed ferrules and could rotate in mating adapters, always had an air gap between the connectors to prevent them rotating and grinding scratches into the ends of the fibers.



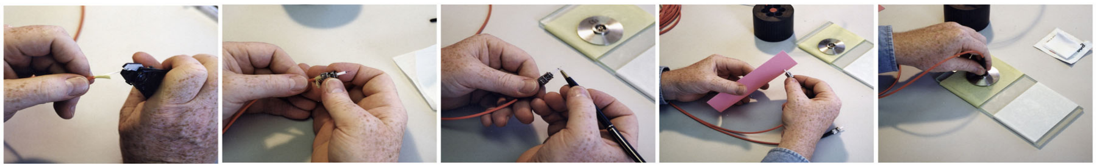
Beginning with the ST and SC which had keyed ferrules, connector ferrules were designed to contact tightly, what we now call physical contact (PC) connectors. Reducing the air gap reduced the loss and reflectance (very important to laser-based singlemode systems).
Making the connector ferrules convex would produce an even better connection. The convex ferrule guaranteed the fiber cores were in contact. The final solution for singlemode systems extremely sensitive to reflections, like CATV or high bitrate telco links, was to angle the end of the ferrule 8 degrees to create what we call an APC or angled PC connector. Then any reflected light is at an angle that is absorbed in the cladding of the fiber.

Termination Procedures

***Whatever you do, read carefully and follow the manufacturer's termination instructions closely*.**
Multimode connectors are usually installed in the field on the cables after pulling, while singlemode connectors are usually installed by splicing a factory-made "pigtail" onto the fiber. That is because the tolerances on singlemode terminations are much tighter and the polishing processes are more critical. You can install singlemode connectors in the field for low speed data networks, but you may not be able to get losses lower than 1 dB!
Cables can be pulled with connectors already on them if, and a big if, you can deal with these two problems: First, the length must be precise. Too short and you have to pull another longer one (its not cost effective to splice), too long and you waste money and have to store the extra cable length – although every installation should have a service loop storing some excess fiber at one end. Secondly, the connectors must be protected. Cable and connector manufacturers offer protective sleeves to cover the connectors, but you must still be much more careful in pulling cables. You might consider terminating one end and pulling the unterminated end to not risk the connectors.
There is a growing movement to install preterminated systems made with the MT 12 multifiber connector. It's tiny _ not much bigger than a ST or SC, but has up to 12 fibers. Manufactures sell multifiber cables with MTs on them that connect to preterminated patch panels with STs or SCs. This works well if you have a good designer and can live with the higher loss typical of these connectors.

Multimode Terminations
Several different types of terminations are available for multimode fibers. Each version has its advantages and disadvantages, so learning more about how each works helps decide which one to use.

Adhesive/Polish Termination



Epoxy/Polish: Most connectors are the simple "epoxy/polish" type where the fiber is glued into the connector with epoxy and the end polished with special polishing film. These provide the most reliable connection, lowest losses (less than 0.5 dB) and lowest costs, especially if you are doing a lot of connectors. The epoxy can be allowed to set overnight or cured in an inexpensive oven. A "heat gun" should never be used to try to cure the epoxy faster as the uneven heat may not cure all the epoxy or may overheat some of it which will prevent it ever curing!
"Hot Melt": This is a 3M trade name for a connector that already has the epoxy (actually a heat set glue) inside the connector. You strip the cable, insert it in the connector, crimp it, and put it in a special oven. In a few minutes, the glue is melted, so you remove the connector, let it cool and it is ready to polish. Fast and easy, low loss, but not as cheap as the epoxy type, it has become the favorite of lots of contractors who install relatively small quantities of connectors.
Anaerobic Adhesives: These connectors use a quick setting adhesive to replace the epoxy. They work well if your technique is good, but often they do not have the wide temperature range of epoxies, so only use them indoors. A lot of installers are using Loctite 648, with or without the accellerator solution, that is neat and easy to use.
A note on adhesives: Most connectors use epoxies or other adhesives to hold the fiber in the connector. Use only the specified adhesive, as the fiber to ferrule bond is critical for low loss and long term reliability! We've seen people use hardware store epoxies, Crazy Glue, you name it! And they regretted doing it.

Crimp/Polish: Rather than glue the fiber in the connector, these connectors use a crimp on the fiber to hold it in. Early types offered "iffy" performance, but today they are pretty good, if you practice a lot. Expect to trade higher losses for the faster termination speed. And they are more costly than epoxy polish types. A good choice if you only install small quantities and your customer will accept them.

Prepolished/splice: Some manufacturers offer connectors that have a short stub fiber already epoxied into the ferrule and polished perfectly, so you just cleave a fiber and insert it like a splice. (See next section for splicing info.) While it sound like a great idea, it has several potential downsides. First it is more costly, five to ten times as much as an epoxy polish type, due to the factory termination procedures, but the termination time is short so it may save that much money in labor cost. Second, you have to make a good cleave to make them low loss. You should use a high-quality cleaver like those used with fusion splicers. Third, even if you do everything correctly, you loss will be higher, because you have a connector loss plus two splice losses at every connection, but with current generation products, the difference can be small. The best way to terminate them is to monitor the loss with a visual fault locator and "tweak" them. Some manufacturers' tool kits include both a high quality cleaver and a VFL to verify the splice, and it's those kits we recommend.

Hints for doing field terminations

Here are a few things to remember when you are terminating connectors in the field. Following these guidelines will save you time, money and frustration.

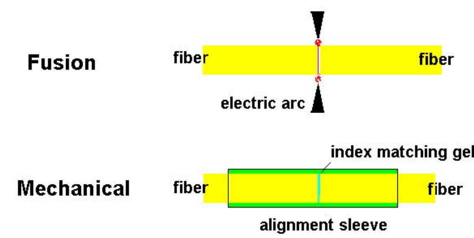
- Choose the connector carefully and clear it with the customer if it is anything other than an epoxy/polish type. Some customers have strong opinions on the types or brands of connectors used in their job. Find out first, not later!
- *Never, never, NEVER take a new connector in the field until you have installed enough of them in the office that you can put them on in your sleep.* The field is no place to experiment or learn! It'll cost you big time!
- Have the right tools for the job. Make sure you have the proper tools and they are in good shape before you head out for the job. This includes all the termination tools, cable tools and test equipment. Do you know your test cables are good? Without that, you will test good terminations as bad every time. More and more installers are owning their own tools like auto cared for.
- Dust and dirt are your enemies. It's very hard to terminate or splice in a dusty place. Try to work in the cleanest possible location. Use lint-free wipes (not cotton swaps or rags made from old T-shirts!) to clean every connector before connecting or testing it. Don't work under heating vents, as they are blowing dirt down on you continuously.
- Don't overpolish. Contrary to common sense, too much polishing is just as bad as too little. The ceramic ferrule in most of today's connector is much harder than the glass fiber. Polish too much and you create a concave fiber surface, increasing the loss. A few swipes is all it takes.
- Remember singlemode fiber requires different connectors and polishing techniques. Most SM fiber is terminated by splicing on a preterminated pigtail, but you can put SM connectors on in the field if you know what you are doing. Expect much higher loss, approaching 1 dB and high reflectance. Splicing pigtails on the cables for termination is a better idea. Change polishing film regularly. Polishing builds up residue and dirt on the film that can cause problems after too many connectors and cause poor end finish. Check the manufacturers' specs.
- Put dust covers on connectors and patch panels when not in use. Keep them covered to keep them clean.

Inspect and test, then document. It is very hard to troubleshoot cables when you don't know how long they are, where they go or how they tested originally! So keep good records, smart users require it and expect to pay extra for good records.

Splicing

Splicing is needed if the cable runs are too long for one straight pull or you need to mix a number of different types of cables (like bringing a 48 fiber cable location into a and splicing it to six 8 fiber cables. And of course, we use splices for restoration, after suffering the number one problem of outside plant cables, a dig-up and cut of a buried cable, usually referred to as "backhoe fade" for obvious reasons!

Splices are "permanent" connections between two fibers. There are two types of splices, fusion and mechanical, and the choice is usually based on cost or location. Most splicing is done on long haul outside plant SM cables, not multimode LANs, so if you do outside plant SM installations, you will want to learn how to fusion splice. If you do mostly MM LANs, you may never see a splice.



Fusion Splices are made by "welding" the two fibers together usually by an electric arc. Obviously, you don't do that in an explosive atmosphere (at least not more than once!), so fusion splicing is usually done above ground in a truck or trailer set up for the purpose. You can get splicing machines that do one fiber at a time or every fiber in a 12 fiber ribbon all at once. Good fusion splicers are expensive, but the splices only cost a few dollars each. Today's singlemode fusion splicers are automated and you have a hard time making a bad splice. The biggest application is singlemode fibers in outside plant installations.

Mechanical Splices are alignment gadgets that hold the ends of two fibers together with some index matching gel or glue between them. There are a number of types of mechanical splices, like little glass tubes or V-shaped metal clamps. The tools to make mechanical splices are cheap, but the splices themselves are expensive. Many mechanical splices are used for restoration, but they can work well with both singlemode and multimode fiber, with practice.

Which Splice ?

If cost is the issue, we've given you the clues to make a choice: fusion is expensive equipment and cheap splices, while mechanical is cheap equipment and expensive splices. So if you make a lot of splices (like thousands in an big telco or CATV network) use fusion splices. If you need just a few, use mechanical splices.

Fusion splices give very low loss and reflectance and are preferred for singlemode high speed digital or CATV networks. However, they don't work as well on multimode, so mechanical splices are often preferred for MM, unless it is an underwater or aerial application, where the greater reliability of the fusion splice is preferred.

Testing Fiber Optics

Fiber optic testing includes testing the fiber as it is made and qualifying components like connectors and splices, but for most installers, testing the installed cable plant is the main interest.

After the cables are installed and terminated, it's time for testing. For every fiber optic cable plant, you will need to test for continuity and polarity (transmitter to receiver and vice versa), end-to-end loss and then troubleshoot the problems. If it's a long outside plant cable with intermediate splices, you will probably want to verify the individual splices with an OTDR also, since that's the only way to make sure that each one is good.

If you are the network user, you will also be interested in testing power, as power is the measurement that tells you whether the system is operating properly.

For testing fiber optic cable plants, you'll need a few special tools and instruments to test fiber optics. See Jargon in the beginning of Lennie's Guide to see a description of each instrument.

Test Equipment

You will need a source and power meter, optical loss test set or test kit with proper connector adapters for the cable plant you are testing and reference cables. Reference test cables must match the cables to be tested and you need mating adapters for the connector types on the cables being tested, including hybrids if needed.

Fiber Tracer or Visual Fault Locator for checking continuity and polarity.

Cleaning materials – commercial connector cleaners or lint free cleaning wipes and pure isopropyl alcohol.

OTDR with launch cable and receive cables for outside plant jobs and sometimes troubleshooting premises cabling.

Know how to use your test equipment

Before you start, get together all your tools and make sure they are all working properly and you and your installers know how to use them. It's hard to get the job done when you have to call the manufacturer from the job site on your cell phone to ask for help. Try all your equipment in the office before you take it into the field. Use it to test every one of your reference test jumper cables in both directions using the single-ended loss test to make sure they are all good. If your power meter has internal memory to record data be sure you know how to use this also. You can often customize these reports to your specific needs - figure all this out before you go it the field - it could save you time and on installations, time is money!

Know the network you're testing

This is an important part of the documentation process we discussed earlier. Make sure you have cable layouts for every fiber you have to test. Prepare a spreadsheet of all the cables and fibers before you go in the field and print a copy for recording your test data. You may record all your test data either by hand or if your meter has a memory feature, it will keep test results in on-board memory that can be printed or transferred to a computer when you return to the office.

A note on using a fiber optic source - eye safety...
Fiber optic sources, including test equipment, are generally too low in power to cause any eye damage, but it's still a good idea to check connectors with a power meter before looking into it. Some telco DWDM and CATV systems have very high power and they could be harmful, so better safe than sorry.

Fiber optic testing includes three basic tests that we will cover separately: Visual inspection for continuity or connector checking, Loss testing and Network Testing.

Visual Inspection

Visual Tracing
Continuity checking makes certain the fibers are not broken and to trace a path of a fiber from one end to another through many connections. Use a visible light "fiber optic tracer" or "pocket visual fault locator". It looks like a flashlight or a pen-like instrument with a lightbulb or LED soure that mates to a fiber optic connector. Attach a cable to test to the visual tracer and look at the other end to see the light transmitted through the core of the fiber. If there is no light at the end, go back to intermediate connections to find the bad section of the cable.

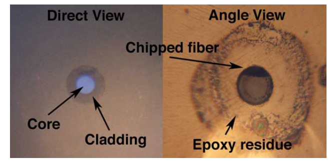
A good example of how it can save time and money is testing fiber on a reel before you pull it to make sure it hasn't been damaged during shipment. Look for visible signs of damage (like cracked or broken reels, kinks in the cable, etc.) . For testing, visual tracers help also identify the next fiber to be tested for loss with the test kit. When connecting cables at patch panels, use the visual tracer to make sure each connection is the right two fibers! And to make certain the proper fibers are connected to the transmitter and receiver, use the visual tracer in place of the transmitter and your eye instead of the receiver (remember that fiber optic links work in the infrared so you can't see anything anyway.)

Visual Fault Location
A higher power version of the tracer uses a laser that can also find faults. The red laser light is powerful enough to show breaks in fibers or high loss connectors. You can actually see the loss of the bright red light even through many yellow or orange simplex cable jackets except black or gray jackets. You can also use this gadget to optimize mechanical splices or prepolished-splice

type fiber optic connectors. In fact- don't even think of doing one of those connectors without one _ no other method will assure you of high yield with them.

Visual Connector Inspection

Fiber optic microscopes are used to inspect connectors to check the quality of the termination procedure and diagnose problems. A well made connector will have a smooth , polished, scratch free finish and the fiber will not show any signs of cracks, chips or areas where the fiber is either protruding from the end of the ferrule or pulling back into it (pistoning.)



The magnification for viewing connectors can be 30X to 400X but it is best to use a medium magnification. The best microscopes allow you to inspect the connector from several angles, either by tilting the connector or having angle illumination to get the best picture of what's going on. Check to make sure the microscope has an easy-to-use adapter to attach the connectors of interest to the microscope.

And remember to check that no power is present in the cable before you look at it in a microscope - protect your eyes!

Optical Power - Power or Loss? ("Absolute" vs. "Relative" dB)

Practically every measurement in fiber optics refers to optical power. The power output of a transmitter or the power input to a receiver are "absolute" optical power measurements, that is, you measure the actual value of the power. Loss is a "relative" power measurement, the difference between the power coupled into a component like a cable or a connector and the power that is transmitted through it. This difference is what we call optical loss and defines the performance of a cable, connector, splice, etc. Power is measured in dB or decibels, a log measurement. dB is the ratio of any two power measurements, dBm is the ratio of a measured power to 1 mW, which makes it an absolute power.

Measuring power

Power in a fiber optic system is like voltage in an electrical circuit - it's what makes things happen! It's important to have enough power, but not too much. Too little power and the receiver may not be able to distinguish the signal from noise; too much power overloads the receiver and causes errors too.

Measuring power requires only a power meter (most come with a screw-on adapter that matches the connector being tested) and a little help from the network electronics to turn on the transmitter. Remember when you measure power, the meter must be set to the proper range (usually dBm, sometimes microwatts, but never "dB" - that's a relative power range used only for testing loss!) and the proper wavelengths - matching the wavelength of the source being used. Refer to the instructions that come with the test equipment for setup and measurement instructions as well as the proper power range for the receiver.

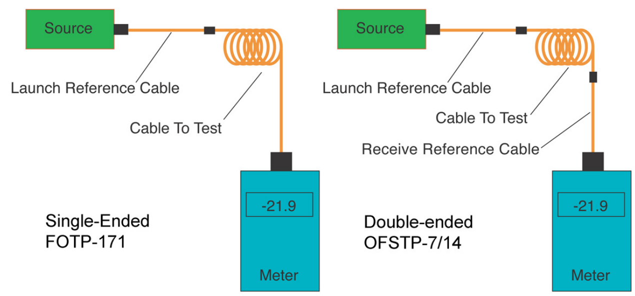
To measure power, attach the meter to the cable that has the output you want to measure. That can be at the receiver to measure receiver power, or to a reference test cable (tested and known to be good) that is attached to the transmitter, acting as the "source", to measure transmitter power. Turn on the transmitter/source and note the power the meter measures. Compare it to the specified power for the system and make sure it's enough power but not too much.

Testing loss

Loss testing is the measuring difference between the power coupled into the cable at the transmitter end and what comes out at the receiver end. Testing for loss requires measuring the optical power lost in a cable (including connectors, splices, etc.) with a fiber optic test source and power meter in what we call a “insertion loss test.”

Two Methods for Testing Loss

There are two methods that are used to measure loss, which we call "single-ended loss" and "double-ended loss". Single-ended loss uses only the launch cable, while double-ended loss uses a receive cable attached to the meter also.



Single-ended loss is measured by mating the cable you want to test to the reference launch cable and measuring the power out the far end with the meter. When you do this you measure 1. the loss of the connector mated to the launch cable and 2. the loss of any fiber, splices or other connectors in the cable you are testing. Reverse the cable to test the connector on the other end.

In a double-ended loss test, you attach the cable to test between two reference cables, one attached to the source and one to the meter. This way, you measure two connectors' loses, one on each end, plus the loss of all the cable or cables in between. This is the method specified in all the standard tests for installed cable plants.

Test Equipment Required

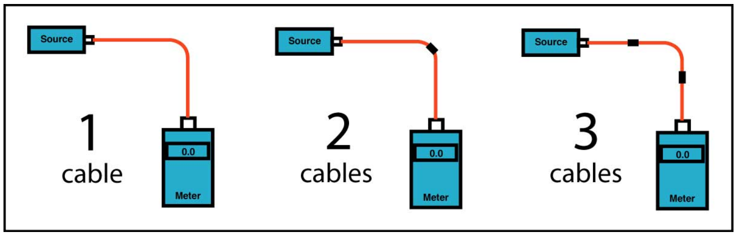
In addition to your power meter, you will need a test source. The test source should be the proper type of source (LED for multimode fiber or laser for singlemode) and wavelength (850, 1300, 1550 nm) for the cable plant being tested.

You also need one or two reference cables, depending on the test we wish to perform. The accuracy of the measurement we make will depend on the quality of your reference cables. Always test your reference cables by the patchcord (single ended) method shown below to make sure they're good before you start testing other cables!

Setting a “0 dB” Reference

Next you need to set your reference power for loss - our "0 dB" value. Correct setting of the launch power is critical to making good loss measurements!

Clean your connectors and set up your equipment like this:
Turn on the source and select the wavelength you want for the loss test. Turn on the meter, select the "dBm" or "dB" range and select the wavelength you want for the loss test. Measure the power at the meter. This is your reference power level for all loss measurements. If your meter has a "zero" function, set this as your "0" reference.



Standards allow setting the reference power for loss using one reference cable, two (both a launch and receive cable mated with a mating adapter) or even three reference cables. Either method is acceptable for tests, even mandatory when your test equipment has connectors different from the cable plant under test, but will reduce the loss you measure by the amount of loss between your reference cables when you set your "0dB loss" reference. Also, if either the launch or receive cable is bad, setting the reference with both cables hides the fact. Then you could begin testing with bad launch cables making all your loss measurements wrong. Make sure your reference cables are good.

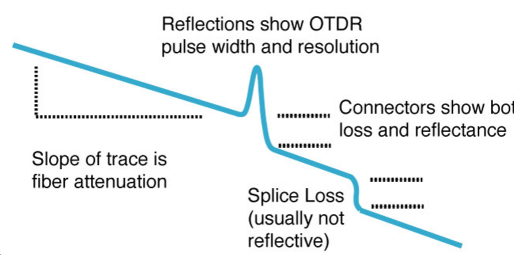
What Loss Should You Get When Testing Cables?
While it is difficult to generalize, here are some guidelines:
-For each connector, figure 0.3-0.5 dB loss (0.75 max)
-For each splice, figure 0.1-0.2 dB (0.3 dB max)
-For multimode fiber, the attenuation coefficient is about 3 dB/km for 850 nm sources, 1 dB/km for 1300 nm. This roughly translates into a loss of 0.1 dB per 100 feet for 850 nm, 0.1 dB per 300 feet for 1300 nm.
-For singlemode fiber, the loss is about 0.5 dB/km for 1300 nm sources, 0.4 dB/km for 1550 nm. This roughly translates into a loss of 0.1 dB per 600 feet for 1300 nm, 0.1 dB per 750 feet for 1550 nm.
So for the loss of a cable plant, calculate the approximate loss as:
(0.5 dB X # connectors) + (0.2 dB x # splices) + fiber loss on the total length of cable

Troubleshooting Hints
If you have high loss in a cable, make sure to reverse it and test in the opposite direction using the single-ended method. Since the single ended test only tests the connector on one end, you can isolate a bad connector - it's the one at the launch cable end (mated to the launch cable) on the test when you measure high loss.
High loss in the double ended test should be isolated by retesting single-ended and reversing the direction of test to see if the end connector is bad. If the loss is the same, you need to either test each segment separately to isolate the bad segment or, if it is long enough, use an OTDR (see below.)
If you see no light through the cable (very high loss – no visible light when tested with your visual tracer), it's probably one of the connectors, and you have few

options. The best one is to isolate the problem cable, cut the connector of one end (flip a coin to choose) and hope it was the bad one (well, you have a 50-50 chance!)

OTDR Testing
As we mentioned earlier, OTDRs are always used on OSP cables to verify the loss of each splice. But they are also used as troubleshooting tools for any cable as long as it is sufficiently long for the OTDR to resolve. Let's look at how an OTDR works and see how it can help testing and troubleshooting. When you finish this section, see the web pages on OTDRs on the FOA online reference guide for a more detailed explanation.

How OTDRs Work
Unlike sources and power meters that measure the loss of the fiber optic cable plant directly just like a transmitter and receiver in a data link, the OTDR works indirectly. Since the source and meter duplicate the transmitter and receiver of the fiber optic transmission link, their measurement correlates well with actual system loss.
OTDR works like RADAR, sending a high power laser light pulse down the fiber and looking for return signals from backscattered light in the fiber itself or reflected light from connector or splice interfaces. At any point in time, the light the OTDR sees is the light scattered from the pulse passing through a region of the fiber. Only a small amount of light is scattered back toward the OTDR, but with sensitive receivers and signal averaging, it is possible to make measurements over relatively long distances.



There is a lot of information in an OTDR display. The slope of the fiber trace shows the attenuation coefficient of the fiber and is calibrated in dB/km by the OTDR. In order to measure fiber attenuation, you need a fairly long length of fiber with no distortions on either end from the OTDR resolution or overloading due to large reflections. If the fiber looks nonlinear at either end, especially near a reflective event like a connector, avoid that section when measuring loss.
Connectors and splices are called "events" in OTDR jargon. Both should show a loss, but connectors and mechanical splices will also show a reflective peak so you can distinguish them from fusion splices which should have no reflectance. Also, the height of that peak will indicate the amount of reflectance at the event, unless it is so large that it saturates the OTDR receiver. Then peak will have a flat top and tail on the far end, indicating the receiver was overloaded. The width of the peak shows the distance resolution of the OTDR, or how close it can detect events.

OTDRs can also detect problems in the cable caused during installation. If a fiber is broken, it will show up as the end of the fiber much shorter than the cable or a high loss splice at the wrong place. If excessive stress is placed on the cable due to kinking or too tight a bend radius, it will look like a splice at the wrong location.

OTDR Limitations
The limited distance resolution of the OTDR makes it very hard to use in a LAN or building environment where cables are usually only a few hundred meters long. The OTDR has a great deal of difficulty resolving features in the short cables of a LAN and is likely to show "ghosts" from reflections at connectors, more often than not simply confusing the user.

Using The OTDR
When using an OTDR, there are a few cautions that will make testing easier and more understandable. First always use a long launch cable, which allows the OTDR to settle down after the initial pulse and provides a reference cable for testing the first connector on the cable. Always start with the OTDR set for the shortest pulse width for best resolution and a range at least 2 times the length of the cable you are testing. Make an initial trace and see how you need to change the parameters to get better results.
Above all - never simply attach an OTDR to the cable plant and hit the "auto-test" button! We know of applications where that was done that cost the installers and users big bucks! ODTRs are not smart enough to make the decisions on setup and pass/fail themselves - they are easily fooled. If you do the setup correctly yourself, you can try "auto-test" and see if it gives reliable results, but never use it without knowledgeable operator oversight.

Restoration
The time may come when you have to troubleshoot and fix the cable plant. If you have a critical application or lots of network cable, you should be ready to do it yourself. Smaller networks can rely on a contractor. If you plan to do it yourself, you need to have equipment ready (extra cables, mechanical splices, quick termination connectors, etc., plus test equipment.) and someone who knows how to use it.
We cannot emphasize more strongly the need to have good documentation on the cable plant. If you don't know where the cables go, how long they are or what they tested for loss, you will be spinning you wheels from the get-go. And you need tools to diagnose problems and fix them, and spares including a fusion splicer or some mechanical splices and spare cables. In fact, when you install cable, save the leftovers for restoration!
And the first thing you must decide is if the problem is with the cables or the equipment using it. A simple power meter can test sources for output and receivers for input and a visual tracer will check for fiber continuity. If the problem is in the cable plant, the OTDR is the next tool needed to locate the fault.

Getting Training
Now that Lennie's Guide has provided you with the basics, you're probably ready to figure out where to go from here. We've been training fiber techs for over 25

years, so we have some strong opinions on the subject. About half the world comes to Lennie to get started! There are many options for further training but first you need to figure out what your career choice is.
If you want to work in engineering for a component manufacturer, you will need to learn the theory behind the technology, so you will probably need to start with university level classes in physics and add classes in electronics, optics and fiber optics. If you want to design networks, you probably need a university education in electronics and communications system design.
If you just want to understand the technology so you can design, install and maintain cable plants and networks for LANS, CATV systems, utilities, etc. you need to know very little about the theory itself, but lots about cables, connectors and hardware and how cable plants are designed, installed and tested. Your training should focus on practical knowledge and lots of hands-on exercises.
You can learn more from the FOA textbooks, *The FOA Reference Guide to Fiber Optics, The FOA Reference Guide to Outside Plant Fiber Optics, FOA Reference Guide to Premises Cabling* or the *FOA Reference Guide To Fiber Optic Network Design.*
You can learn a lot from the web. The FOA online guide (www.FOAguide.org) or Fiber U (www.fiberu.org) are great places to start. Learn what you can online then look at attending an FOA-approved school to learn more. Work toward getting your certification from The FOA.

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